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cdio™

18th CDIO International Conference

PROCEEDINGS – FULL PAPERS

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Editorial

The CDIO approach is an innovative educational framework which aims for an education that supports students in the acquisition of strong technical fundamentals while simultaneously developing the necessary professional skills required of a practicing engineer. This is done by providing students with dual-impact learning experiences that are based upon the lifecycle of an engineering project, the Conceiving — Designing — Implementing — Operating (CDIO) of real-world products, processes, and systems. Throughout the world, more than 190 institutions have adopted CDIO as the framework of their curriculum development.

The Annual International Conference is the key event for the CDIO community where CDIO practitioners from all over the world come together, share knowledge and promote the advancement of the practice of the CDIO initiative for producing the next generation of engineers. It includes presentations of papers as well as specialized seminars, workshops, roundtables, events, and activities. The 18th International CDIO Conference took place in Reykjavik, Iceland, June 13–15, 2022, hosted by the Department of Engineering at Reykjavik University. Due to the worldwide pandemic situation, the last two CDIO International Conferences, in 2020 and 2021, were held solely online. This year, therefore, the organizers were especially pleased to be able to welcome you to a long-awaited onsite event!

The main theme of this year is Surviving and Thriving – Preparing for the Future. This theme is visible in the keynote presentations, paper presentations, roundtables, and workshops. The rich topical program, which partly touches on lessons learnt from the recent pandemic situation, facilitated a lively discussion, and contributes to the further advancement of engineering education.

The conference includes three types of contributions: Full Papers, Project in Progress contributions, and Extended Abstracts for Activities. The Full Papers fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. All contributions have undergone a full single-blind peer-review process to meet scholarly standards. The Projects in Progress contributions describe current activities and initial developments that have not yet reached completion at the time of writing. The Extended Abstracts summarize the Roundtable Discussions and Workshops held at the event.

Initially, 180 abstracts were submitted to the conference. The authors of the accepted Full Paper and Projects in Progress abstracts submitted 124 manuscripts to the peer review process. During the review, 391 review reports were filed by 102 members of the 2022 International Program Committee. Acceptance decisions were made based on these reviews. The reviewers' constructive remarks served as valuable support to the authors of the accepted full papers when they prepared the final versions of their contributions. We want to address our warmest thanks to those who participated in the rigorous review process.

This publication, which is available as an electronic publication only, contains the 86 accepted Full Papers that were presented at the conference, of which 4 are Advances in CDIO; 58 CDIO Implementation; and 24 Engineering Education Research. These papers have been written by 251 different authors representing 28 countries. Additionally, 20 CDIO Project in Progress contributions were presented at the conference and are not included in this publication. Also, in addition to individual contributions from authors, a total of 24 collaborative contributions for activities in 9 Workshops, 12 Roundtable Discussions and 3

Working Groups took place, as well as a range of social events.

We hope that you find these contributions valuable in developing your own research, curriculum development, and teaching practice, ultimately furthering the engineering profession. We also hope that you benefit through the truly unique community of practice that exists within the CDIO Initiative. A total of 71 educational institutions from 30 countries, representing 6 continents, were present during the conference. The total number of registered participants at the conference was 228. A great opportunity to discuss and share with colleagues, as global awareness and partnerships are of major importance in the education of the next generation of engineers.

The CDIO2022 Program Committee wishes all of you a wonderful CDIO experience!

Reykjavik, June 12, 2022

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Contents

Part I

Advances in CDIO

CONTINUAL IMPROVEMENT IN CDIO: ENHANCING FACULTY COMPETENCY IN REFLECTIVE PRACTICE

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ABSTRACT

An increasingly popular tool used by teachers to continually update and expand their professional knowledge base and to improve their teaching practices so as to address the learning needs of students is reflective practice; which requires teachers to look at what they do in the classroom and think about why they do it, if it works and why it works; and vice versa. This paper advocated for the specific elaboration on the use of reflective practice in the CDIO Framework. It consists of 2 main parts. The first part questions of the meaning of reflective practice in the “traditional” sense as currently used in the literature. The second part proposes an “extended” use to drive continual improvement at the program level. For the first part, the paper first presents a quick literature review of reflective practice and other similar sounding words such as reflection, reflexivity, etc and strives to clarify the subtle differences among them. The paper then argues that the word ‘reflection’ as used in CDIO Standards 9 and 12 also needs further elaboration as they appeared to address 2 different target groups, namely students and lecturers respectively. The paper argued that clarity is necessary as witnessed by the increasing number of papers presented at International CDIO Conferences had used the terms interchangeably and can cause confusion among the CDIO community; as evidenced by the “quick-and-dirty” review on past papers retrieved from the CDIO Knowledge Library. The first part concludes with sharing of an evidence-based reflective practice toolkit from Singapore Polytechnic which had made reflective practice mandatory for all teaching staff. The second part of the paper argues for the use of reflective practice beyond individual lecturers, and advocated for use in continual improvement alongside the self-evaluation process based on the 12 Core CDIO Standards. This part briefly discusses papers from the earlier “quick-and-dirty” study to look for those with focus on program evaluation. The paper then shares the author’s own approach which is derived from the metaphor of *Mirror*, *Microscope* and *Binoculars* widely used in service learning projects. More specifically, the paper demonstrates how the same metaphor can be used to guide the self-evaluation by mapping each item to the 12 CDIO Core Standards. Lastly, this paper concludes by proposing performance indicators that can be used to assist lecturers in assessing the effectiveness of his/her reflective practice process which is applicable to both teaching and learning setting as well as program evaluation.

KEYWORDS

Reflection, Reflective Practice, Continual Improvement, CDIO Standards 9, 10, 11 and 12

NOTE: Singapore Polytechnic uses the word ‘courses’ to describe its education ‘programs’. A ‘course’ in the Diploma in Chemical Engineering consists of many subjects that are termed ‘modules’; which in the universities contexts are often called ‘courses’. A teaching academic is known as a ‘lecturer’, which is often referred to a as ‘faculty’ in the universities.

INTRODUCTION

In their paper, Cosgrove & O'Reilly (2019) suggested that engineering education in general and CDIO in particular, should embrace a third dimension – that of reflexivity – to complement its existing 2 dimensions of theory and practice. The author agrees with this. There is in fact an increasing mention on the use of reflections as presented in CDIO papers, either to improve students learning, enhance faculty professional development, or guide decisions in program evaluation. Often case, the word 'reflection' is used quite interchangeably alongside 'reflective practice' and 'critical reflection', and more recently, another similar sounding word: 'reflexivity'. Readers may be confused over the meaning and intent of these words, and how to use them in their own curriculum redesign efforts.

This paper will not go into any details the earlier thinking on the topic of reflection from great contributors such as John Dewey, David Kolb, Donald Schon, Jack Mezirow, Graham Gibbs, Stephen Brookfield, etc; as these had been very well covered by other authors elsewhere (see for example Fook, 2015; Finlay, 2008; Khan, 2006; Moon, 2001)

LITERATURE REVIEW: REFLECTION, REFLECTIVE PRACTICE, REFLEXIVITY

What is 'reflection', 'reflective practice', and 'reflexivity'? Often times, the words 'reflection', 'reflective practice' and 'reflexivity' are used interchangeably, even appearing in a same paper. What about other related terminologies such as 'reflective writing', 'reflective learning', 'critical reflection', 'situated reflective practice', etc? Confusion over these words had persisted over the years (Alexander, 2017).

The following widely quoted paragraph from Smyth (1992) attest to the confusion about 'reflection': "…*reflection can mean all things to all people…it is used as a kind of umbrella or canopy term to signify something that is good or desirable…everybody has his or her own (usually undisclosed) interpretation of what reflection means, and this interpretation is used as the basis for trumpeting the virtues of reflection in a way that makes it sound as virtuous as motherhood*." Another observation came from Loughran (2002) who charged that "r*eflection has developed a variety of meanings as the bandwagon has traveled through the world of practice. Its allure is caught up in the seductive nature of a notion that rings true for most people as something useful and informing in the development and understanding of, in this case, teaching and learning in teacher education practices*."

One explanation for this is because, taken literally, 'reflection' is a word we use in everyday conversations. In common-sense terms, reflection lies somewhere around the notion of learning (Moon, 2001). We reflect on something in order to consider it in more detail (e.g. "Let me reflect on that for a moment"). Usually we reflect because we have a purpose for reflecting – a goal to reach. Sometimes we find ourselves 'being reflective' and out of that 'being reflective', something 'pops up'. Moon (1999) suggests that the differences in approach are accounted for largely by different focuses – either on the process of reflection, on the purpose for it or the outcomes of reflection – in effect, how it is used. Moon (2001) further noted that "there is no point in defining reflection in a manner that does not relate to the everyday use of the word if further confusion is not to be created"; and offered the following definition: "*Reflection is a form of mental processing – like a form of thinking – that we use to fulfil a purpose or to achieve some anticipated outcome. It is applied to relatively complicated or unstructured ideas for which there is not an obvious solution and is largely based on the further processing of knowledge and understanding and possibly emotions that we already possess*."

Along the same line of reasoning, reflection can be contrasted with reflective practice. Reflection is broader and relevant to all aspects of living – it is a way of approaching an understanding of one's life and actions. Reflective practice, on the other hand, is more focused on professional practice (Fook, 2015). Eby (2000) suggested that reflective practice can be seen as a synthesis of reflection, self-awareness and critical thinking. Many writers also make a distinction between reflection and critical reflection. Critical reflection is widely attributed to Jack Mezirow, who contended that reflection may lead to transformative learning that results in new and transformed meaning schemes and perspectives (Mezirow, 1991). Fook (2015) suggested that critical reflection be considered as being a subset of reflective practice. Critical reflection, when used specifically to improve professional practice, is reflective practice that focuses on how a practice might change in order to bring about change in the social situations in which professionals work. In order to be able to critically reflect, obviously one must be able to reflect. However, not all reflective practice will lead to critical reflection – that is, to fundamental changes.

Reflexivity, like reflection, has its fair share of definitions (for example, see Fook, 2015) and objections (see for example, Alexander, 2017). It has its origin in social research and is typically associated with the ability to recognize that all aspects of ourselves and our contexts influence the way we research (Fook, 2015). Therefore, in order to be reflexive, we need to be aware of the many and varied ways in which we might create, or at least influence, the type of knowledge we use.

Finlay & Gough (2003) suggested that one think of reflection, critical reflection and reflexivity as forming a continuum. At one end stands reflection, defined simply as 'thinking about' something after the event. At the other end stands reflexivity: a more immediate and dynamic process which involves continuing self-awareness. Critical reflection lies somewhere in between. For the remainder of this paper, the author will use the term 'reflective practice' in a more inclusive manner to embrace the full spectrum from 'reflection' to 'reflectivity' (Finlay & Gough, 2003).

REFLECTIVE PRACTICE IN CURRENT CDIO STANDARDS (VERSION 3.0)

Currently, in version 3.0 of the CDIO Standards (Malmqvist et al, 2020), there are 2 mentions of 'reflection': once in Standard 11 Learning Assessment and once in Standard 12 Program Evaluation. The reference to 'reflection' in Standard 11 is towards student reflections as one of the possible ways of assessing students in their learning. On the other hand, in Standard 12 the reference to 'reflection' is with regards to 'instructor', presumably implying reflecting on the various aspects of the rest of the CDIO standards. A key question that can arise from this is: "Does faculty knows how to evaluate student reflections?" This in turn begs another question of equipping faculty with the right competency. According to Dewey (1933), reflection does not consist of a series of steps or procedures to be used by lecturers. Rather, it is a holistic way of meeting and responding to problems, a way of being as a lecturer. It involves intuition, emotion, and passion and is not something that can be neatly packaged as a set of techniques for lecturers to use (Dewey, 1933). Reflective action is also a process that involves more than logical and rational problem-solving processes.

Another related question is then: "How do we teach students reflective practice?" McLeod, et al (2015) had noted that lack of adequate training of lecturers to teach reflective practice had been an on-going challenge. Marcos, et al (2009) from their extensive surveys of the literature (comprising 50 conceptual papers, 122 articles on teacher development, and 49 teacher accounts of reflection) found that there are lack of alignment between what had been advocated in research (models of reflection) with what teachers actually did in teaching. The authors concluded that the concept of teacher reflection on action is still very much in flux despite the many years of study.

Currently there is no explicit reference in the CDIO Standards to developing faculty capacity to engage in reflective practice as part of their professional development to improve their teaching competence, or to facilitate reflections among their students (Standards 9, 10). The next section discusses how members in the CDIO community used reflective practice in the works reported.

SOME "INVESTIGATIVE" WORK DONE: REFLECTION AS USED IN CDIO PAPERS

A literature search was carried out on 13 Feb 2021, looking for articles in the CDIO Knowledge Library using the keywords 'reflective practice', 'reflection', 'reflections', 'reflexivity OR reflexive'. The returns after 4 rounds of searching were 35, 74, 39 and 8 papers respectively. There are a total of 23 repeat returns, i.e. different keyword search returned the same papers. Removing the repeats, the final number of unique papers is 133. Each of these papers was then scanned using a keyword search 'reflect' or 'reflex' to identify if usage of words such as 'reflective practice', 'reflection', 'reflections', 'reflexivity', 'reflexive', or other related words such as 'reflective learning', 'reflection journal', 'reflective thinking', etc can be found in the full paper. Papers with none of these words but showed the 'everyday use' of the word 'reflect' for example: the "*the decision made reflected the constraint faced*…." were deemed not relevant and discarded. There is no paper with the word 'reflex'. The final number of papers that form the basis for review is then 93. All the papers did not make distinctions between the words 'reflection', 'reflexivity' etc; and just used them interchangeably – including past paper from this author! The papers were then classified into 3 baskets: looking at how the words are used in each paper: (1) improving student learning, (2) enhancing staff competency, and (3) assisting program evaluation. The results are shown in Table 1 below.

Table 1. Number of Papers and Use of Reflection (as of 13 Feb, 2021)

Purpose of Reflection	Number of Papers
Improve student learning	68
Enhancing staff competency	26
Assisting program evaluation	4

One may notice that the total number of papers in Table 1 added to more than 93. This is because some papers covered the use of reflection in more than 1 areas. Notwithstanding that, it can be seen the major use of reflection as reported by members of the CDIO Community is in improving student learning. The most frequent approach used is to require students to submit reflection journals.

The "quick-and-dirty" approach by the author obviously had its limitations. Notwithstanding the ability of the search engine in the Knowledge Library to precisely return the necessary papers, obviously a wider net can be cast to ring in more works that are captured in other databases. However, the purpose here is just to have some sensing of what is it liked "out there in the CDIO community", and therefore the author deemed that effort is sufficient for his needs.

EVIDENCE-BASED REFLECTIVE PRACTICE IN SINGAPORE POLYTECHNIC

Reflective practice had been widely used in teacher and nursing education. The main outcome of reflection as either stated or implied by most authors is learning. Loughran (2002) summed it up well, when he noted “reflection as a meaningful way of approaching learning about teaching so that a better understanding of teaching, and teaching about teaching, might develop.” Boud et al (2005) suggested that learning can occur in 4 areas: (1) new perspectives on experience, (2) changes in behavior, (3) readiness for application, and (4) commitment to action. Detailed discussion of these benefits are beyond the scope of this paper, and interested readers can read up in various literature, for example York-Barr, et al (2005).

In the tertiary education such as Singapore Polytechnic (SP), many if not all, of our lecturers were hired directly from the industries. The foremost consideration for employment is the relevant work experience that they bring into the classroom, to help bridge theory and practice. These lecturers are not schooled in the practice of doing reflection in their prior professional role. Now in the educational context, they are expected to “think like a teacher”, for example, in addressing challenges associated with student learning. Without reflection, a problem is unlikely to be acted on if it is not viewed as a problem (Loughran, 2002). Often, it is assumed that reflection is an introspective after-the-fact description of teaching (Ward & McCotter, 2004). However, if done incorrectly, rationalization and justification of practice may then be misconstrued as reflection.

Rogers (2001) noted that reflection is most likely to be facilitated with the use of deliberate and planned techniques. Specifically, research indicates that reflection can be facilitated through individual and group activities as well as with the use of a skilled mentor or coach (e.g. e.g. Loughran, 2002; Schon, 1987), writing assignments of various types (e.g. reflection journals, portfolios) as well as directed discussions, for example seminar group discussion (Loughran, 2002), and critical incidents (Brookfield, 1990).

Recently, SP made reflective practice a required item for all its teaching staff. This initiative was launched alongside another drive to encourage staff to take up action research, to try out different teaching approaches in one’s respective module and feel what it is like to teach in a particular manner. The approach to reflective practice in SP is grounded in Schon’s ‘Reflection-on-Action’ (Schon, 1983) and Brookfield’s 4 Lenses of Reflection (Brookfield, 1995). It makes use of a series of structured questions based on a specific developmental experience (Seibert & Daudelin, 1999) to guide the reflection process. It was designed by Dennis Sale before his retirement from SP and is termed evidence-based reflective practice tool (EBRPT), which can equally be used as a guide for the design of learning events (Sale, 2020). It is termed ‘evidence-based’ as it involves more than personal reflections in isolation, but also other valid evidence sources (e.g. students, peers, expert mentors, surveys). When conducted thoughtfully it enables a better understanding of what is happening, and how, in terms of student learning. From this basis the lecturer can frame and enact more effective and creative instructional strategies with a high predictive capability for enhancing the learning experience and attainment levels for students (Sale, 2020).

The EBRPT is a heuristic (set of guiding principles) for conducting evidence-based reflective practice when evaluating learning experiences (e.g. lessons, modules). It specifically focuses on Reflection for ‘Prediction’ (i.e. pre-lesson analysis and inference and interpretation) and ‘Diagnosis’ (i.e. post-lesson analysis and evaluation) and on the impact of the instructional strategy in terms of evidence-based teaching framing (i.e. effective strategy/method use, application of core principles of learning). It is not exhaustive or summative in terms of capturing all relevant features and processes relating to learning in a complex interactive classroom context. However, it facilitates a thinking process that enables appropriate analysis and subsequent inferences and interpretations about what has occurred, with what consequences (e.g. impact on learning), concerning key aspects of the learning experience. The EBRPT can be customized to any reflection needs, by modifying the list of questions based on the topic of interest. An example of the EBRPT that was used by the author for his work in implementing flipped classroom (Cheah & Sale, 2019) using Sale's Core Principles of Learning (Sale, 2015) is shown in Appendix 1.

USING REFLECTIVE FOR CONTINUAL IMPROVEMENT IN CDIO IMPLEMENTATION

Using reflections for program improvement had been reported by various contributors from the CDIO Community. To the best knowledge of the author, there are 4 papers based on his "quick-and-dirty" study as reported in Table 1. This is briefly summarized below.

Clark and Robin (2011) reported on the use of reflection in an interactive workshop to evaluate the impact of introducing CDIO across the first-year undergraduate curriculum in Aston University; facilitate by an Engineer and a Social Scientist, both of whom have expertise in Engineering Education Research and Evaluation. Edelbro et al (2017) described the use of joint (group) reflections at Luleå University of Technology in an industry engagement process to discuss the competence of graduates from the Department of Civil, Environmental and Natural Resources Engineering and future needs in the industry. This is in response to the dwindling interest from students despite a very positive prospects for professionals in the field. Gonzales, et al (2013) reported on Pontificia Universidad Javeriana's use of reflections to support its CDIO implementation in its four undergraduate programs (Civil, Electronics, Industrial Engineering and Software), which resulted in the introduction of 6 types of workspaces that support the CDIO standards and integration of competencies. Lastly, Garcia, et al (2014) presented a case study of the implementation for the Electronics Engineering program in the university.

AUTHOR'S WORK: USING REFLECTIVE PRACTICE FOR CONTINUAL IMPROVEMENT

The author had been using the CDIO Standards to inform areas of improvement needed in the Diploma in Chemical Engineering (DCHE) since it adoption of the CDIO Framework in 2007. With the mandate of SP Management that all lecturers are to engage in reflective practice, there was an epiphany on the part of this author that his work in continually improving the DCHE curriculum can benefit from an approach to reflective practice that he adopted recently: one that look at reflection at 3 levels using the metaphor of *Mirror*, *Microscope* and *Binoculars*.

This approach was initially developed for reflection in service learning projects and is widely attributed to Cooper (1997; quoted in McCarthy, 2013). This approach helps one to frame his/her reflection from different perspectives, as follows (Ferrell, 2015):

- The *Mirror* perspective asks students to reflect on the micro level: how did they, as individuals, act in the experience? How did they work within the team? Students may also reflect on their values, their assumptions and biases, and how they were influenced, challenged, or successful in their project.
- The *Microscope* perspective is dedicated to encouraging students to reflect about the project itself, including how it benefitted the community they worked in and the members

of that community. The microscope may be focused on topics such as what impacts the student's project had, how their experiential learning confirmed or contrasted with their classroom learning, and whether or not they would do anything differently if they were to do the project over again.

- The *Binoculars* perspective helps students to look at their experiences in order to reflect on their learning, including identifying areas where they could further enhance their learning and continue their development as critical thinkers. This perspective also encourages students to consider social issues on a larger scale by thinking more holistically about the outcomes of their project within a wider context.

As examples of its application, reference shall be made to the work done in studying the impact of Industry 4.0 on DCHE the details of which had been reported elsewhere (Cheah & Yang, 2018). In this adaptation, the *Binoculars* metaphor is useful in helping one to look far and forward into the external environment that can affect how a program had been designed in terms of the adequacy of its curriculum in meeting stakeholder requirements. An environmental scan was conducted using STEEP (Social, Technological, Economical, Environmental, Political) analysis to ascertain the needs for new knowledge, skills and attitudes required in the workplace as the chemical processing industries adopted Industrial Internet of Things technologies, under the Singapore Government' SkillsFuture Initiative. This had led to the redesigning of new learning workspaces and acquisition of new pilot plants equipped with smart sensors and state-of-the-art control systems. Virtual reality had been introduced as part of safety orientation, and we are in the process of adding digital twin to the learning resources. We also formulate plans for some lecturers to go for industrial attachments to update their know-how in terms of the chemical industries' use of industrial internet of things technologies to improve their chemical plant operations.

Next, the author uses the *Microscope* and advises the Course Management Team (CMT) in a major revamp in the course structure to introduce a new spiral curriculum for DCHE, which aligns to the Skills Framework for Energy & Chemicals Sector (Cheah & Yang, 2018). The *Microscope* metaphor is very appropriate as carrying out gap analysis and skills mapping is akin to the process of looking at a specimen under the microscope, in that one is moving along the course structure to identify suitable modules to integrate appropriate skills and attitudes; so that they can be systematically developed in a progressive manner to the desired levels of proficiency. The desired outcomes of each module can then be written using suitable taxonomy (e.g. Bloom). Also as part of this revamp, self-directed learning (SDL) was integrated across DCHE's 3-year curriculum, starting from Year 1 (see for example, Cheah, et al, 2019).

Lastly, the author uses the *Mirror* to evaluate his own skills in designing integrated learning experiences that integrates SDL into DCHE core modules. He also practices SDL himself by undertaking to learn story-boarding skills so as to able to design learning tasks based on digital twin for students to learn in an asynchronous manner. This effort also permits him to converse better with the programmer of the project, speaking "their languages", quite literally.

MOVING AHEAD: ENHANCING FACULTY COMPETENCY IN REFLECTIVE PRACTICE

With more and more lecturers asking students to submit reflection journals or portfolios, it is imperative that they have a clear understanding of reflective practice, and should themselves engage in reflective practice to improve their own teaching competence. Therefore, this paper suggests that use of reflection and reflective practice is made more explicit in the CDIO

Framework, not only to improve the lecturer's teaching but also for program evaluation. All lecturers must contribute to the continual improvement of a program of which he/she is very much a part of. A program is only as good as the team of lecturers delivering it.

Table 2 shows how the metaphor of *mirror*, *microscope* and *binoculars* can be applied to various CDIO Standards. Given the interconnected nature of the CDIO Standards, such "mapping" will necessarily be broad, but it is the author's belief that this will help lecturers focus better during the reflection process.

Table 2. "Mapping" of the 3 Levels of Reflection to CDIO Core Standards

Type	Focus of Reflective Practice for Continual Improvement (Standard 12)
Mirror	Faculty reflects on his/her own competence in conducting reflective practice; critically challenging one's own approach in light of the evidence obtained (e.g. use of EBRPT) in personal, interpersonal, product, process, system and service building skills (Standard 9); and skills in designing integrated learning experiences and in using active and experiential learning techniques (Standard 10). Faculty also reflects on his/her skills in facilitating students' development of their own reflective practice, as well as their reflections of how well they develop the various CDIO skills and how to assess them (Standard 11).
Micro-scope	Faculty reflects on how the course(s) he/she teaches fit into the program structure in terms of an integrated curriculum (Standard 3) or Design-Implement Experiences (Standard 5), so as to progressively develop and assess the desired skills and/or attitudes to the required levels of proficiency (Standards 2 and 11). This in turn can suggest appropriate learning activities to develop the said competency (Standard 7) and approaches to active and experiential learning (Standard 8). Faculty can also reflect on to what extent his/her own module(s) made use of competencies imparted to students in earlier stage(s) of study; and in what way his/her own module(s) contribute to furthering development of competencies in later stage(s) of study.
Bino-culars	Faculty reflects on how changes in various aspects of the external environment (social, technological, economics, environmental, etc) affect the stakeholders' requirements for the program's graduates (Standards 1, 2). These will also inform of the relevance of the topics in the CDIO Syllabus, which in turn will inform the need to review and redesign a program's structure (Standard 3), and possible also to content of Introduction to Engineering (Standard 4). This also includes the study on reconfiguring the program's learning workspaces to support the desired learning environment (Standard 6). The findings will in turn point to faculty professional development needs (via the *Mirror*, and Standards 9, 10); and a relook at various other CDIO Standards related to teaching and learning as covered in *Microscope*.

Just to be clear, this paper does not advocate the creation of another CDIO Standard. Rather, the author is drawing on his work as described earlier, and the call of Cosgrove & O'Reilly (2019) noted at the beginning of this paper, to suggest that reflective practice be made explicit in the CDIO Framework, using the metaphor *mirror*, *microscope* and *binoculars*. Being explicit serves to convey the message that it is necessary to train faculty in reflective practice, given its complex and situated nature, such that it cannot work if applied mechanically or simplistically (Finlay, 2008). This point is well captured by Larrivee (2000), who noted that: "*Unless teachers develop the practice of critical reflection, they stay trapped in unexamined judgments, interpretations, assumptions, and expectations. Approaching teaching as a reflective practitioner involves fusing personal beliefs and values into a professional identity, resulting in developing a deliberate code of conduct*." This is best done with explicit mention of faculty professional development program on reflective practice in Standards 9 and 10.

More specifically, the author would suggest that the "Description" for Standard 12 be amended to read as follows (where italics represent the author's modifications):

> "Program evaluation is a judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals. A CDIO program should be evaluated relative to these 12 CDIO Standards and any optional standards that it has adopted. Evidence of overall program value can be collected with course evaluations, *outcomes from* instructor *reflective practice*, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence should be regularly reported back to instructors, students, program administrators, alumni, and other key stakeholders. This feedback forms the basis of decisions about the program and its plans for continuous improvement. *Instructor should use an evidence-based reflective practice that systematically review his/her program or course(s) for areas of improvement.*"

Lastly, the author would also like to propose the use of some "performance indicators" that can assist lecturers in assessing the effectiveness of his/her reflective practice process. Without reinventing the wheel, the author finds the work of Koole, et al (2011) appropriate for this need. These authors viewed reflection as 3 phases in a cyclical process; and offered 3 "operational indicators" as shown in Table 3. In addition, Jay & Johnson (2002) in their efforts to guide teacher educators in teaching reflection to pre-service teachers, suggested a typology of reflective practice as shown in Table 4.

Table 3. Performance Indicators for Reflection Process (Koole, et al, 2011)

Aspect of Reflection Process	Indicators
Reviewing the experience	The ability to describe an event/situation adequately
	The ability to identify essential elements and to describe own thoughts and feelings
Critical Analysis	The ability to ask searching questions
	The ability to answer searching questions and being aware of the frames of references in use
Reflective Outcome	The ability to draw conclusions
	The ability to describe concrete learning goals and plans for future action

Table 4. Typology of Reflection: Dimensions and Guiding Questions (Jay & Johnson, 2002)

Dimension	Definition	Typical Questions
Descriptive	Describe the matter for reflection.	What is happening? Is this working, and for whom? For whom is it not working? How do I know? How am I feeling? What am I pleased and/or concerned about? What do I not understand? Does this relate to any of my stated goals, and to what extent are they being met?
Comparative	Reframe the matter for reflection in light of alternative views, others' perspectives, research, etc.	What are alternative views of what is happening? How do other people who are directly or indirectly involved describe and explain what's happening? What does the research contribute to an understanding of this matter? How can I improve what's not working? If there is a goal, what are some other ways of accomplishing it? How do other people accomplish this goal? For each perspective and alternative, who is served and who is not?
Critical	Having considered the implications of the matter, establish a renewed perspective.	What are the implications of the matter when viewed from these alternative perspectives? Given these various alternatives, their implications, and my own morals and ethics, which is best for this particular matter? What is the deeper meaning of what is happening, in terms of public democratic purposes of schooling? What does this matter reveal about the moral and political dimension of schooling? How does this reflective process inform and renew my perspective?

Critical reflection requires one to continually examine one's own thoughts, perspectives, biases, and actions. Lecturers new to reflective practice may initially be very uncomfortable with the process, perceiving it as a form of self-criticism. Especially when the practice is mandated by higher management, there is fear that the outcome can be used as a tool of accountability and/or competence recording (McGarr & O'Gallchóir, 2020). Hobbs (2007) in fact argued that requiring individuals to be open and honest in the context of assessment tends to provoke strategic response and often hostility. This may be the case even if the reflective process is carried in solitude, out of fear that this outcome will be used in performance evaluation should it ever become available. Not everyone may be so readily in "coming to terms" with his/her teaching experience, in particular negative ones, or one that contradicts his/her own belief, or in admitting mistake made.

For reflective practice to be useful, the author supports the stand that the outcome of reflective practice is to be used strictly for continual improvement and not for appraisal. This will encourage lecturers to reflect constructively and in a more systematic manner (as opposed to "reflecting on anything" in the broadest sense of the word), assisted by the use of metaphors and guidance questions shared earlier. There will be a progressive developmental pathway for lecturers to hone this important competency to develop into a critical thinker to continually improving one's teaching and learning, which subsequently leading them to reflect more critically on how they use the CDIO Framework for designing or redesigning a curriculum, not only within one's own module(s) but for the whole program. Such collective efforts will better drive continual improvement effort that not only bring benefits to students learning, but also help the lecturers themselves to grow professionally; and produce an up-to-date and relevant curriculum.

In his capacity as Lead Teaching and Learning Specialist in SP, the author can put together 2 staff development programs to drive the use of reflective practice in DCHE. One program can be aimed at the DCHE Course Chair and members of the CMT. The focus here is at the diploma level, looking at change drivers in the school's operating environment and its impact on the diploma's current teaching. The *mirror*, *microscope* and *binoculars* metaphor can best be used alongside CDIO Standard 1, 3, 5, 9, 10 and 12 to identify areas in the curriculum that merit reviewing and areas where faculty competence needs to be strengthened.

The other program can focus on improving the lecturers' teaching and learning competency in the modules there are teaching. Here it is also worth noting that the Course Chair and the CMT members are also lecturers themselves, and they are also module coordinators and module team member themselves. As lecturers, everyone can use EBPRT with the *mirror*, *microscope* and *binoculars* metaphor, as part of each's action research effort. In this case, the focus is likely centred more on CDIO Standards 2, 7, 8 and 11. The lecturers can also use the performance indicators (Table 3) and guiding questions (Table 4) for self-evaluation purposes in appraising their own experience in developing competency in reflective practice.

CONCLUSION

This paper takes the position that given the importance of reflective practice in teaching and learning, and its increasing use within the CDIO Community, there is a need to establish some common understanding of the terms used. The paper also shared the approaches to reflective practice in the author's own institution and how he uses the metaphor of *mirror, microscope and binoculars* as part of his reflective practice to drive continual improvement using the CDIO Framework. The paper proposes that reflective practice should be made explicit in the CDIO Framework and provides some suggestions on how the metaphors can be used, along with broad guidance questions and operational performance indicators to help lecturers evaluate the effectiveness of their own reflection process. The author suggests that this enhancement be included in the existing Standards 9, 10 and 12, with specific references that faculty uses reflective practice to review his/her effort teaching. The aim is to assist lecturers develop their reflective practice competencies in a progressive manner much like the development of competencies espoused in the CDIO Framework; not only to improve one's teaching and learning but to also contribute effectively to a program's continual improvement.

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APPENDIX 1 Sample of Evidence-based Reflective Practice Tool

EVIDENCE-BASED REFLECTIVE PRACTICE TOOL (EBRPT)	
Topic reflected on: ***Utilizing Core Principles of Learning***	
In the learning experience, was there:	Evidence of Effectiveness *What specific Strategies, Methods and/or Resources were employed to enhance this aspect of the learning process, and how effective were they? (Based on your observation and any other feedback if available (e.g., peer observation, student feedback)*
Communication to Students of the Learning Goal/Outcomes, Purpose and Expectations	
Activation of Prior Learning and connections to new knowledge presented?	
Emphasis on Key Concepts and Principles that underpin understanding of this topic?	
Use of activities that involved Good Thinking to facilitate understanding?	
Variation in the modes and methods of information presentation and interaction?	
Application of practices consistent with Human Memory processes (e.g., chunking of content to minimize cognitive overload; rehearsal/review activities)?	
Incorporation of Formative Assessment to provide quality two-way feedback?	
Use of Deliberate Practice to enhance understanding and/or skill acquisition?	
Interactions/activities to foster a climate conducive for building rapport, encouraging Success and a sense of Fun?	
An aspect(s) of Creativity (e.g., Story, Humour, Activity, Presentation Style, Example) that significantly enhanced motivation in this learning experience?	

THE CDIO SYLLABUS 3.0 - AN UPDATED STATEMENT OF GOALS

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ABSTRACT

The CDIO Initiative is going through a process of reconsidering and updating the CDIO approach for engineering education development. Previous work resulted in substantial updates of the twelve CDIO standards and the introduction of "optional" CDIO standards. This paper reports on a similar review and update of the CDIO Syllabus to version 3.0. It has been developed by a working group consisting of four sub-groups and iterated and refined guided by feedback from the whole CDIO community. There are mainly three external drivers that

motivate the changes: sustainability, digitalization, and acceleration. There is also an internal driver in the form of lessons learned within the CDIO community, from using the Syllabus in curriculum and course development. Approximately 70 updates are proposed, amongst them three additions on the X.X level, namely 1.4 *Knowledge of Social Sciences and Humanities*, 3.1 *Teamwork and Collaboration*, and 5.3 *Research*.

KEYWORDS

CDIO Syllabus, Sustainability, Digitalization, Acceleration, Standards 1-12, Optional standards

INTRODUCTION

During the past few years, the CDIO Initiative has gone through a process for reconsidering and updating the CDIO approach for engineering education development. The first stages of this work consisted of a substantial updating of the original twelve, now called "core", CDIO standards (Malmqvist et al., 2020a) as well as the introduction of a first set of four so-called "optional" CDIO standards that codify additional educational good practises that have been developed within the CDIO community (Malmqvist et al., 2020b). What remains now is to establish a new version of the CDIO Syllabus.

The starting point of the CDIO Initiative was to consider what knowledge, skills, and attitudes engineering students needed to learn to prepare for engineering practice. The aim was to create a clear, complete, and consistent set of goals for first-degree engineering education. The resulting document was called the CDIO Syllabus, a list of topics that indicate desirable competences of graduating engineers. This makes the Syllabus a reference framework that can be used to select goals for curricula and courses. The first version of the CDIO Syllabus was published in 2001 (Crawley, 2001).

The Syllabus has been thoroughly reviewed and updated once before, resulting in version 2.0 (Crawley et al., 2011). The 2011 review was based on comparison with the UNESCO Four Pillars of Learning (Delors, 1996), various national accreditation and evaluation standards, and other forms of input received over the decade since the Syllabus was originally formulated. A major result was the formulation of two additional sections concerning leadership (4.7) and entrepreneurship (4.8). Minor updates were also made to address innovation, invention, internationalization, mobility, and sustainability, resulting in, for example, the added subsection *Sustainability and the Need for Sustainable Development* (4.1.7).

In the decade since the previous review, three change drivers in particular affect what competences are desired of graduating engineers. One change driver is the growing awareness and evidence of the impact of human activities on our planetary system and ecosystems and the urgent needs for societal transformations to ensure sustainable living conditions for ourselves and future generations (e.g., UN, 2015; IPCC, 2018; WWF, 2020). Another change driver is digitalization as a key technology enabling engineers to address novel problems and existing problems in more effective ways, which also brings along new risks to mitigate. The third change driver is the conception of the world as accelerating, rapidly changing, and increasingly complex which is embodied in narratives about Industry 4.0, Society 5.0, and the VUCA world (e.g., Kamp, 2020), requiring decision-makers to continually be ready to reconsider and adapts. In addition to these external driving forces, there is also within the international CDIO community extensive experience of the use and customization of the CDIO Syllabus. A fourth, internal change driver is thus to take into account the lessons learned from using the Syllabus in curriculum and course development.

This paper describes the review process and the proposed changes, resulting in the CDIO Syllabus 3.0.

THE CDIO SYLLABUS

The starting point of the CDIO Initiative was to consider what knowledge, skills, and attitudes that engineering students should learn to prepare for engineering practice. The resulting document was called the CDIO Syllabus (Crawley, 2001). It was originally structured in the four sections 1-4 according to Figure 1. The first section is a placeholder for the fundamental knowledge relevant for a particular educational program, the second section lists personal and professional skills, while the third contains interpersonal skills. The fourth overarching section contains the ability to conceive, design, implement and operate products, processes, systems, and, services in the enterprise and societal context – or what could be called the CDIO shorthand for engineering competencies. The sections contain two additional levels of detail, here referred to as the X.X and X.X.X levels, and an unnumbered list below the X.X.X level. The update of the Syllabus presented in this paper has implied extensive revisions and modifications on all levels, including, as indicated in Figure 1, the addition of a fifth "*Expansion*" section.

Figure 1. The four sections of the original CDIO Syllabus (Crawley, 2001) complemented with a fifth "Expansion" section in the updated CDIO Syllabus 3.0.

The recommended use of the CDIO Syllabus is as a source of inspiration or as a frame of reference, for instance when considering possible features in a program, comparing programs, or discussing the contributions of courses in a curriculum. Since the Syllabus is very extensive, it must be emphasized that it is intended to be comprehensive but *not prescriptive*. Hence, no program can be expected to address every topic. Formulating the goals for a specific program always implies a process of customization for the particular context, set of conditions and stakeholder needs.

To facilitate many different uses, as the ones mentioned above, the Syllabus is formulated in a hierarchical structure. To avoid being overwhelmed by the length and level of detail of the document, the recommendation is then to focus on the appropriate level. For instance, when discussing priorities in a curriculum, the second level (X.X) may well suffice. On the other hand, an instructor working on course development may choose to find inspiration in all the lower-level details (X.X.X and the accompanying topics), but should do so without feeling compelled to address each single topic.

UPDATING THE CDIO SYLLABUS

Overall Process

As described in the introduction, the updating of the Syllabus from the prevailing version 2.0 (Crawley et al., 2011) into a new version 3.0, has been motivated by the emergence of external change drivers and internal experiences within the CDIO community, categorized in the following four themes:

1. Sustainability
2. Digitalization
3. Acceleration
4. Experiences

A small initial working group was established in February 2021 with representatives from six European universities. The group was organized in four subgroups, responsible for each of the four themes. The subgroups had initial online meetings during February. The whole group gathered again for an online meeting in March for sharing of ideas and establishment of preliminary principles and processes for the updating, format of this paper, overall planning, and an online collaboration platform.

The working group was established in connection to the CDIO 2021 conference and more members were invited. For the subgroups 1-3 the updating was based on the identification and review of a broad spectrum of recent literature related to these three themes, whereas subgroup 4 reviewed all papers in the proceedings from the International CDIO Conferences for the previous three years. Competences and related topics that could enhance the Syllabus with regard to the four themes were identified and changes to the Syllabus were drafted. Inputs from the different members were discussed and negotiated, first within each subgroup and then by the whole working group, in an iterative process with several online meetings, to ensure validity and applicability.

In September 2021, a first public draft of the updated Syllabus was compiled and circulated to all CDIO member universities for review. The received feedback was thoroughly discussed and further processed at the CDIO International Working Meeting, held online during November 17-18 in successive sessions in three time zones. The working group, which had now been expanded with representatives from universities in Singapore, Russia, and Canada, continued to process through online collaboration, and compiled a final version of the updated Syllabus and finalized the draft version of this paper in January 2022. More details about the background and motivation and methods for revision and updating with regard to the respective themes are provided in the result section below.

RESULTING UPDATES

Overall

As presented in detail in the following subsections, revisions have been made with regard to all four themes in the Syllabus sections 2, 3, and 4. As indicated in the previous section, only a few updates have been made on the X, X.X, and X.X.X levels, whereas most updates are found in the lists under the X.X.X levels.

The former sections 4.7 *Leading Engineering Endeavors* and 4.8 *Engineering Entrepreneurship*, that were added in the previous Syllabus revision (Crawley et al., 2011), have been renumbered to 5.1 and 5.2 and have, together with a newly developed section 5.3 Research, been included in a new Syllabus section 5. As pictured in Figure 1, this new section 5 is denoted “Expansion” in accordance with the notion used in Crawley et al. (2011). The rationale for this new section is that, in contrast to sections 1-4 that relate to competences needed by all graduates, the expansions in section 5 are only relevant to certain subsets of students, since not all will undertake research endeavours, aim at leadership positions, or become entrepreneurs.

Revisions made with regard to the themes Sustainability, Digitalization, Acceleration, and Experiences, have called for an enhancement of the roles of social sciences and the humanities in engineering education. As a consequence, the title of Section 1 has been updated to now read “Fundamental knowledge and reasoning”, where “Fundamental” has replaced the former “Disciplinary”, while a section has been added 1.4 Knowledge of social sciences and humanities.

In this text, “Category” refers to level 1 (X) changes, “Subcategory” to the levels 2 and 3 (X.X and X.X.X). A “Topic” is an unnumbered item (typically level 4) and subtopics are unnumbered items corresponding to level 5. Additions or deletions of items make reference to the numbering and level. The term “Aspect changes” is used for changes that imply modifications of a category/subcategory/topic definition but not additions/removals.

Sustainability

Background and motivation

One of the major change drivers motivating and guiding the revision of the CDIO framework, is the recognition that engineering and engineering education plays critical roles in the societal transformations that are needed for ensuring a healthy planet and sustainable living conditions for ourselves and future generations (e.g., Enelund et al., 2013; UN, 2015; IPCC, 2018; WWF, 2020; UNESCO, 2021).

The CDIO Standards have been updated accordingly (Malmqvist et al., 2020a,b) and the overarching CDIO rationale in Standard 1 now reads “*Adoption of the principle that <u>sustainable</u> product, process, system, and service lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education*”. In Standard 1 it is also stated that “*The consideration of environmental, social, and economic sustainability is an integral part throughout the lifecycle*”. Sustainability and sustainable development are further explicitly reflected in Standards 2, 3, 7, 9, and 11, and hereby permeate the whole set of core Standards. The importance of and opportunities with engineering education for sustainable development are further emphasized by the new optional CDIO Standard for Sustainable Development (Malmqvist et al., 2020b).

Sustainability was also one of several targets in the previous revision of the CDIO Syllabus (Crawley et al. 2011), resulting in the addition of terms such as environmental and sustainability, mainly in section 4, and a new subsection 4.1.7 *Sustainability and the Need for Sustainable Development*. Rosén et al. (2019) explored to what extent and how the key competencies for sustainability outlined in UNESCO (2017) are reflected in the Syllabus. It was concluded that the Syllabus was already to some extent aligned with the UNESCO competencies. Similarities were identified between the integrated problem-solving key competency in the UNESCO framework and the Conceive-Design-Implement-Operate competences in the CDIO framework as overarching and integrating competencies. However, needs and opportunities for enhancing the CDIO Syllabus with regard to sustainable development were also identified.

Method

In the here proposed update of the CDIO Syllabus, the needs and opportunities identified in Rosén et al. (2019) have been further refined and implemented. Rosén et al. (2019) however concluded that the UNESCO (2017) definitions of the key competencies are quite limited. The updates proposed here have therefore been further informed by key competency frameworks presented in EOP (2020), Lozano (2017), Wiek et al. (2011; 2016), also by the 2030 Agenda (UN, 2015), of course also by the CDIO Standards 3.0, and by principles and perspectives proposed by Becker et al. (2015), Choi & Pak (2006), EU (2018), Mathebula (2018), McDonough & Braungart (2002), Raworth (2017), and Rist (2019). Through individual working group members' analysis and several video conference discussions, the most essential elements to be included in an engineering education key competency base-line have been negotiated, and corresponding proposals for updating the CDIO Syllabus have been formulated. The initial stage of the Syllabus updating with regards to sustainability can hence be described as an interpretive process, informed by principles of Education for Sustainable Development (ESD), and guided by conceptual reasoning and discussions between colleagues.

Results

The urgent need for and systemic characteristics of societal transformations and the crucial role of engineers in sustainable development, have been taken as motivations for quite substantial updating of the CDIO Syllabus with regard to sustainability. The following are the major changes that are proposed in the [Appendix].

Section 2.3 *System thinking* has been enhanced from the previous narrow focus on technical systems to a more holistic perspective on technical systems' and human societies' embedment in, and dependency and impact on, the ecological and planetary systems. 2.4 *Attitudes, thought and learning* has been enhanced with regard to the self-awareness and critical-thinking key competencies for sustainability. 2.5 *Ethics, equity and other responsibilities* has been enhanced with regard to the self-awareness, normative, and anticipatory key competencies for sustainability.

In section 3, the competences previously outlined in section 3.1 *Teamwork* and its subsections 3.1.1-5 have been substantially elaborated and condensed into a new subsection 3.1.1 *Working in teams*. The term '*Collaboration*' has been introduced and included in the titles of section 3 and subsection 3.1 to complement the more instrumental competences related to 'teamwork' with a broader set of competences related to collaborations with broader and more heterogeneous groups of stakeholders which are outlined in the new subsections 3.1.2 *Multi-perspective collaboration* and 3.1.3 *Stakeholder engagement*. As a consequence of these changes, subsection 3.2.10 *Establishing Diverse Connections and Networking* has been moved and now constitutes subsection 3.1.4. *In* 3.2.7 *Inquiry, Listening and Dialog*, the aspect Body language and the silent voice has been added.

Section 4.1 has been retitled to *Societal and environmental context* (previously *External...context*) and enhanced with regard to historical, cultural, and global perspectives, and self-awareness, normative, anticipatory, and systems-thinking, key competencies for sustainability. A new section 4.1.6 *Visions of the future* has been added. Section 4.2 *Enterprise and business context*, has been enhanced to emphasize that technology should contribute to a sustainable development, and that indirect stakeholders must be considered and cared for. 4.3 *Conceiving, system engineering and management* has been enhanced to especially include strategic competency in the context of understanding needs and setting goals in a new subsection 4.3.1 *Understanding societal and planetary goals and constraints*. 4.4 *Designing* has been elaborated on what is meant by design for sustainability. In 4.6 *Operating* circularity has been added to lifecycle management, and the concept of values and costs has been broadened in subsection 4.6.5 which is renamed to *Disposal, end-of-life, and circularity*.

Further, section 5.1 *Leading engineering endeavors* has been enhanced with regard to the self-awareness key competency related to topics that lead to delivering on the vision.

As a consequence of the here proposed Syllabus updates and the already updated CDIO Standards 3.0, we are also somewhat ironically proposing to eliminate subsection 4.1.7 *Sustainability and the Need for Sustainable Development* that was added in the previous revision of the CDIO Syllabus (Crawley et al., 2011). It is no longer relevant to 'hide' sustainable development in a subsection on the X.X.X-level, instead we advocate that different aspects of sustainability and sustainable development should be enhanced and added in several of the sections and subsections as proposed above and in the [Appendix].

Digitalization

Background and motivation

Digital competences were certainly important for graduating engineers in 2001 and 2011 when the previous versions of the CDIO Syllabus were created. Yet, a lot has happened since then. Global connectivity, access to data, and increasing computational capabilities have reshaped the engineering landscape. Digitalization and the emerging technologies have also brought issues in ethics, safety and security to the agenda from new perspectives. Different digital systems have become vital tools in all engineering domains – and they will be important enablers when addressing the Sustainable Development Goals (SDGs) and shaping the future society (UN, 2015; 2020; 2021). One important question is which data literacy skills (Kamp, 2019) shall be taught in the different fields of engineering education for future professionals, and how these skills should be reflected in the CDIO Syllabus.

Method

The theme of digitalization was approached by reflecting the previous versions of the CDIO Syllabus, realizing that the earlier vision of the future of engineering may have put more trust in digital tools than the actual praxis was at the time. Also, the digitalization-driven updates in the CDIO Standards 3.0 (Malmqvist et al., 2020a, b) were revisited, and relevant literature discussing the digitalization-related competences were identified and analyzed. A team of CDIO practitioners reviewed recent publications on impact of digitalization and suggested core digital competences, met on several occasions online to deliberate on the relevance of the findings to CDIO, and where best to locate the skillsets underpinning digital competences.

Results

Digital knowledge and skills are integrated to both discipline-dependent and discipline-independent as well as to professional practice sections of engineering curricula (e.g., Mesároš et al., 2016; Ramadi et al., 2016; Adriole, 2018) which challenges the placement of these competences in the CDIO Syllabus. Accordingly, many articles and reports seem to focus on digitalization-related competences of different fields that made it difficult to identify general guidelines to the work (Gurcan, 2019).

Also, the organization of the cross-cutting themes, and the level of details were discussed (Martín Núñez & Díaz Lantada, 2019; Cruz et al., 2020). That is, some parts (e.g., teamwork) of the CDIO Syllabus might not be deep enough for digitalizations to appear. Should these competences be focused on particular sections, or would it be more appropriate to embed them to the other parts of the Syllabus? We decided to follow the same approach used for the updating of CDIO Standards 3.0 whereby these are infused into various subcategories in the Syllabus instead of having a separate standalone subcategory at X.X level.

The work of van Laar et al. (2017) was found useful, as it identified concepts being used to describe skills needed in a digital environment, that go beyond mere technical use, and focus on 21st century digital skills. The framework these authors offered aligned well with the CDIO Syllabus and the dimensions of digital competences recommended had great overlaps with key categories in CDIO Syllabus. Margarov & Konovalova (2019) on the other hand, proposed four broad categories of digital competences (ICT-skills): general, professional, problem-oriented and complementary. They highlighted three aspects of the digital economy where these skills will be of relevance: cognitive, socio-behavioral, and technological. Oberländer, Beinicke & Bipp (2020) provide a holistic view of the concept of digital competences. They proposed 25 dimensions that constitute digital competences at the workplace. The components underlying these aspects can again be found diffused in the CDIO Syllabus.

Cross-checking was carried out against the current version of the Syllabus and it was found that most had already been covered, albeit in different categories. Hence the work concentrated mostly on updating relevant categories of the existing CDIO Syllabus to reflect application of digital skills and impact of digitalization on education.

Acceleration

Background and motivation

Since 2001, when the CDIO Syllabus 1.0 was published (Crawley, 2001), a number of impactful global events (The Twin Towers, the financial crises of 2008, Space X's disruption of the space industry, "tipping-point" scenarios driven by global warming, Covid-19 etc.) have highlighted our often very limited pre-understanding of complex, "unknown-unknowns" events, along with the need for urgent, yet appropriate response. Also is society experiencing a moment of great upheaval under the influence of transformative technologies and rapid economic and societal developments. We are living in an age where change in society, technology and science is accelerating at a pace humankind has never seen before. An ever-growing part of the world's population is becoming digitally connected, has access to a wealth of accumulated knowledge and adds to it in a worldwide collaborative effort. Rapidly evolving markets, changing regulations, breakthroughs in technologies and political instabilities make it hard to look too far into the future. It gives rise to high unpredictability and urgent challenges - environmental, social and economic, and feeds the sense we live in an "accelerating" world where the half-life of expert knowledge and timescales for knowledge acquisition and decision-making are being compressed. Engineering education must prepare students to thrive in this world of flux, to be ready, no matter what comes next. It must empower them to be leaders of innovation, to not only be able to adapt to a changing world, but also to change it.

Method

The identification of acceleration was initiated by a literature search in Scopus and leading engineering education journals and conference proceedings. Few papers were found to focus exclusively on acceleration-related skills, but some informative publications were found, including Passow & Passow (2017), Kamp (2019; 2020), and Margarov & Konovalova (2019).

A team of CDIO practitioners then reviewed the publications on the impact of acceleration, identified acceleration-related themes and topics and proposed some additional categories, topics and aspects as candidates for modification or addition in the CDIO Syllabus 3.0. The group met on several occasions online to discuss the relevance of the findings to CDIO, and where best to locate the acceleration skills.

Results

The acceleration-related themes identified in the literature, included interdisciplinary knowledge and collaborative skills, an extended and more holistic view on "systems", methods for the advanced use and situation analysis, for faster and more exhaustive design space exploration, and for agile and change-driven development processes. Moreover, the important abilities of mental flexibility (like agility and adaptability), self-leadership (like self-confidence and coping with uncertainties), self-directed learning and the development of relationships (like empathy, trust) werere brought forward. As the "acceleration" dimension overlaps with both sustainability (e.g., interdisciplinarity, holistic thinking) and digitalization (e.g., fast access to and reliance on massive datasets, cybersecurity), the text in the paragraphs below aims to minimize repetition of what has already been stated in this paper.

Specifically, in subcategory 2, *Personal and Professional Skills and Attitudes*, the perspective in *2.3 Systems thinking* has expanded from a systems' view focused on deterministic technical systems to one that embraces human-systems interaction, transdisciplinary approaches, uncertainty and complexity. In 2.4 *Attitudes, thought and learning,* a new subcategory 2.4.3 *Adaptability, resourcefulness and flexibility* has been created to collect such competences. The topics are partly redistributed from other categories. In 2.4.7 *Lifelong Learning and Educating*, *Learning agility* has been added to the subcategory heading in order emphasize the need for fast updating of skills and knowledge. Several topics on 2.4.7 are added and/or updated to reflect this expanded scope. In *2.5 Ethics, equity and other responsibilities,* aspects of "acceleration" have been added to the subcategories 2.5.1 *Ethics, Integrity and Social Responsibility*, 2.5.3 *Proactive Vision and Intention in Life*, and 2.5.4 *Equity, Diversity and Inclusiveness* (renamed).

In category 4 *Conceiving, Designing … The Innovation Process*, aspects of "acceleration" that have been added to *4.1 Societal and environmental context,* consider interdisciplinarity (4.1.2 *The Impact of Engineering on Society and the Environment*) and global communities (4.1.7 *Developing a Global and International Perspective)*. The *4.3 Conceiving, Systems engineering and management* has aspect additions to 4.3.2 *Understanding Needs and Setting Goals* – (related to capturing user scenarios and requirements margins) and 4.3.4 *System Engineering, Modeling and Interfaces* – aspects related to "trust" in designed systems and autonomous and self-evolving systems. Several topics have been added to 4.3.5 *Development Project Management* – they reflect a variety of system development and program management processes. *In 4.4 Designing*, an aspect related to very fast design loops have been added to 4.4.1 *The Design Process*. The expanded view of systems is also incorporated in 4.5

Implementing where 4.5.5 *Test, Verification, Validation and Certification* has an added aspect related to validation of systems with evolved, “learned” behaviors.

Finally, an aspect related to developing technology from research observation level to product commercialization has been added to 5.1.8 *Innovation – the Conception, Design and Introduction of New Goods and Services in 5.1 Leading engineering endeavors.*

Experiences from the CDIO community

Background and motivation

While the three first change drivers were related to a major societal trend, the fourth was instead more inward-looking. Here, the impetus to change comes from the practical experiences reported in the CDIO community. In addition to the CDIO conference papers, the survey included the special issue “Scholarly Development of Engineering Education – the CDIO approach” in the European Journal of Engineering Education (Edström, Malmqvist & Roslöf, 2020). Of particular interest is curriculum or course development that addresses learning outcomes that may not yet be fully present in the CDIO Syllabus. Hence, we are searching for work with a scope that goes beyond what was reflected in the CDIO Syllabus 2.0, and that may be taken as arguments for changing or expanding it.

Method

The first stage of the work was to manually go through the proceedings of the International CDIO Conferences 2018-2020, in total 219 papers or 2630 pages, and the special issue mentioned above. The aim was to identify papers addressing aspects of what students should learn, but that were not obviously already covered in the Syllabus. An important criterion was that topics had to be novel and universal, i.e., not subject-dependent. Papers related to sustainability, digitalisation or acceleration were forwarded to the colleagues who were reviewing these themes. For the remaining papers, a closer analysis followed, considering where in the Syllabus the topic could belong and whether it was already present, either in part or under other terms. The analysis was checked by another member of the working group in a round-robin fashion. Finally, the group jointly prioritized the topics, and formulated the proposed changes.

Results

The first result of the investigation of CDIO literature can be seen as a clear validation of the CDIO Syllabus. A very large majority of the work that was reviewed did not warrant changes or additions, mainly because the topics were found to be already sufficiently present in the CDIO Syllabus. This applied to numerous papers addressing topics like life-long learning, self-directed learning, creative thinking and systems thinking, safety, ethics and social responsibility, just to mention a few.

Interdisciplinarity - Several authors note the need to collaborate around solutions for global societal and environmental challenges (Enelund & Henricson Briggs, 2020; Fouw et al., 2020). Besides engineering competences, real-life assignments often demand interdisciplinary and transdisciplinary systems thinking, and an open entrepreneurial mindset (Klaassen et al., 2020; Boon, 2018; MacLeod, 2018; Spelt, 2017). Engineering students need to discover that it is impossible to know enough to fully understand wicked problems (Kamp, 2019). Such problems may require an interdisciplinary approach, with multiple disciplines involved, or even transdisciplinary - beyond the current disciplinary map. While already present in the Syllabus, it was proposed to strengthen holistic thinking and transdisciplinary approaches in sections 2.4.3, 2.4.4, 2.5.5. and 4.1.2.

Internationalization - As noted by Salti et al. (2019), "*Embedding the internationalization process within the CDIO context would certainly benefit the higher education institutions and the attributes of their graduates*" (p.20). It is increasingly important to see cultural differences and opportunities in a more globalized world where products, systems and services are delivered not just locally but globally (Van Puffelen & van Oppen, 2020; Mejtoft et al., 2020; Kjellgren, et al., 2018). According to Säisä et al. (2020), international connections and activities are typical in project-oriented organizations in many engineering domains. Similar considerations are also coming from the sustainability and acceleration perspectives. The need is also indicated by the optional CDIO standard for Internationalization and Mobility (Malmqvist et al., 2020). Internationalization is present in the Syllabus, but the competences need to be made more explicit or precisely described. As a result, modifications are proposed in 2.3.1, 2.4.4, 2.4.5, 3.1, 3.2.2, 4.1.2, and 4.1.7.

Development methodology - Over the years, methods and tools for developing engineering products, systems and services have developed, increasingly based on incremental development to ensure quicker time-to-market and a focus on families of products, systems and services (Säisä et al., 2018, D Ha et al., 2019). We also note that the expression "conceive - design - implement - operate" is sometimes misconceived as implying a linear or waterfall development process. We propose modifying 4.4.2 and 4.6.3 to cover a diversity of methods.

History of Technology - Smulders et al. (2018) propose that students should learn about the process of technological innovation in the history of technology, combining an innovation theoretical lens with a socio-interactive lens to bring the stories to life: "*What troubles did they encounter? What assumptions were needed to go and how was it accepted? How did they conquer resistance to change?*" When the historical context is brought up in section 4.1.4, this perspective has indeed been lacking and we propose to add: "The history of technological innovation and how society and technology have co-evolved".

Research - The work by Gunnarsson et al. (2019) mentions the LiTH Syllabus, a modified version of the CDIO Syllabus developed and used at Linköping University (2019). The major adaptation there is to add a new section that enables the use of the CDIO framework by also non-engineering programs.. The section covers various aspects of defining, executing and reporting research and development projects. Also Chuchalin (2020) addresses research skills. Many engineering programs contain a research project, most often in the form of thesis work but also other types of undergraduate research projects are increasingly implemented as learning activities. We find the research competence a welcome addition. While some aspects are already present in 2.2 *Experimentation, investigation and knowledge discovery*, these can be extended to embrace a more general view on research approaches and methodologies. We propose to add a section 5.3 *Research*, with four subtopics: 5.3.1 *Identification of needs, structuring and planning of research projects*; 5.3.2 *Execution of research*; 5.3.3 *Presentation and evaluation of research*; 5.3.4 *Research ethics*.

Learning through reflective practice - Junaid et al. (2018) bring up the skills and habits associated with keeping professional logbooks. Among various functions this can generate reflection that supports the engineer to develop professionally through their own work. Junaid et al. refer to Ericssen's concept of deliberate practice, i.e., practice with the aim of improving expertise and performance. We see no reason to specify a particular genre of writing in 3.2 Communication skills. However, in that section, writing was never seen as a tool for reflection or self-development, and we propose adding "Reflective writing (writing to learn)". Likewise, in 2.4.6 Lifelong Learning and Educating we propose to add "Learning from experience through reflective practice". While reviewing 2.4.6 we also note the mention of learning styles. These are contested and seen by many researchers as urban myths (see for instance Coffield, 2012). We therefore propose to remove "One's own learning styles".

DISCUSSION

Evolution vs. revolution

It has been ten years since the CDIO Syllabus was last revised (in 2011), and within the CDIO community there is a widespread understanding and consensus that it is now timely and necessary to update the Syllabus. Engineering education development needs to take into account the development of society and technology, and keeping the CDIO Syllabus current is a way to support this.

The discussion is however to what degree the work should be incremental or radical. There is at the moment an unresolved tension between being compatible with current educational practices and positioning CDIO as far more future-oriented. For example, some call for higher education to move beyond the idea of detailed pre-conceived curricula, toward models where students have more agency of the directions of their studies (see e.g. Osberg & Biesta, 2020). Others have identified a need for changes in adult learning where people move into and out of higher education throughout their professional careers, taking only shorter and more focused courses (Mense et al., 2018). Such changes could have profound implications for the CDIO approach. However, the exploration of such implications is beyond the scope of the current set of revisions.

The Syllabus has been updated to be backwards compatible in numbering and general structure even as the contents have been extensively expanded and modified. The Syllabus is an important instrument that this group has wished to keep intact for the purpose of helping practitioners who have already invested in its use. There is for instance among current users of the Syllabus an interest in preserving continuity in their local curriculum documentation, for instance regarding the numbering of topics. While retaining the structure was not always compatible with the wish for a simple and logical document, it has here been accommodated to the extent possible. Changes on the higher levels are proposed only after much consideration. It has been far easier to propose updates to the lower-level descriptions of the topics. The update contains a very large number of such edits, in particular in the lists below the X.X.X level.

Furthermore, the changes proposed here are less often about removing topics, since there could be stakeholders for whom an item is (still) important. The Syllabus aims to be comprehensive, and contain a wide range of topics that *could* be addressed in an education, and a topic is thus never prescriptive. Therefore, it generally makes more sense to add or elaborate on topics, or choose broader terms that cover more ground.

On the other hand, allowing the document to sprawl creates challenges of its own, perhaps particularly to new collaborators. The alternative would be to start from a blank slate and make the resulting document as "clean" and accessible as possible. While this "revolutionary" approach would require an even larger effort of the community than was made here, it could certainly be in the interest of many collaborators, not least because there are benefits in participating in such a full process. This option could therefore be considered in future revisions.

Inherent tensions

The process of revising the Syllabus was conducted in subgroups along the different change drivers. They used different sets of sources and stimulus for revisions. The sustainability group used research and reports on changes to education that seek to enable a new, sustainable direction of societal development. As a basis for promoting changes to education in general and engineering education in particular, such literature argues that the acceleration of human economic activity is a root cause for our current predicament and requires radical departures from current societal and educational practices. In contrast, the acceleration subgroup identified trends of increased acceleration as a call to support students in a work environment likely to change at an ever-faster rate. In our work, we did not necessarily take into account that the different values at work here could be contradictory, nor how CDIO students should position themselves with respect to such accelerating increase in economic activities: to embrace them, to understand them or even challenge or reject them.

Global representation and relevance

The number of people who have been mainly involved in this work is limited, and many of them come from just some parts of the world. This implies a risk that the review is made with limited perspectives. It has been mitigated by inviting the whole CDIO community in an open review process with opportunity to give feedback. Enhanced perspectives are also included through the literature that is underlying the Syllabus revision, with papers by authors from and other parts of Africa, Asia, Europe, North and South America, and reports from international bodies such as IPCC, UNESCO, and WWF. However, it can always be discussed or questioned if this has been enough to accomplish an update of the Syllabus that does not miss certain perspectives or is biased towards a certain direction. A conclusion from these experiences for future reviews, is to ensure that global representation and participation are taken into account.

The Syllabus is not an objective, value-free document. It must be noted that some of the inherent values might be more representative for democratic societies. This can be challenging in contexts where the overall societal and political climate is more restrictive. Engineering educators in authoritarian regimes could find great difficulties in addressing some of the new topics in the Syllabus, such as inclusiveness and collaborations. There may for instance be contexts where the inclusion of *Diverse, Underrepresented, and Conflicting Stakeholders input* (3.1.3) could put engineers at serious professional or even personal risk.

Recommendations for future work

Updating the CDIO Syllabus to version 3.0 offers an opportunity to renew the validation with current professional practice. Another avenue is to investigate how the Syllabus is used among CDIO implementers, and create support for the users. For instance, the Syllabus is intended to aid the formulation of learning outcomes for engineering degree programs. However, as noted earlier by Crawley (2001), it is not an instrument that is sufficient for directly formulating learning outcomes. With the current revision adding many new topics to the overall Syllabus, the task of finding meaningful, cohesive subsets of topics of relevance for degree programs may become even more challenging. Future work that supports new adopters in using the Syllabus to formulate learning outcomes would be welcome.

As always, the CDIO community is encouraged to use the new version and report experiences, and to formulate lessons learned and critique that can inform future updates. One practical way to enable monitoring of such work is to add keywords to conference papers in which the Syllabus or particular Syllabus topics are addressed. While the Syllabus aims to be comprehensive, it should never be seen as complete and final. In addition to the updates presented and discussed in this paper, we fully expect further additions and changes that may become necessary by specific local needs, evolved understandings and knowledge, and changes in future circumstances.

In 2011, the CDIO Syllabus 2.0 (Crawley et al., 2011) was compared with a number if international and national standards for engineering education accreditation, including ABET, EUR-ACE, the British UK-SPEC, the Swedish degree ordinance and the Canadian CEAB, and it was concluded that "*The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession, and its greater levels of detail facilitate program and course development. A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes*". Of course also these other standards have been updated. For example, ABET has made amendments to its student outcomes accreditation criteria, which will be effective for the 2019-20 academic year. (ABET, n.a.). The EUR-ACE standards (ENAEE, 2011) have also been updated, as recently as 2021. Taking into consideration the changes in ABET, EUR-ACE, and other accreditation standards will be worthwhile for CDIO to review its mapping to these standards in terms of the new Syllabus version 3.0.

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COMPARING THE CDIO STANDARDS WITH THE WORK-INTEGRATED LEARNING CERTIFICATION

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ABSTRACT

Improving the quality of higher education is an important responsibility of universities and colleges. Several approaches have been developed with the goal of improving the quality of university study programs. In this paper we compare the CDIO (Conceive, Design, Implement, Operate) and the work-integrated learning (WIL) initiatives based on recently completed WIL certifications at University West. Through a series of workshops, the CDIO standards are compared with the aspects and criteria of the WIL certification guidelines, to identify overlapping areas and differences between the two initiatives. The results show that both initiatives overlap but also differ in several aspects. These differences could be useful to strengthen the WIL certification process at University West as well as clarifying the connection between CDIO and work-integrated learning.

KEYWORDS

AIL, WIL, Engineering education, Quality in higher education

INTRODUCTION

Higher education institutions (HEIs) need to continuously improve their quality to prepare students for the society of the 21st Century. One important quality aspect is to develop efficient ways of collaborating with various partners in the surrounding community. For the quality of HEIs to develop, the society must be viewed as a valuable resource. Close ties with business and industry, and diversity among staff and students are necessary, especially within engineering education. An engineering degree should prepare students to develop a wide range of knowledge and skills. These range from scientific and mathematical to technical knowledge, but also include soft skills (Schulz, 2008) such as teamwork, business skills and critical analysis. These soft skills are also central sustainability competences (Swedish Regeringskansliet, 2018; UNESCO, 2017). It is vital that learning for engineers takes place in the context of authentic engineering problems and processes, to develop these skills and to put theory into practice (Mitchell, Nyamapfene, Roach, & Tilley, 2019).

Several initiatives focused on incorporating these skills in higher education exist. CDIO (Conceive, Design, Implement, Operate) is one of the most prominent initiatives within engineering education (CDIO, 2021). It targets the typical tasks an engineer performs when bringing new systems, products and services to the market or to society. The CDIO initiative was created to strengthen active and problem-based learning and improve students' communication and professional skills. CDIO focuses on improving practical and work-related skills to better prepare engineering students for their future professional life.

At University West in Sweden, another initiative, Arbetsintegrerat lärande (AIL), has been adopted as the main philosophy in all education programs. “Arbetsintegrerat lärande” normally translates to work-integrated learning (WIL). However, the meaning of the term WIL at University West differs slightly from the common definition. Outside University West, WIL often refers to activities where students spend periods working at a company, for example in the form of co-op, cooperative education (Cooper, Orrell, & Bowden, 2010). At University West, WIL includes a broader set of activities targeting practical skills, such as project work and lab exercises using realistic cases, tools, and environments (Lundh Snis & Smidt, 2021).

Currently at University West, all education programs, for example, in engineering, economics, nursing, and psychology are undergoing a WIL certification process. According to the authors' perspective, WIL shares much of the same philosophy as CDIO for engineering educations, however the relation between these two initiatives is currently not clear. The goal of this study is therefore to map similarities and differences between the CDIO initiative and the WIL certification. Specifically, the following questions were asked:

- What are the similarities between CDIO and the WIL certification?
- What is unique to CDIO and unique to the WIL certification?

The comparison between the CDIO and the WIL initiatives is based on recently completed WIL certifications at University West and was carried out through a series of workshops, where the CDIO standards (Malmqvist, Edström, & Rosén, 2020) were compared with the aspects and criteria of the WIL certification guideline (Lundh Snis & Smidt, 2021) to identify overlapping areas and the differences between the two initiatives. The results of the study show that there is indeed a large overlap between the initiatives but also several unique aspects, which could be of interest to the CDIO and the WIL communities.

The remaining part of the paper is structured as follows. In “Educational framework initiatives”, the CDIO initiative, the WIL certification and other approaches to improve higher educations are described. Then, related work and the method used in this study are presented. In section “Results”, the comparison between the CDIO standards with the WIL certification are described, followed by an overlap analysis. Finally, conclusions and future work are presented.

EDUCATIONAL FRAMEWORK INITIATIVES

Several frameworks for improving higher-education programs have been created during the last decades, here we describe the most well-known.

The CDIO initiative

The Conceive, Design, Implement, and Operate (CDIO) initiative (CDIO, 2021) is one of the most prominent initiatives within engineering education. It focuses on the typical tasks an engineer performs when bringing new products, systems and services to the market or society. CDIO is an innovative framework for educating the next generation of engineers. Students are taught engineering fundamentals within the context of real-world systems and products.

Having engineers be able to engineer is the goal. CDIO is an initiative aimed at fostering active learning and problem-based learning as well as improving students' communication and professional skills. It helps engineers prepare for the workplace by improving practical and work-related skills (Crawley, Malmqvist, Östlund, & Brodeur, 2007).

Academics, industry, engineers, and students were involved in the development of the CDIO initiative, which was specifically designed to be adaptable for all engineering schools at universities. Since CDIO is an open architecture, it can be adapted to meet the specific needs of any university engineering program, and it is being adopted by a growing number of engineering educational institutions around the world. CDIO is currently used in, for instance, college aerospace programs, applied physics programs, electrical engineering programs, and mechanical engineering programs.

The CDIO proposes a set of standards (Malmqvist, Edström, & Rosén, 2020) that serve as the guiding principles (or best practices) for implementing CDIO in an engineering program. The twelve CDIO standards address:

- program philosophy (Standard 1),
- curriculum development (Standards 2, 3 and 4),
- design-build experiences and workspaces (Standards 5 and 6),
- new methods of teaching and learning (Standards 7 and 8),
- faculty development (Standards 9 and 10), and
- assessment and evaluation (Standards 11 and 12).

These standards describe a program's defining traits, serve as educational reform standards, allow for comparability with other programs, and give a mechanism for self-evaluation to assist ongoing progress. Furthermore, they enable benchmarking with other programs and provide a tool for self-evaluation to support continuous improvement.

The WIL certification at University West

“Arbetsintegrerat lärande” normally translates to work integrated learning (WIL). At University West WIL is defined as a pedagogical practice where students' learning takes place through the integration of theoretical and practical knowledge and experiences. This knowledge is taken from educational contexts within the framework of both college and university and working life and civil society and where internship-related elements in higher education are designed and implemented in collaboration with working life (Lundh Snis & Smidt, 2021). WIL includes a broader set of activities targeting practical skills, such as project work and lab exercises using realistic cases, tools and environments. This view is similar to Billets definition: **“**Work-integrated learning is a pedagogical practice whereby students come to learn from the integration of experiences in educational and workplace settings” (Billet, 2009).

Outside University West, WIL often refers to activities where students spend periods working at a company, for example in the form of co-op, cooperative education (Cooper, Orrell, & Bowden, 2010). According to Schedin and Hassan (2016), from a socio-cultural standpoint, the WIL model can be seen as a process of interaction between students in the educational environment and in a practical setting such as a company. This interaction gives students the option to work with tools, such as machines and experimental equipment, doing laboratory demonstrations, and participating in projects at a company. Learning and growth are shared responsibilities that take place in universities and companies, integrating theory and practice.

The WIL certification of education programs at University West has the purpose to ensure that work-integrated learning in a systematic way permeates the educations, and that all students are given the opportunity to critically reflect on the relationship between theory and practice. Besides WIL, the creators of the certification process chose to also include sustainability. This could have been a separate activity but was decided to be merged with the WIL certification. Several aspects and criteria are defined and need to be fulfilled by an education program to get a WIL certification (see Table 1).

Table 1. The aspects and criteria used when evaluating an education program for the WIL certification.

The WIL certification	**Aspects**
1 Integration	How WIL and sustainable development is *integrated* into the programme as a whole/the common thread that places work-integrated learning in a context – focus on organisation, planning, implementation, and follow-up of the programme
2 Pedagogy	The application of WIL educational theory – focus on teaching practices, models, methods, and activities
3 Collaboration	Forms of *collaboration* with prioritised partners and other actors in the surrounding community
4 Communication	How the WIL and sustainable development perspective in the degree programme is *communicated* clearly and intelligibly for the benefit of students and colleagues as well as for collaboration partners and the surrounding community
The WIL certification	**Criteria**
A Pedagogical theory	The programme rests on an educational philosophy in which the link between theoretical and practical knowledge is justified and discussed in relation to the goals and content of the programme.
B Theory and practice	The integration of theory and practice at a general level systematically permeates and supports progression in the programme and prepares the students for working with and driving sustainable development/change in society.
C Activities	Through practice-related activities, the student is given the resources to develop educationally, learning to problematise, challenge, and integrate practical/experience-based and theoretical knowledge, and to do so through analytical reflection.
D Participation	The degree programme is composed of practice-related activities/modules that are shaped and carried out in collaboration with actors in the surrounding community, and that these are developed in a way that strengthens integration of theoretical and practical knowledge.

When applying for the WIL certification, program managers write an overall program description for the education program, where they describe and justify with concrete examples how WIL in a systematic way permeates the education and how to achieve sustainability aspects through WIL elements. To describe this, the aspects and criteria listed in Table 1 are applied (Lundh Snis & Smidt, 2021). There is no assessment rubric or maturity scale used.

Other frameworks

Among other approaches to improve education programs is the Framework for Improving Student Outcomes (FISO) which is the continuous improvement framework for all Victorian government schools, used in Australia (FISO, 2021). In USA there is the Accreditation Board for Engineering and Technology (ABET) that is a type of quality assurance that is used in a variety of fields, including computing, engineering, and science (Rashideh, Alshathry, Atawneh, Al Bazar, & Abualrub, 2020). However, these approaches are not considered further in this work.

RELATED WORK

Several earlier research studies have looked at the connection between CDIO and WIL. Schedin and Hassan (2016) present a learning model for WIL and the relation of this model to CDIO standards 7 and 8. This learning model is based on collaboration with industry partners to guarantee an internship position to students. Industry based projects and final thesis are also integrated onto the learning model. This is then connected with standard 7 of CDIO, since the standard supports the learning of disciplinary knowledge integrated with personal, interpersonal, and product and system building skills. The learning model proposed by Schedin and Hassan (2016) promotes critical thinking and problem-solving activities, and this relates to standard 8 which support active learning.

Brodie, et al. (2014), investigate the possibility of implementing the CDIO framework for distance and online education. In this context, there is little support from industries for practical activities and project work. Therefore, the authors suggest complementing the implementation of CDIO in online education with WIL. The advantage of this would be to receiving input from industry with respect to formulating real world design problems and engaging students in the design and construct phases of CDIO.

Einarson et al., (2016), present a set of learning outcomes, inherent to Demola and based on CDIO and WIL. Demola is a platform for collaborations between academy and industry with focus on multi-disciplinary student projects. The authors underline the connection between WIL and standards 7 and 8 of CDIO, similarly to Schedin and Hassan (2016). The authors mention that universities are still struggling to implement WIL because of several problems like, establishing sustainable industry academic contacts, strategies for project ownership and intellectual property rights and guarantees regarding the fulfilment of academic goals. The Demola platform helps in implementing WIL since it includes templates for academic-industry contracts and process models. In an extension of their work, Einarson and Saplacan, (2016), compare the set of learning outcomes from CDIO Standard 2, which is part of Demola, with the national Swedish higher education ordinance (Högskoleförordning, 1993) to show how Demola may adapt to national goals.

METHOD

The purpose of this study was to compare all standards of the CDIO initiative to the WIL certification and is based on recently completed WIL certifications at University West. To accomplish this, we chose to conduct a series of workshops where we compared the CDIO standard documents (Malmqvist, Edström, & Rosén, 2020) with the guideline document for the WIL certification (Lundh Snis & Smidt, 2021). Participating in the workshops were the four authors of this paper. Two participants have previous experience of CDIO activities at different universities, one participant was involved in approving the WIL certification criteria and certification of programs, and all authors participated recently in the WIL certification process of a program at University West.

To structure our process of identifying overlapping areas and mapping differences, a table with the CDIO standards along rows and the aspects and criteria of the WIL certification along columns were used. Going through the CDIO standard consecutively, the texts were interpreted, analysed, and reflected upon for each of the WIL aspects and criteria. All common traits and reflections, or the absence of them were noted in the matrix. The matrix provides a good overview for the presentation of the results. A Venn diagram was used to illustrate overlaps and differences. Finally, based on feedback from presenting an abstract of the draft work at a local conference at University West, the main findings were summarized and developed in more details (Loconsole et al, 2021).

RESULTS

To structure our main findings from the comparison of the CDIO standards and the WIL certification, we chose to map all standards, aspects, and criteria using a Venn diagram (see Figure 1). In the left-hand circle we find the CDIO standards and on the right-hand side, the WIL certification aspects and criteria. The matrix from our comparison of the CDIO standards with the WIL certification can be seen in Table 2. The filled circles indicate strong overlap, the striped circles medium overlap, the dotted circles weak overlap, and empty squares no overlap.

A general observation, when going through all material, is that the CDIO standards are clear and well defined. On the other hand, the WIL certification guidelines were harder to interpret because they were wordier and more complex. This made it necessary, for the comparison, to rely more on our own interpretations and experiences with the WIL certification.

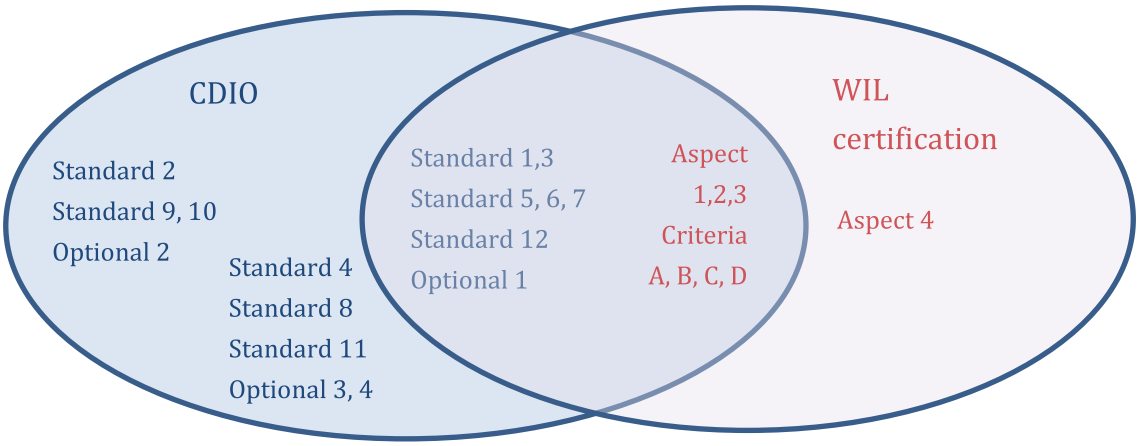

Figure 1. Venn diagram showing the overlapping and non-overlapping areas between CDIO and the WIL certification.

Table 2. Resulting mapping of the CDIO standards and the AIL certification guidelines.

	WIL aspects				WIL criteria			
CDIO Standards 3.0	1 Integra-tion	2 Peda-gogy	3 Collabo-ration	4 Commu-nication	A Peda-gogical theory	B Theory and practice	C Activi-ties	D Partici-pation
1 Context	Strong	Medium			Strong	Strong	Strong	
2 Learning outcomes			Weak	Weak	Weak			Weak
3 Integrated curricu-lum	Strong		Medium			Strong	Strong	Medium
4 Introduction to en-gineering	Weak					Weak		
5 Design-implement Experiences		Strong				Strong	Strong	Strong
6 Learning work-spaces		Strong			Weak	Weak	Weak	Weak
7 Integrated learning experiences	Medium	Medium			Medium	Strong	Strong	
8 Active learning		Medium					Medium	Medium
9 Faculty compe-tence			Weak					
10 Teaching compe-tence								
11 Learning assess-ment							Weak	
12 Program evalua-tion	Strong			Weak				
Optional standards								
1 Sustainable devel-opment	Strong					Strong		
2 Simulation-based maths								
3 Entrepreneurship			Weak				Weak	Weak
4 Internationalization & mobility		Weak	Weak				Weak	
Strong	Strong overlap. Similar description and meaning. CDIO supports the WIL certification and vice versa.							
Medium	Medium overlap. Similar meaning but not as clear connection.							
Weak	Weak overlap. Frameworks support each other somewhat.							
	An empty square means no overlap.							

Analysis

The following standards were found to be unique to CDIO:

- **Standard 2, Learning outcomes**. The WIL certification has no explicit learning outcomes. This is a major difference since CDIO includes an extensive syllabus defining detailed learning outcomes (Crawley, Malmqvist, Lucas, & Brodeur, 2013). However, during our analysis, we realized that the WIL certification implicitly relies on the learning outcomes defined by the Swedish national higher-education goals (Högskoleförordning, 1993). Although the connection between these high-level national goals and WIL are unclear.

- **Standard 9 and 10, Faculty competence and teaching competence.** Teachers' disciplinary and pedagogical competence development are not considered in the WIL certification. A faculty competence focus would have been a valuable thing for the WIL certification since not only students should experience WIL but also teachers doing, for instance, a sabbatical or a practical experience period in industry to improve their competences.

The following standards were found to be stronger in CDIO:

- **Standard 4, Introduction to engineering.** The WIL certification has no similar requirement. Although the WIL certification does not require an "introduction to engineering" course, such a course would support the WIL integration (aspect 1).
- **Standard 8, Active learning.** Active learning is not explicitly mandated by the WIL certification. On the other hand, active learning often comes naturally from the focus on work integration since activities involving practical experiences and learning are commonly active by nature.
- **Standard 11, Learning assessment.** Learning assessments in the WIL certification are not included. This is not surprising since the WIL certification is also lacking learning outcomes making it hard to evaluate aligned assessments.

The following aspect was found to be stronger in the WIL certification:

- **Aspect 4, Communication.** Communication is an important aspect in WIL certification which is not emphasised as much in the CDIO standards. The idea with communication in the WIL certification is to spread awareness and teach the pedagogy behind WIL to students, colleagues, collaboration partners, and the surrounding community.

During the analysis, a weak point in both initiatives were discovered:

- **Research as a profession.** Several students will, after graduating, end up in a research-related position, for example, as a Ph.D. student. This is especially true for programs at the master's level. Neither the CDIO initiative nor the WIL certification include this aspect. Doing research is also a profession with some specific knowledge and skills required.

For the optional standards; Sustainable development is included in both initiatives. Simulation-based math is very engineering specific; hence it is not applicable to the broader WIL certification. Entrepreneurship and internationalization are not explicitly mentioned in the WIL certification but are valuable WIL activities.

DISCUSSION

An interesting observation is that the WIL certification is broader than the CDIO initiative. For example, at University West, nurse educations are also being WIL certified. These educations also target a specific profession although they do not include all the conceive, design, implement, and operate activities. This indicates that the CDIO standards and syllabus may be seen as two parts. One part focusing on good pedagogical practices for profession-oriented educations and another part specific for engineering educations.

Communication was found to be a weak point in CDIO since there is no standard focusing on communication explicitly. Nevertheless, looking closer, one could argue that communication is implicit in many of the standards. For example, in the assessment rubrics for several standards, the highest level (5) mandates evaluation and feedback from students, instructors, and external stakeholders. In contrast, the WIL certification sees this as important enough to include as one of the aspects. The reason for this can be found in the pedagogical philosophy behind WIL, which we interpret as: (1) to integrate theory and practice, and (2) to acknowledge that external parties have knowledge and skills that staff at a university lack. Thus, focusing on communication encourages a greater exchange of knowledge.

One of the weak aspects found in WIL was the lack of learning outcomes. We believe that the WIL certification could be strengthened by adding learning outcomes. This would make the WIL certification easier to understand, more concrete and specific. The WIL certification also lacks an explicit focus on active learning even if active learning is common in practice. Active learning would also be good to include as an explicit aspect in the certification.

CONCLUSIONS

This paper has presented a comparison between the CDIO standard documents and the guideline and criteria documents for the WIL certification at University West, Sweden. The comparison identified some overlapping areas and differences between the two initiatives. The results can be summarised as follows:

1. The two initiatives have similarities. As can be seen in the Venn diagram in Figure 1 and in Table 2, the standards 1, 3, 5, 6, 7, 12, and optional standard 1 of CDIO are overlapping with aspects 1, 2, 3 and criteria A to D of the WIL certification.
2. Unique aspects are present in both initiative: Standard 2, learning outcomes, standards 9 and 10, faculty and teachers' competence development (both pedagogic and disciplinary) are unique to CDIO while aspect 4 communication is unique to the WIL certification.
3. Both initiatives lack focus on the research profession. None include the connection to continued (academic) studies and research.
4. The CDIO standards are well structured and easy to understand. The WIL certification guideline uses complex, hard to interpret language that could be simplified.

The results clarify the relationship between CDIO and WIL and can be useful when implementing the CDIO standards or the WIL certification. Especially if the educational program already complies with the CDIO standards or have obtained a WIL certification, then, some standards or aspects might already be fulfilled.

One interesting extension of this work would be to clarify the implicit learning outcomes of the WIL certification and investigate the connection with the learning outcomes defined by the Swedish national higher-education goals (Högskoleförordning, 1993). Another possible extension of this study is that part of CDIO could be adopted towards education programs outside engineering.

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BIOGRAPHICAL INFORMATION

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Andreas de Blanche (PhD) is an associate professor in computer science and engineering at the department of engineering at University West in Sweden. He was vice chair of University Wests board on Research and Education when the WIL certification was developed. The board determined the WIL certification criteria and certified the first ten programs. His main interests include engineering education, high performance computing and blockchain technology.

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DOES A MASTER'S PROGRAM IN ENGINEERING REQUIRE A FINAL PROJECT?

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ABSTRACT

Within engineering education frameworks worldwide, requirements for a master's degree are diverse and very few graduate-level engineering courses are recommended for accredited programs. To ascertain how common the requirement for a final project at the master's level is, an ad hoc review of international master's programs was conducted. This review included several of the highest-ranking universities internationally and selected universities in Europe. From this review, it is established that the standard practice is to require students attempting a master's degree in engineering to complete what we term a final project course, which may or may not be research-focused, and typically corresponding to one semester of work. This paper summarizes how the considered universities integrate a final project course into their programs and distinguishes how these might differ from traditional research-focused master's dissertations. We discuss some practical difficulties of managing such projects. We conclude by providing a rubric for self-assessment and final project course integration that aligns with the criteria for continuous improvement in a graduate program quality framework.

KEYWORDS

Final project course, dissertation, thesis, learning outcomes, rubric, Master of Science. Standards: 2, 5, 8.

INTRODUCTION

An inherent goal of engineering education is to prepare graduates for the challenges they may face as professional engineers in the workplace. Educational programs will prepare students differently, depending on the needs, traditions and cultures in the relevant country as well as the values of the specific university. Therefore, engineering programs vary (usually within accreditation constraints) and thus the graduating students will have distinct nuances to their list of graduate outcomes.

One relevant skill is the student's ability to complete large, challenging and complex projects, where the student is required to incorporate diverse discipline-specific skills, as well as both personal and interpersonal skills. Traditionally, this particular attribute has been trained and evaluated using a final project course (FPC) positioned in the educational program towards the end of the master's qualification.

As far as possible, the learning outcomes of the FPC in engineering should reflect the main areas of the future engineer's transversal practical skills, as emphasized by Kamp (2016) and one such view is outlined in Figure 1. These capabilities should also be inherent in the learning outcomes and in any potential rubric for engineering programs' self-assessment of the FPC.

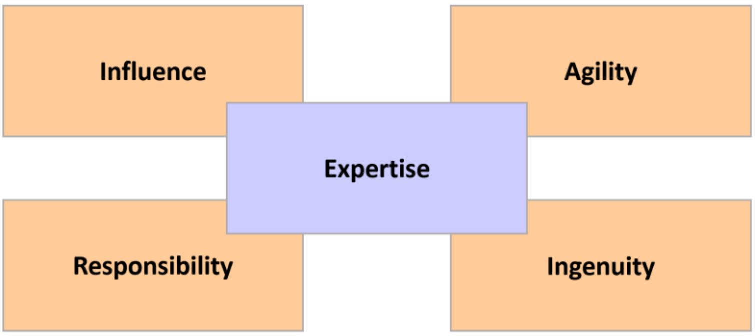

Figure 1. Five main areas of the future engineer's transversal capabilities (Adapted from Institut Mines-Telecom: *Portrait de l'ingénieur 2030* (In French, 2014), www.imt.fr/limt-presente-le-portrait-de-lingenieur-2030/).

Final project course (FPC)

In this paper we use the term final project course (FPC), as a general term to capture all the different formulations of the large, challenging, and complex project a master's student may be required to complete. It is often also referred to as a final research project, final-year project, final design project, capstone project, terminal project or final internship. Typically, this FPC corresponds to one semester (approximately 30 ECTS) and is most often placed near the end of the educational program at the master's level.

We distinguish between two classes of FPC: research focused and non-research focused. The research-focused class contains the *master's dissertation*[1], traditionally found in the sciences, whereas the non-research focused class contains all formulations of the FPC which do not explicitly develop the engineering student's ability *as a researcher* and are typically design-focused.

It is important to state up front that most programs are sufficiently vague in their FPC description such that the requirements could be met either through a research-focused or non-research focused submission. Where this is the case, our classification in Table 1 relies on the specific wording of their stated course outcomes or on the examples provided by the institution for previously completed FPCs.

[1] We further distinguish between a *dissertation*, which occurs at master's level and does not require an original research contribution (instead it *disserts* a specific topic), and a *thesis*, which occurs at PhD level and does have an originality requirement (by definition).

For example, in the Course Learning Outcomes section from the course handbook (for 2019/2020) for the Department of Engineering Science at Oxford University (specifically as they relate to the FPC, which is referred to as 4YP in the handbook):[2]

- “The scientific practice and application of mathematics in a substantial group project (3YP) and higher-level individual project, (4YP)” on page 12, and
- “The collection, analysis and application of data through laboratory based coursework (practicals), group project (3YP) and an individual *research* project (4YP).” on page 13 (emphasis ours).

These stated outcomes led us to classify the Oxford engineering FPC as research focused. In contrast, the course website for the Cambridge Department of Engineering[3] describes the FPC as potentially involving “blue-skies research” or “direct industrial application”. However, the examples they provide include: “Design of Temporary Shelters for Refugees”, “Designing Long Span Bridges and Tall Buildings”, “Wheelchair Design” and similar. Although these examples may include a research component, their provided descriptions led to the classification of the Cambridge engineering FPC as non-research focused.

The CDIO framework and the FPC

In accreditation reference and orientation guides, and in educational frameworks like the CDIO, there exist few guidelines about structural requirements of an engineering education at graduate level, and, as such, the requirements for an FPC worldwide vary significantly.

This can be contrasted with the guidelines available for undergraduate engineering education. The CDIO international framework suggests, in one of its standards (number 4), the course “Introduction to Engineering”. As a good practice, it is recommended that this course is placed early in the curriculum structure thus engaging freshman students in the practice of engineering through problem solving and simple design exercises, preferably in teams. The course also includes personal and interpersonal knowledge, skills, and attitudes that are essential at the start of a course or program to prepare students for more advanced product, process, system, and service building experiences.

In the CDIO Design-Implement Experiences standard (number 5), opportunities to conceive, design, implement and operate products, processes, systems and services are suggested for inclusion in required co-curricular activities. For example, these opportunities should be made available in undergraduate research projects and internships at the end of the program. Regardless of these skills being introduced and developed at undergraduate level, many leading international institutions require a further FPC at the master’s level. Furthermore, there is a significant variation in the offered FPCs learning outcomes, focus and content.

In this paper we review a dozen engineering programs at international institutions and universities that culminate in a professional engineering degree at the master level, in an effort to ascertain how common a FPC is, its size (as measured in ECTS credits) and its formal intention. After summarizing the results, we discuss various aspects of the FPC, and make recommendations on its learning outcomes. Furthermore, we suggest a maturity rubric, as exists in the CDIO framework, to formalize the evaluation of the implementation quality of the FPC. In practice, engineering programs consider FPC a necessity and therefore the CDIO consortium may envision to extend its framework to harmonize FPCs at participating universities and institutions.

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[2] https://eng.ox.ac.uk/media/4738/2nd-3rd-and-4th-year-course-handbook-2019.pdf
[3] https://www.admissions.eng.cam.ac.uk/course/fourthyear

SURVEY OF FPC REQUIREMENTS

At the beginning, we set out to ascertain how common a FPC is at the senior or master's level and map the similarities between the requirements where possible. The survey was conducted as an ad hoc review including some of the top-tier universities internationally and selected universities in Europe. The data was inferred from webpages of the programs, curriculum handbooks and sometimes by private communications. There are variations on how FPC is organized and therefore some details in Table 1 are institutionally dependent and prone to ambiguities. The criteria we used was that students graduating from the program were able to apply to become chartered engineers or professional engineers. This typically meant that the students had completed a BSc degree in engineering, or related field, and then one to two years at the MSc level.

The results are summarized in Table 1.

Based on the ad hoc survey summarized in Table 1, we may conclude that the norm at many leading international institutions and universities offering engineering degrees is that students at the master's level complete a FPC. This course can be a research or design activity, and is most often 30 ECTS, but 24 and 60 ECTS variations were also observed. There is a diversity of its intended learning outcomes and style, but the vast majority of the surveyed institutions require a research-focused dissertation. Details on the FPC variations across the different surveyed institutions are provided below.

Variations in the FPC

When considering some of the top-ranking engineering institutions worldwide, MIT, Oxford and Cambridge all require a research-focused dissertation in their master's degrees. At Stanford and NTU, there are both research and non-research focused FPCs, but the non-research focused variants can only result in the award of a Master of Science (MSc) degree. Thus, four out of five of the top ranking institutions considered require the student to complete a research dissertation to obtain a Master of Engineering (MEng) degree or Engineer's degree (ED).

All engineering programs in Iceland require a master's dissertation, which is most often 30 ECTS in size. In the occasions where the dissertation constitutes 60 ECTS of the degree additional emphasis is placed on making an original research contribution, which is not typical at the master's level.

Throughout the rest of Scandinavia, almost all the surveyed programs require a 30 ECTS master's dissertation, with a 60 ECTS variant available at Chalmers. The exception is an option at Aalto which offers an "Aalto Thesis" FPC where "2–4 students from different fields form a team for a 6-month project to solve a work-life partner's real and complex challenge through their master's thesis", but currently this option is on a break.

In France (Rouvrais et al., 2018) the FPC is a structured internship in the industry, lasting 4 to 6 months, resulting in a final report. The student writes a report, evaluated by the company advisor, a faculty member and an external evaluator, and then there is a formal defense. This internship is the last course in the program (e.g. min 24 ECTS), other shorter internship periods exist from freshman level.

Table 1. Review of FPC requirements at top international institutions as well as Scandinavia and France.

	Country	University	Structure of Engineering Program	FPC Focus
Top Ranking Engineering Institutions	United Kingdom	University of Oxford	4-year degree in Engineering Science. Awards Master of Engineering (MEng).	Research.
	United Kingdom	University of Cambridge	4-year degree in Engineering. Awards Master of Engineering (MEng).	Non-research.
	United States	Massachusetts Institute of Technology (MIT)	4-year undergraduate awarding Bachelor of Science (BSc). Additionally, three primary tracks of master's level study: Master of Science (MS)[4] Master of Engineering (MEng) Engineer's Degrees (ED)	 Research. Research. Research.
	United States	Stanford University	4-year undergraduate awarding Bachelor of Science (BSc). Additionally, two primary tracks of master's level study: Master of Science (MS) Engineer's Degree (ED)[5]	 Non-research. Research.
	Singapore	Nanyang Technological University (NTU)	4-year undergraduate awarding Bachelor of Engineering (BEng). Additionally, two primary tracks of master's level study: Master of Engineering (MEng) Master of Science (MSc)	 Research. Both variants.
Scandinavia	Iceland	University of Iceland	3-year undergraduate awarding Bachelor of Science (BSc). Additional 2-year master's program awards Master of Science (MSc).	Research.
	Iceland	Reykjavik University		
	Denmark	Technical University of Denmark (DTU)		
	Denmark	Aalborg University		
	Norway	Norwegian University of Science and Technology (NTNU)		
	Norway	University of South-Eastern Norway (USN)		
	Sweden	Chalmers University of Technology		
	Sweden	Lund University		
	Finland	Aalto University	3-year undergraduate awarding Bachelor of Science (BSc). Additional master's program awards Master of Science (MSc).	Both variants.
France	France	Institut Mines-Télécom (IMT)	5-year degree in Engineering. Master's Degree of Engineering Science	Non-research.

[4] MIT is the only institution on this list to abbreviate Master of Science as "SM" instead of the typical "MS" or "MSc".
[5] At Stanford, the MS is a pre-requisite for the ED.

The emerging Skolkovo Institute of Science and Technology was founded in 2011 in a partnership with MIT and is based on the CDIO vision. At Skolkovo a significant part of the MSc program in engineering is devoted to a “Research and MSc thesis project” (36 ECTS out of 120 ECTS total for the MSc program, see www.skoltech.ru). The emphasis at Skolkovo is very much in alignment with the programs listed in Table 1.

SUPERVISION AND MENTORING PROCESSES FOR FPC

The role of the supervisor(s) for the FPC is to guide the student throughout the whole project and be supportive when needed, with the learning outcomes serving as the guideposts. The supervision should focus on the student’s expertise and discipline, and stimulate the student’s ingenuity and agility. The supervisor should, at least implicitly, make the student aware of his responsibility as an engineer and the influence he or she may have as an engineer in the future (Kamp, 2016).

Workload

The FPC is typically a significant part of the engineering program (30 to 60 ECTS), and may therefore require advising and/or supervision from faculty members. In such courses the program-level leaders of engineering departments are concerned with how to balance the workload on the faculty and external stakeholders while maintaining training and supervision quality and the autonomy of the learner.

The supervision is multi-faced and can be done either by an individual or by a small team, and the supervisor has to be aligned with the type of setting the student is working in, be it within the university or in an internship. Due to the many facets of the supervision and mentoring, the university may want to complement the advising, as for example outlined by Saalman et al. (2009). This may include pedagogical tutors, writing workshops and facilitating collaboration teams to make the students journey (Audunsson et al., 2018) through this often challenging final course more fruitful and a discussion forum on different modes of how to approach the report writing (e.g. Hakkala and Virtanen, 2019).

To formalize and streamline the advisory process the department may set up a formal checklist with the learning outcomes and a sequence of milestones to promote time management. Well-prepared learning outcomes facilitate the assessment activities (Rouvrais and Chiprianov, 2012; Valderrama et al., 2009) and may aid the advisor and inform the student of the expectations during the dissertation (FCR) work.

Quality assurance

In addition to general quality assurance systems within engineering departments and institutional and external qualification framework, departments may want to consider additional requirements. The final project is a signature work by the student and also reflects the quality of the educational program. Therefore, one option is to mandate that the final report is open to the public and other institutions. For example, in Iceland all final reports at the MSc-level are placed in a web-based depository open to all, and the only exception is if the report contains confidential information, including market or industrial advantages. In this case, the public release of the report will be delayed for an appropriate time period. Another quality-assurance check worth considering is to have an open presentation of the project work when completed, sometimes referred to as a dissertation defense, although the term defense may not be appropriate at this level. A view from the student's side was discussed by Kindgren et al. (2012). In their paper they outlined how reflection documents submitted by students after completing a master's dissertation could be used as a tool for program evaluation.

FPC LEARNING OUTCOMES

The main purpose of the FPC is to synthesize competence in discipline-specific and personal skills as benchmarked with the integrated curriculum plan. The different forms of the FPC have been highlighted, with this paper emphasizing the distinction between those that are research focused (and thus require the student to develop capacity as a researcher) and those that are not.

The learning outcomes of this final project course should focus on training engineering professional activities that integrate personal, interpersonal, conceiving, designing, implementing and operating skills and competencies with disciplinary knowledge. Thus, in effect, the learning outcomes should reflect that this is the final training effort by the program to prepare the student for the workplace. The specific learning outcomes may be country specific, university or discipline specific and reflect the needs of the society in addition to the values and vision of the university. Furthermore, the learning outcomes should be aligned with the CDIO framework, i.e. Standard 2, and be the culmination and synthesizing of previous courses that involve conceive, design, implement and operate.

Should Masters of Engineering be trained researchers? Not necessarily, but they should be capable of leading, managing and reporting on large, complex projects. Therefore, the learning outcomes for the final project should reflect the difference between a degree in engineering and traditional research-led master's dissertation for science degrees or future PhD students.

These objectives and learning outcomes are integrated in the rubric in Table 2, and are the cornerstone to constructive alignment with FPC activities and assessment modes.

REFERENCE MODEL AND RUBRIC FOR MSC FINAL PROJECT COURSE

In alignment with the CDIO principles and best practice at the master's level in engineering, we present in Table 2 a rubric for self-assessment of master's-level FPC. The rubric includes process maturity levels to meet the coherent adoption and continuous improvement strategy (Rouvrais & Lassudrie, 2014).

Table 2. Rubric for self-assessment for a master's- level engineering final project course (FPC).

Maturity Scale	Criterion
5	The final project course (FPC) is regularly monitored, evaluated and revised with respect to curriculum integration, learning outcomes, supervision and professional experience, based on feedback from students, instructors and other stakeholders.
4	There is documented evidence of the impact of the implementation of the FPC according to the integrated curriculum plan and constructive alignment principles.
3	FPC is being implemented across the curriculum according to the integrated curriculum plan and supervision requirements.
2	FPC has been approved by stakeholders, implemented as a research lab work, industry partnership, design or research project, with learning outcomes that train professional activities that integrate personal, interpersonal, conceiving, designing, implementing and operating skills and competencies with disciplinary knowledge.
1	A curriculum analysis has been conducted to identify the need for a FPC to synthesize competence in discipline and personal skills benchmarked with the integrated curriculum.
0	There is no evidence of a large FPC at the MSc level engineering program.

CONCLUSION

The review presented in this paper shows that the norm at several leading universities is that students complete a final project course (FPC) near the completion of the engineering program at the master's level, being a substantial part of their program, typically equivalent to one semester of work or 30 ECTS, and in some cases even 60 ECTS. This is inferred from an informal ad hoc survey of a dozen universities in several countries, including five top-ranking engineering institutions.

During this ad-hoc review using data available on the web it became apparent that many programs are sufficiently vague in their FPC description that it was difficult to explicitly categorize FPC as either a research-focused or non-research focused, and often both options were offered. Four out of five of the top-ranking institutions considered, see Table 1, require the student to complete a research-focused dissertation to obtain a Master of Engineering (MEng) degree or Engineer's degree (ED). In most of the engineering programs in Scandinavia, Table 1, students must complete a research-focused dissertation to obtain a Master of Science degree. In France, full collaboration with industry is a must for the FPC. Within the CDIO educational framework, there is no obvious requirement for a final project course, but rather an integrated curriculum including courses that involve conceive, design, implement and operate.

The main purpose of the FPC is to synthesize competence in discipline and personal skills as benchmarked with the integrated curriculum and prepare the student for engineering professional activities. The FPC can be implemented as a research lab work, industry partnership, design or an applied research project. Because the project is the student´s signature work, the assemblage of several such projects is one of many gauges on the department's output and provides significant contribution when reviewing engineering programs.

The suggested rubric (Table 2) for quality and maturity of a master level engineering FPC is based on the CDIO educational framework, the placement of the FPC in the program and stakeholders interest, and the learning outcomes. The rubric is for program-level self-assessment, including mapping the process maturity level and state of adoption, as well as for continuous improvement. The proposed FPC rubric has the same structure as the rubrics used for evaluating the twelve CDIO standards.

It is evident that several leading universities consider FPC a necessity and in an effort to harmonize its contribution to engineering education the CDIO consortium may want to consider recognizing the FPC and include its contribution in the CDIO framework.

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Part II

CDIO Implementation

ENHANCING INTERACTION WITH EXTERNAL STAKEHOLDERS IN PROGRAM MANAGEMENT

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ABSTRACT

Interaction with the surrounding society and external stakeholders is an important component when developing and managing high quality and relevant education programs. This paper presents some of the outcomes of the project MERUT which was carried out during 2018 – 2020 with support from the Swedish innovation agency Vinnova. The key outcome is a toolbox offering a structured way to describe and handle methods and tools for stakeholder interaction. The methods of interaction are organized in three categories, denoted A, B, and C, where category A includes methods for external stakeholders to influence the management and development of the education program. Category B consists of means for external stakeholders to have an active role in course modules, and category C contains methods and tools to evaluate the quality and relevance of the education from, for example, alumni or employer perspective. Examples from the different categories are presented, including the CDIO Syllabus Survey, alumni surveys, and reflection documents.

KEYWORDS

Stakeholder interaction, Syllabus survey, program evaluation, Standards: 2, 3, 4, 5, 12

INTRODUCTION

Interaction with the surrounding society and external stakeholders is an important component when developing and managing high quality education programs. The interaction can be done in many ways, but the overall aim is to develop and ensure the quality and relevance of the program. Interaction with various stakeholders is also a vital component of the CDIO framework, and there are obvious connections to several of the items in the CDIO Standards. See (CDIO Standards, 2022). For example, Standard 2 about Learning outcomes says *Specific, detailed learning outcomes for personal and interpersonal skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders*. Also, Standard 12 about Program evaluation says *A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purpose of continuous improvement.* In several cases, the criteria for the highest level in the rubrics used for self-evaluation based on the CDIO Standards refer explicitly to stakeholders.

There are numerous ways and methods for interaction with external stakeholders when developing, re-designing, maintaining, and running education programs, and the aim of this paper is to propose a structured way of describing such methods and their purpose. The main messages of the paper are:

- A toolbox for methods and tools for stakeholder interaction arranged in three different categories depending on the role and purpose of the interaction.
- Examples of tools and methods in each category, where some tools are new or applied in new contexts and some methods are established, but now placed in the proposed framework.

Stakeholder interaction in higher education has been studied from many different perspectives, and there are many publications in the field. Comprehensive overviews of the field, with extensive lists of references, are given in (Fagrell, 2020) and (Fagrell, Fahlgren, & Gunnarsson, 2020). Among the references one can mention (Thune, 2011) and (Anderson, 2001) discussing various aspects of the interaction between universities and industry.

The paper is organized as follows. The first section gives a short description of the MERUT project, in which the toolbox and some of the tools were developed, and in the following section the toolbox itself is presented. In the next section the similarities and differences between quality and relevance are discussed, and in the three following sections the different categories of tools and methods are discussed. For each category some examples of methods and ways for interaction with external stakeholders are discussed. Finally, the paper ends with a summary and conclusions.

THE MERUT PROJECT

During 2018 – 2020 the Swedish funding agency Vinnova sponsored 18 projects dealing with various aspects of the interaction between Higher education institutions (HEIs) and external stakeholders. On the national level the collection of projects was called the K3-initiative (K3 for the knowledge triangle), and each project involved several HEIs, and had its own project leader, steering group, etc. See (K3, 2022). The various projects worked independently, but with some overall national coordination and cross-contacts where the scope of the individual projects had some overlap. The overall aim of the K3-initiative was to enhance the ability and capacity of the HEIs to interact with external stakeholders to strengthen the quality of the education and research at the HEIs and the mechanisms to transfer and utilize the knowledge from the HEIs in industry, public sector, and civil society. The topics of the individual projects ranged from ways to include the interaction with external stakeholders in the quality assurance system of the HEI, how the interaction with external stakeholders can be made more structured via strategic collaboration agreements, to ways to include the ability for interaction with external stakeholders in the regulations for recruitment and promotion.

One of the K3-projects was named MERUT (Swe: Metoder för relevansbedömning av utbildning), and it included seven HEIs, representing a variety of disciplines (engineering, medicine, humanities, etc). See (MERUT, 2022). The project management was located at Royal Institute of Technology (KTH) in Stockholm, and the overall aim was to study various aspects of how the relevance and quality of education programs can be improved via various forms of interaction with external stakeholders. The project included several sub-projects and it resulted in several useful outcomes. In addition to the toolbox for ways and methods for stakeholder interaction, which is the key message of this paper, the re-design of the Bachelor's program in biomedicine at Linköping University using the CDIO framework was one important outcome. See Fahlgren, et al. (2018) for further information about this re-design.

THE TOOLBOX

The outcome of the MERUT project that is the focus of this paper is summarized in the graphical illustration in Fig 1., where different methods and tools for interacting with external stakeholders are structured in a systematic way. The dark blue boxes represent the conditions and regulations that are formulated on national and governmental level. The boxes within the shaded green area represent internal structures and processes that the HEI to a large extent can form itself, given the conditions stated in the dark blue boxes. The light blue boxes represent external stakeholders of different types, including alumni, employers, representatives in various boards or groups related to the education program. The arrows from the light blue boxes to boxes within the green shaded area represent flow of information between the external stakeholder and program management as well as course modules. This information flow can be either formal and structured or informal.

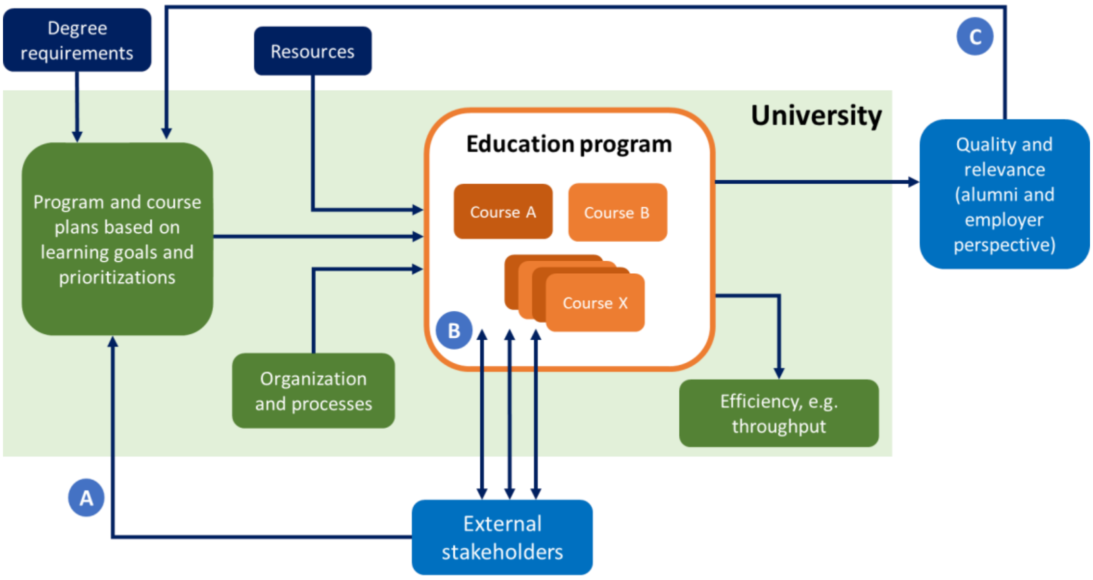

Figure 1. Graphical illustration of how the interaction with external stakeholders can be structured. The dark blue boxes represent the conditions and regulations that are formulated on national and governmental level. The boxes within the shaded green area represent internal structures and processes that the HEI to a large extent can form itself, given the conditions stated in the dark blue boxes. The light blue boxes represent external stakeholders of different types, including alumni, employers, representatives in various boards or groups related to the education program.

It should be stressed that this is not the first time the mechanisms around an education program is described schematically using a block diagram including feedback loops. Fig 4.1 in Crawley, et al. (2014) is one example. Also, feedback mechanisms are natural components of quality systems, which is illustrated in, for example, Fig 9.3 in Crawley, et al. (2014).

Using Fig 1 the methods and tools of interaction are organized in three categories, denoted A, B, and C in the figure, and the categories have the following meaning:

A. Methods for external stakeholders to influence the management and development of the education program. This includes having representatives from external stakeholder in e.g., program or advisory boards, but also the use of systematic tools such as the CDIO Syllabus Survey to collect opinions and expectations from future employers and other stakeholders concerning the expected knowledge and skills of the graduates.

B. Means for external stakeholders to have an active role in course modules. This includes e.g., learning activities which are, partly or in total, carried out in close collaboration with an external stakeholder, in the form of a project course, internship etc. The category also includes the use of adjunct teachers in the education program, i.e., persons employed externally but with a part time position at the university.

C. Tools and methods to evaluate the quality and relevance of the education from e.g. alumni or employer perspective. This includes alumni surveys of various type, but also surveys and reflections carried out by the students at the very end of the education.

The sections below present examples of methods and tools from each of the categories.

QUALITY AND RELEVANCE

Before discussing examples from the different categories there will be some reflections on the concepts of quality and relevance in higher education, and some findings from (Fagrell, Fahlgren, & Gunnarsson, 2021) will be presented. Quality is a crucial aspect in higher education, and it has received extensive attention by many researchers. See for example (Green, 1994) and Schindler, et al. (2015). The meaning and importance of the word relevance has however not been studied to the same extent. In the preparation of the paper (Fagrell, Fahlgren, & Gunnarsson, 2020) a simple survey was carried out with the aim to get some clarification of the concepts. The survey was handed out to some of the participants at the national conference Forskning om högre utbildning in 2018 and some of the Swedish participants at the CDIO conference in Japan 2018. The survey consisted of a small set of open questions about the similarities and differences between the quality and relevance. In total 23 persons answered the survey, and a common view from the participants, from both HEIs and external stakeholders, is that relevance is related to aspects outside the HEI, like, for example, the needs from society, industry, and the labor market in general. Representatives from external stakeholders stressed the connections between relevance and the knowledge and skills needed for the professional career. A general conclusion is that relevance has many similarities with quality, but it needs to be related to something or someone. In many cases quality and relevance are seen as subsets of each other and complementing each other rather than being opposites. Furthermore, there is a strong connection between relevance and the job market, but that this connection is not as strong for quality. Further details can be found in (Fagrell, Fahlgren, & Gunnarsson, 2020, 2021).

CATEGORY A

This category includes various ways of involving external stakeholders in the management of education programs, and two examples from this category are given. Based on an interview study with representatives from external stakeholders a checklist has been developed. The second example is an adaption and application of the CDIO Syllabus Survey to biomedicine.

External stakeholders in program management

The involvement of external stakeholders in higher education takes various forms and modes and is often not firmly institutionalized (Thune, 2011). This is also a main conclusion from the study within the project MERUT about how external stakeholders are involved in program management at seven higher education institutions in Sweden (Fagrell, Fahlgren & Gunnarsson, 2020). Despite a variation of the cases (engineering or non-engineering, vocational qualification, or general qualification), the expectations, comments and arguments from the external stakeholders were similar. The external stakeholders want to send messages to higher education institutions about changes in their business sectors, and about the subsequent changes in knowledge and skills in the labor required, to encourage the higher education institutions to adjust and develop their programs. However, the external stakeholders do not expect immediate changes because of their comments, neither do they see themselves as a part of a quality assurance scheme at the higher education institution.

Checklist

One of the main observations in (Fagrell, Fahlgren, & Gunnarsson, 2020) is that mutual expectations is a key factor when involving external stakeholders in program management. In several of the interviews that form the basis for the findings in the paper this is brought up as a subject for development. This involves questions about the role of the group in which the external representative participates, various feedback mechanisms, etc. To support the involved persons and provide some clarifications a simple checklist has been proposed, and the checklist is presented in Fig 2. The intention is to support both program management and the representatives from external stakeholders. In addition, the checklist is divided into questions related to *Structure,* which for example encompasses the role of the group in the internal organization of the HEI and *Contents*, which involves questions around the role of the external representative.

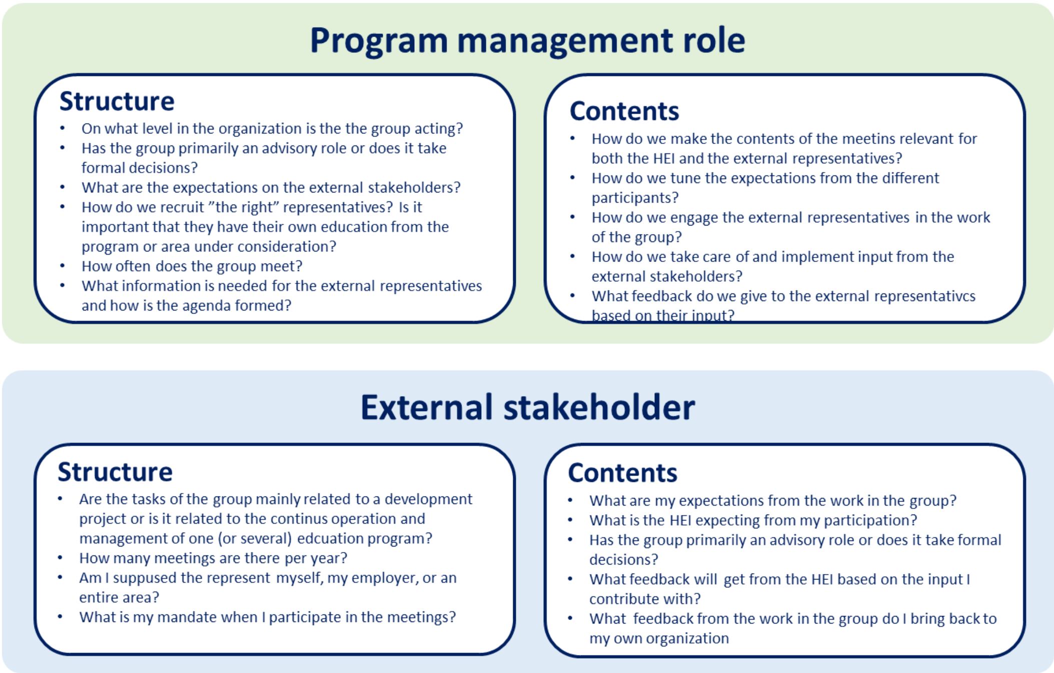

Figure 2. Checklist when involving external stakeholders in program management.

The checklist was presented and discussed during a roundtable discussion at a national conference about engineering education (*Den 8:e Utvecklingskonferensen för Sveriges Ingenjörsutbildningar*) in November 2021. The document was received very positively and was judged to be very useful in the process of involving external stakeholders in the management of education programs.

CDIO Syllabus Survey

The CDIO Syllabus Survey is a systematic tool for collecting the views and opinions of external stakeholders concerning the expected knowledge and skills of the graduates from an education program. The CDIO Syllabus itself was first presented in (Crawley, 2001), and it is one of the two fundamental documents of the CDIO framework. The document, together with revised and translated versions of it, can be found via the CDIO web site, the (CDIO Initiative, 2022). The CDIO Syllabus consist of four main sections with corresponding sub-sections and sub-sub-sections.

I - Disciplinary knowledge and reasoning.
II - Personal and professional skills and attributes
III - Interpersonal skills: Teamwork and communication.
IV - Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context – The innovation process.

In addition to introducing the CDIO Syllabus, (Crawley, 2001) presents the first examples of application of the Syllabus survey. This was later followed by, for example, Bankel, et al. (2003), which presents the outcome of the Syllabus survey from the four original collaborating universities in the CDIO Initiative. A thorough description of how the survey is designed is given in Crawley, et al. (2014). In the survey a selected set of stakeholders are asked to, from their perspective, rate the expected levels of proficiency of the graduates in the CDIO Syllabus knowledge and skills, according to a proposed scale. As in e.g (Crawley, 2001) and Bankel, et al. (2003) the focus has been on Sections 2, 3, and 4 of the CDIO Syllabus. There are numerous other examples of applications of the survey, and further examples can be found via the link Knowledge library of the CDIO web site. The usefulness of the CDIO Syllabus is illustrated in in Fahlgren et al., (2019), where it is presented how the CDIO Syllabus was adapted to the biomedicine field, and how the Syllabus Survey was designed based on the adapted version. The cited paper presents how the survey was carried out, and observations between different groups of stakeholders are discussed. In addition, similarities and differences when comparing with the engineering field are presented. These findings support that the CDIO Syllabus Survey is a very useful tool in Category A of the toolbox.

CATEGORY B

Category B involves a multitude of modes for interaction between course modules and external stakeholders, and they can roughly be divided into two different sub-categories. The first sub-category is when the students temporarily leave the HEI and spend a shorter or longer time with a company or some other external stakeholder. This sub-category includes activities ranging from study visits for a few hours to internships or a Master's thesis carried out in industry over a whole semester. In the second sub-category one finds ways of interaction where the "outside world" visits the HEI and contributes to the activities in a course module. Examples from this category encompass, for example, guest lectures, persons from industry having adjunct positions teaching in course modules, and project tasks proposed by external stakeholder. Within the CDIO Initiatives several examples of project-based learning activities based on tasks from external stakeholders have been reported over the year. A related case is challenge-based learning (CBL) which has received considerable attention during the recent years. In CBL a key component is that the student teams should work on a challenge provided by an external stakeholder. Some reflections about the connections between CBL and the CDIO framework are given in Kohn Rådberg, et al. (2020) and (Gunnarsson & Swartz, 2021).

CATEGORY C

This category, which is closely related to CDIO Standard 12 (Program evaluation), is about methods for "measuring" the quality of the education provided by an education program. Ideally one would like to have some simple indicators showing this quality, but this isn't realistic, and instead some indirect indicators are used. Various mechanisms for national evaluations or accreditations can also be placed in this category.

Alumni surveys

Alumni surveys is a common tool for collecting information about the quality of an education program. Several such studies have been reported over the years, and from the CDIO community one can mention (Bisagni, Ghiringhelli, & Ricci, 2010) and (Wiklund, Lindblad, & Gunnarsson, 2005). One phenomenon that has been observed during the last decade is that it has become more and more difficult to reach high enough response rates to make the results useful.

Reflection documents

As pointed out above, the risk of getting a low response rate is a key challenge when using alumni surveys to capture the quality and relevance of an education program. An alternative could be to use a survey at the very end of the program, and this was one of the key ideas behind the introduction of *reflection documents* as a part of the examination of the Master's theses within the engineering education programs at Linköping University. Of course, the students have not yet started their professional career, but since the big majority carry out the Master's thesis externally at a company, they will get a good insight into the life as an engineer in industry. Therefore, it will be possible to do some reflections on to which extent the education program has given them the necessary knowledge and skills. Another reason for introducing the reflection documents is that it is a good habit to summarize the "lessons learned" at the end of all larger projects. The introduction of the reflection documents was inspired by the same document from the LIPS project model, which was developed during the early years of the CDIO Initiative to support several of the project courses which were introduced in different programs, see (Svensson & Gunnarsson, 2012). The first generation of reflection documents was introduced in 2011, and some initial findings were presented in (Kindgren, Nilsson, & Wiklund, 2012). Some revisions of the structure of the document and the issues to reflect upon led to the second generation. Up to now the documents have been handled manually as pdf documents sent back and forth between student, examiner, and the program board. Recently a project has been initiated, where the aim is to create a web-based system for writing, assessing, and storing the documents.

DISCUSSION AND CONCLUSIONS

A toolbox for methods and tools for interaction with external stakeholders has been proposed, and examples of tools in the different categories (as presented in Fig. 1.) have been presented. For simplicity and clarity each method is only placed in one category, although some of the methods in the toolbox can possibly be placed in more than one category.

The toolbox has been developed in the Swedish context with some inspiration from the organization and processes at the home universities of the authors, and there can of course be variations in the applicability depending on national and local contexts.

It should also be stressed that the examples that are presented in the different categories are just examples, and that there are numerous other tools and methods that can be placed in the different categories. The key message of the paper is the toolbox itself.

The toolbox is one of the main outcomes of the MERUT project and main message of this paper. Some of the tools and methods presented above are also outcomes of the MERUT project, while some are existing tools developed in other contexts. The main contributions in the paper concerning the new or adapted tools are:

- The survey about similarities and differences between quality and relevance
- The interview study with representatives from externa stakeholders
- The checklist when involving external stakeholders in program management
- The adaptation and application of the CDIO Syllabus Survey to the Bachelor's program in biomedicine.

Finally, it should be stressed that the toolbox and the tools within it are just tools. The overarching aim is always to design, manage, and run education programs that enable for the students to obtain the knowledge and skills needed for the professional career. In that work the interaction with external stakeholder is an indispensable component.

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SUSTAINABLE DEVELOPMENT IN ENGINEERING EDUCATION

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ABSTRACT

At present, education has challenges to adequately react to the sustainability crisis taking place all around us. Education should provide students with competences, which help them to act in a changing world, bringing it towards a sustainable future. The impacts of the sustainability crisis, climate change or loss of biodiversity are usually not very common topics in the discussion on the development of education: how education should react and ensure competences and motivation to mitigate them. However, higher education institutions (HEIs) are now increasingly responding to the challenge and taking action to promote sustainability. In Finland, HEIs have published their programmes to advance sustainable development (SD) and responsibility in education. These programmes cover the practical steps for embedding sustainability issues in education. In addition, the CDIO framework for engineering education has added the optional standard for engineering education to contribute to sustainable development as a key competence. In this paper, we first discuss the key concepts and challenges in embedding sustainable development in education and the learning objectives. We explore how higher education (HE) in Finland introduces the practical steps in embedding SD in education and describe this implementation process at Turku University of Applied Sciences (Turku UAS) in Finland. The special focus of our description is on the work in progress in the engineering programmes at Turku UAS. Because the CDIO optional standard in SD was launched quite recently, the work is in progress and there are still several open questions and challenges. The purpose of this paper is to discuss these challenges and share best practices to be able to genuinely incorporate SD into engineering education.

KEYWORDS

Sustainable development, engineering education, higher education, sustainable development education, Optional standard 1

INTRODUCTION

The 2030 Agenda for Sustainable Development (Agenda 2030), agreed by the UN Member States, aims at sustainable development, taking equal account of the environment, the economy and the human being (United Nations, 2015). The goal of Agenda 2030 is to ensure by 2030 that all learners receive the knowledge and skills necessary to promote sustainable development. At present, education has challenges to adequately react to the sustainability crisis taking place all around us. Studies show that sustainable development is mainly mentioned in the general objectives of education, but in practical activities and teaching it is not very noticeable in most European HEIs (Konst & Scheinin, 2020). Education should provide the students with knowledge, skills and competences as well as develop attitudes and values, which help them to act in the changing work environment and society bringing them towards a sustainable future. The impacts of the sustainability crisis and climate change are often ignored in the discussion on the development of education: how education should react and ensure competences and motivation to mitigate them. Recent research publications set demands on the development of education. For example, the loss of biodiversity requires economics and engineering to develop more sustainable use of natural resources (Dasgupta, 2021).

In this paper, we first discuss what sustainable education means in the context of higher education and what a sustainable higher education institution is like. The are several challenges in embedding sustainable development in education and the learning objectives, and the problem definition of this paper focuses especially on that how these challenges are approached in our case example. In more detail, this means that we first explore how higher education in Finland introduces the practical steps in embedding SD in education and describe this implementation process at Turku University of Applied Sciences (Turku UAS) in Finland. The special focus of our description is on the work in progress in engineering programmes at Turku UAS aiming to fulfil the requirements set by the CDIO Optional standard 1, Sustainable development. Because the CDIO optional standard in SD was launched quite recently, the work is in progress and there are still several open questions and challenges. The purpose of this paper is to discuss these challenges and share best practices to be able to genuinely incorporate SD into engineering education.

SUSTAINABLE DEVELOPMENT IN HIGHER EDUCATION

The characteristics of sustainability in higher education has been described by several researchers during the last decades. Beynaghi et al. (2016) suggest that the advancement of sustainability through societal collaboration and functions such as education and research will increasingly constitute a core mission for universities. They frame possible future orientations through three different scenarios called a socially, environmentally and economically oriented university. Pursuit of sustainable development through each of these would involve unique and fundamental changes. These would have an impact on all university actions, e.g., on the university mission, focus areas, disciplines and faculties, education in sustainable development, external partners, projects and research activities, outputs with societal stakeholders, and geographical focus (Beynaghi et al., 2016).

Lozano et al. (2013) suggest that to become leaders and change drivers in sustainable development, universities must ensure that the needs of present and future generations are better understood and considered in all university actions: education, research, campus activities and stakeholder relationships. This requires university staff having a deep understanding of SD so that they can effectively educate and motivate students to help make the transition to sustainable societies and societal patterns. To do so, the university management and staff must be empowered to redesign their thinking patterns and implement new paradigms and ensure that SD is like a ‘Golden Thread’ throughout the entire university system (Lozano et al., 2013).

Transition towards real sustainability needs real actions; the strategy and the mission together with different SD programmes are not enough. For example, practices according to which the

HE sector globally carries out their daily activities is an important demonstration of how to reinforce the desired sustainable values and achieve environmentally responsible living standards, and finally moderate and renew the operation of the whole society (Lukman & Glavič, 2007; Friman et al., 2018). The coverage of SD activities seems to be a remarkable measurement of the maturation level of the university. In addition, the university's own, shared SD profile supports the in-house development process of different actors, also informing the external partners and stakeholders about the priorities in SD.

Higher education cannot be renewed by developing learning contents only. Making real change also requires redesigning structures, processes and ways of action in higher education institutions (Ávila et al., 2017). Strategic decision-making, management commitment and practical actions are needed in everyday life to promote a sustainable future and solutions. HEI staff plays a significant role when redesigning education towards sustainability. If especially teachers and lecturers do not commit to the reforms, or resist them, the reforms tend to fail. The teaching staff needs support, motivation and further training when education aims at the desired direction (Blanco-Portela et al., 2017; Kairisto-Mertanen & Konst, 2020). As always with change processes, the reform needs to be implemented so that participants themselves perceive the need for change, and thus a will to do things differently, in a new way. The systemic nature of sustainability issues requires deep and extensive understanding of the hierarchy of SD topics and their interdependencies. This usually requires time and plenty of discussion, as well as inclusion (e.g., Holm et al., 2015).

In addition, integration of SD in higher education is challenging because of the extensive, hierarchical and systemic nature of the concept. The Sustainable Development Goals (SDGs) adopted by the United Nations (2015) are often used as a framework for the topics covered. They form an ambitious set of 17 overarching global goals to combat poverty and achieve sustainable development by 2030, covering topics from gender equality to climate change, and education to clean drinking water. There is also a hierarchy between the SDGs; the SDG 'wedding cake' (Figure 1) shows the biosphere as the foundation of economies and societies and as the basis of all SDGs. Such a conceptualization adopts an integrated view of social, economic, and ecological development. Third, the SDGs form a system having interlinkages and interdependencies in between and affecting one will affect also the others more or less.

Figure 1. A new way of viewing the sustainable development goals (Azote for Stockholm Resilience Centre, Stockholm University, 2016)

APPROACHING SD EDUCATION IN FINNISH HIGHER EDUCATION

As stated earlier, studies show that sustainable development is often mentioned in the general objectives of higher education, but in practical activities it has not been visible. However, the situation is gradually changing. Real integration of sustainable development is crucial for the development of future education. According to the “Competences 2035” report published by the Finnish National Agency for Education, sustainability competence will be the most important skill in future working life, even surpassing digital skills (Finnish National Agency for Education, 2019). In Finland, higher education institutions have published their joint sustainable development and responsibility programmes in late 2020, and these programmes are based on the UN Sustainable Development Goals. Thus, many HEIs have started to bring sustainability into the activities of education and everyday practices and focused their teaching and research more on sustainability solutions. This work has been encouraged especially in engineering education also by the CDIO optional standard 1, Sustainable development.

SD Programmes in Finnish HEIs

In Finland, higher education institutions, both universities and universities of applied sciences, published their programmes in the end of the year 2020 to advance sustainable development (SD) in education. These programmes cover the promises and practical steps for embedding sustainability issues in education. The topics which are covered are especially how to foster sustainable development (so-called handprint)

- in all study fields and programmes, which contents should be covered, and how learning best takes place,
- how SD can be integrated in RDI (research, development and innovation) activities of HEIs
- how SD is implemented in HEI management and staff development and
- how to mitigate carbon emissions and diminish environmental impacts of HEIs’ activities (so-called footprint)

In addition, sustainable development is aimed at also in the regional, national and international outreach and partnership of HEIs.

Because sustainable development and responsibility programmes are rather fresh, their implementation is not fully covered yet. However, all universities and universities of applied sciences are progressing in their SD activities. Their web pages communicate about their sustainable development activities and progress in various ways, and the majority of HEIs have also included sustainability in their strategy and mission statements.

The Optional CDIO Standard 1

There have been several independent proposals for potential optional CDIO standards since 2008, but Malmqvist, Edström, & Hugo (2017) provided the first combined proposal of optional CDIO standards. The optional standards have then been discussed and worked on in CDIO meetings, round tables and workshops. Finally, in June 2020, the optional standards were approved in the council meeting. The optional standards are fully available on the CDIO website and more broadly presented in a paper by Malmqvist et al. (2020).

The four optional standards are:

- Optional Standard 1: Sustainable development

- Optional Standard 2: Simulation-based mathematics
- Optional Standard 3: Engineering entrepreneurship
- Optional Standard 4: Internationalization & mobility

With these standards, the CDIO community has agreed on new key competences to CDIO programmes to support their development activities. With optional standard 1. Sustainable development, the aim is that

- the programme identifies the ability to contribute to sustainable development as a key competence of its graduates
- engineering studies are rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address sustainability challenges.

Although CDIO is typically connected to engineering education, there are several universities where the CDIO approach is used in other fields as well (Malmqvist, Leong-Wee, Kontio, & Trinh, 2016). The new optional standards do not make an exception is this general suitability. Rosen et al. (2021) write that "Although the SD standard was developed for engineering education programs, it could probably be applied for education programs in other disciplines as well." They continue that this new standard on sustainable development is concluded to be a useful tool for evaluating, promoting, guiding and integrating sustainable development, in basically any engineering programme. It is recommended that the new standard is used for setting university-wide goals and for providing teachers and programme directors with a framework for enhancing the future relevance of engineering education programmes.

IMPLEMENTING SD EDUCATION AT TURKU UAS

Turku University of Applied Sciences has its own programme for sustainable development and responsibility based on a joint programme of HEIs. In its strategy, Turku University of Applied Sciences (Turku UAS) has committed itself to achieving climate goals of the region, and the goal is to be carbon neutral by 2025. However, the development of education is seen as the main role of Turku UAS in sustainability work. The aim is that all students have at least a basic knowledge of sustainability issues, and that most degree programmes include a significant number of studies in sustainability in relation to that field of study. In addition, an important role in the SD work of Turku UAS is played extensively by the establishment and implementation of research and development projects for the region and its operators. Research, development and innovation (RDI) is and will therefore be directed towards projects that clearly implement the objectives of SD work. Key research and development themes in SD at Turku UAS include clean water, circular economy, renewable energy production and energy storage, and the production and use of open information to prevent climate change.

Turku UAS' unit of Future Learning Design supports degree programmes and trainings to integrate SD issues into studies. The goal of Turku UAS' pedagogical approach, innovation pedagogy, is that the graduating students have the prerequisites for a good life, and knowledge, skills and attitudes to participate in creating a sustainable future. This requires that the students, teachers and other UAS staff understand the concept of SD and its hierarchical and systemic nature and are aware of that they can make a sustainable impact for the creation of the future by their own and joint activities. This goal has been described in Turku UAS' joint learning plan, the Innopeda curriculum, which gives also concrete tips and ideas to increase SD understanding in all study fields and degree programmes. There is not a separate compulsory SD course for all students, but degree programmes can decide themselves how to integrate SD issues in the studies.

Turku UAS has three faculties, Engineering and Business being the biggest of them. In this faculty, the CDIO approach is followed, not only in engineering programmes but in business and administration programmes as well. In early 2021, all CDIO optional standards 1–4 were introduced for the faculty's degree programme leaders and their personnel. Each programme chose their programme representatives for each optional standard to join the faculty wide development process.

The process of adopting these new optional standards is presented in figure 2. *The first stage* "Why" was conducted during the spring of 2021, by the degree programmes discussing how they understand the standard and how they see its importance in their programme. The programme representatives had joint meetings to share their thoughts and ideas. *The second stage* "Where are we" started in the late spring. A self-assessment form was created to find out the position of the programmes in the rubric scale, to identify the rationale confirming it, and to consider whether they can improve it. All degree programmes conducted this self-assessment process. The findings were collected and discussed together. *The third stage* "How" to identify actions and next steps to support implementation of the standard and to make preliminary plans for the steps and to identify what it is needed will start in early 2022. In practice this means preparing an implementation plan to be presented first for the faculty management group. In late 2022 it can be evaluated how the implementation process has started.

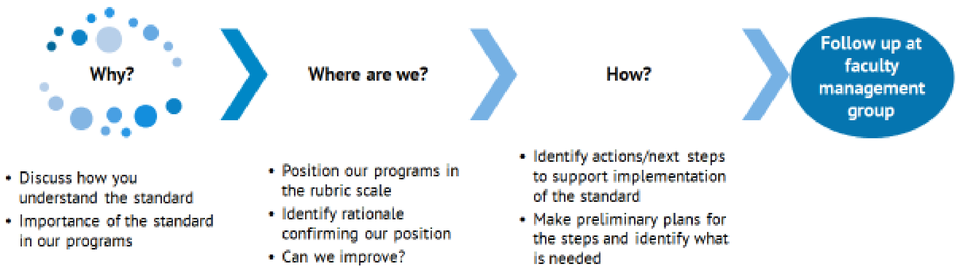

Figure 2. The adaptation process of optional standards at Turku UAS' faculty of Engineering and Business

CONCLUSIONS

The joint programme for the sustainable development and responsibility of universities of applied sciences in Finland encourages to act, and it is relevant that universities of applied sciences have raised sustainable development to the strategy level in their decision-making and made action plans for concrete progress. The CDIO standard supports the work in practice, but the actions are still at the early stages, and it is important to take care of the plans being implemented and monitored.

The change process is challenging and time-consuming. The HEI staff plays a crucial role when redesigning education towards sustainability. Especially the teaching staff needs support and further training when education aims at the desired direction. The reform needs to be led so that the participants themselves perceive the need for change, and thus a will to do things differently, in a new way. In other words, there are needed changes in ways of thinking before the ways of actions will change. The hierarchical and systemic nature of sustainability issues requires deep understanding of SD topics and their interdependencies. This usually requires time and plenty of discussion and inclusion, for example encouraging open discussion and offering opportunities for sharing ideas and good practices.

Turku UAS is working towards integrating sustainable development and responsibility in all its actions and in all study fields and disciplines. At Turku UAS, further training of the whole staff, encouraging discussion and participation as well as sharing best practices are seen as relevant tools in making the changes.

The Turku UAS approach concerning sustainable development in education is very much in line with the CDIO concept of an integrated curriculum (Standard 3), meaning that sustainable development should not just be considered as a couple of separate courses but instead be integrated with existing studies. Also, Rosen et al. (2021) recommend SD be interwoven with the learning of disciplinary knowledge and its application in professional engineering. The process of adopting the CDIO optional standard in SD is still in progress. However, the process has good opportunities to succeed, because the staff is participating the process in all its stages and there is room for open discussion and sharing ideas. In addition, further training in SD is offered for the staff, in its contents and in pedagogical solutions as well. This far, the findings show the faculty staff being committed to the process of adopting the optional standards well and striving for their successful implementation.

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SUSTAINABLE DESIGN AND PRODUCT DEATH

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ABSTRACT

This paper details the methods of teaching and assessment in a third-year engineering module, Sustainable Design and Product Death, which was developed in alignment with CDIO standards. The module elaborates on engineering design and design approach with a special focus on sustainability. Design for Total Control is at the helm of the module to ensure engineering students are equipped with the knowledge, tools, and skills to consider sustainability throughout the product lifecycle and have complete control of product development, from cradle to grave. The module also aims to equip students with the knowledge and practice of the Triple Bottom Line framework to account for the environment, as well as the socio-economic impact of their product development practice. The students enrolled in the module come from Mechanical, Biomedical, Electronics and Sport Engineering backgrounds, hence catering to a diverse audience was given particular attention throughout the delivery of the module. The module delivery included a blend of conventional lectures with student-driven seminars to encourage collaborative learning in a hybrid, on-site and online learning environment. The excellent student outputs and their use of various engineering tools to improve product sustainability presented here are a testament to the success of the module structure and delivery. The positive student feedback ratings and high student attainment presented, further reinforce the effectiveness of the teaching methods adopted and the content covered in the module.

KEYWORDS

Sustainable Product Design, Sustainable Development, Triple Bottom Line, Engineering Education, Standards 1, 2, 3, 5, 6, 7, 8

INTRODUCTION AND BACKGROUND

The drastic shift in societal focus to environmental longevity has triggered businesses globally to measure their impact on the world around them. There is a pressing need to evaluate the harm caused to global resources by the activities of these businesses (Jackson et al., 2011). Indeed, the current consumption and development patterns are proving exceedingly hard to sustain in a world with an ever-increasing population and growing consumer demand (Tischner & Charter, 2017) and are causing irreparable social and environmental damage (Watkins et al., 2021). Businesses not only need conscious awareness of their impact but also need to modify policies and procedures to mitigate this impact – this process broadly comes under the umbrella of Sustainable Development (WCED, 1987).

Triple Bottom Line accounting provides a framework to measure sustainability (Elkington, 1997) and demonstrates the success of an organisation steered towards sustainable development using three separate aspects, economic, social, and environmental (Goel, 2010). These have also been alternatively defined as the 3Ps: planet, profit, and people. Businesses benefit tremendously by focusing on all three of these aspects while developing products and services (Tischner & Charter, 2017). Product design plays a crucial role in reducing the negative social and environmental impact (Watkins et al., 2021) and promotes positive economic impact of the business. This is especially true since product design and development influences 80% of the economic cost as well as 80% of the social and environmental impact of a product (Tischner & Charter, 2017; Johnson & Gibson, 2014; McAloone & Bey, 2009).

Traditionally, designers were only responsible for design, while production came under the domain of manufacturers. The current increased demand in design function means that this separation in design and manufacturing tasks is no longer possible and the designer needs to take complete control of the entire lifecycle of the product, from concept generation to the end of its life (Johnson & Gibson, 2014). Considering the Triple Bottom Line, sustainable product design must not only consider conventional design aspects (functionality, aesthetics, etc.) and eco-design, whereby the environmental impact is given considerable importance, but also the social and ethical issues around the development of the product (Tischner & Charter, 2017; Watkins et al., 2021) as shown in Figure 1.

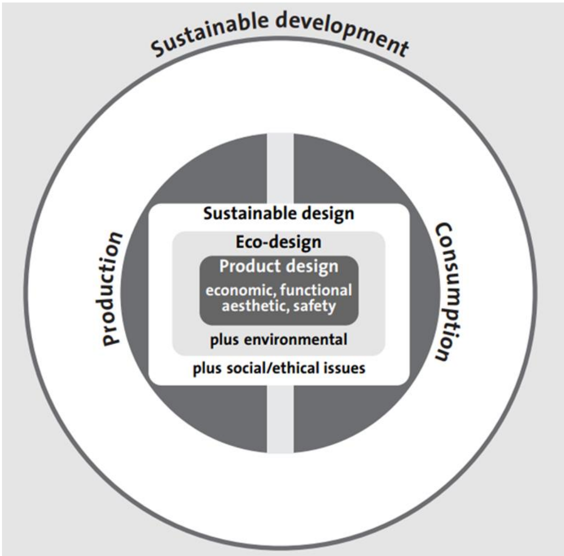


Figure 1:The relationship between eco-design, sustainable product design and sustainable development (Charter & Tischner, 2017)

It is essential that sustainable development is integrated in the development of future engineering education (Gumaelius & Kolmos, 2020) as higher education can help students recognise, understand, critically analyse, and resolve complex issues around sustainability (Seatter & Ceulemans, 2017). Kioupi & Voulvoulis (2019) consider sustainable development as an ideal end goal and highlight educational programs can equip the current and future generations with the tools to achieve this goal. The integration of sustainable development in education does however, come with its own challenges. Once such challenge is that sustainable education is prescriptive in establishing certain environmental targets (Alvarez & Rogers, 2006) due to which student input is neglected and they are simply assigned a supposedly correct stance on sustainability issues (Cheah, 2021). Instead, the aim should be to use sustainability issues as a probe to encourage student thinking (Seatter & Ceulemans, 2017). Students should hence be provided with necessary challenges, knowledge, and tools to resolve the complex issues around sustainability and a learning environment that is conducive to critical thinking.

CDIO standards offer guidelines for educational reform (Rosén et al., 2021) and integration of sustainable development is evident in the updated twelve core CDIO standards (Malmqvist et al., 2020). The department of engineering at Nottingham Trent University (NTU) is still in its infancy but is making great progress in aligning its courses with CDIO standards and developing them further. Two of the courses that have been previously reported are Innovation and Engineering Solutions (Siegkas, 2019; Butt & Siegkas, 2021) as well as Product Design and Case Studies (Siegkas, 2021). This paper presents teaching methods and assessments that are part of the latest module developed within the engineering curriculum at NTU, that adopts several CDIO standards to inform and enhance the student learning experience. The module entitled 'Sustainable Design and Product Death' integrates sustainable development with engineering education as a means to provide engineering students at NTU the tools and knowledge to holistically tackle sustainability issues in line with the Triple Bottom Line. As opposed to being prescriptive, the module presents students with an opportunity to critically analyse and solve sustainability related issues in engineering design.

MODULE DESCRIPTION AND DELIVERY

The module in question here is a third-year optional module for all engineering disciplines at NTU (Electronic, Mechanical, Sport and Biomedical Engineering). Due to the diversity of the students' engineering backgrounds, the content of the module was kept fairly broad. Although, not a prerequisite, Innovation and Engineering Solutions (Butt & Siegkas, 2021; Siegkas, 2020) and Industrial Design and Product Case Studies (Siegkas, 2021) reported previously, have some similar content to this module however, Sustainable Design and Product Death is still an introductory course and can be treated as a stand-alone module. The main aim of the module was to introduce sustainable engineering within the domain of engineering design to encourage product development in any engineering discipline that is not only mindful of the resources used but also the product's use and eventual disposal all the while considering socio-economic factors. The overlap between these two domains allowed students at NTU to take direct and complete control of the entire design cycle while considering sustainability at each stage of product development (Figure 2).

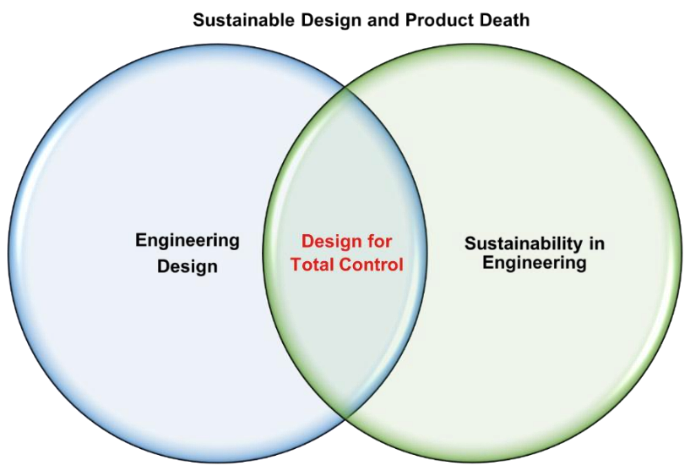


Figure 2: Overlap between conventional engineering design and sustainable engineering to provide complete control over sustainability considerations throughout product development

The module was delivered via 11 lectures (2 hours each), 10 seminars/tutorial sessions (2 hours each) and a further 10 drop-in sessions (1 hour each). The lectures covered the theory of engineering design, sustainable engineering in practice and deployed a range of industrial examples to contextualize the product lifecycle. The lectures were adapted from the book by Johnson & Gibson (2014) and the content was divided into two main sections:

Design: The lectures covered the entire design process such as the phases of design, evolution of design, design information, design output and tools used for the design processes. The conventional design cycles including (but not limited to) Concept, Detailed and Final Design Specifications were demonstrated but themes of environmental impact and sustainability at each stage were discussed. The discussion also involved the energy and financial expenditures at each stage (sourcing, manufacture, design, etc.). In essence, the classic design and manufacture model was illustrated and compared with the Sustainable Engineering Design Whole Life Model (Figure 3) and the aim of this comparison was to ensure that sustainability is embedded through the product lifecycle. Various design tools were also taught which included TILMAG, morphological analysis, heuristic redefinition, etc. for the generation of ideas. The lectures were kept interactive with discussions around product development and industrial examples that allowed students an opportunity to provide their input in the product development lifecycle.

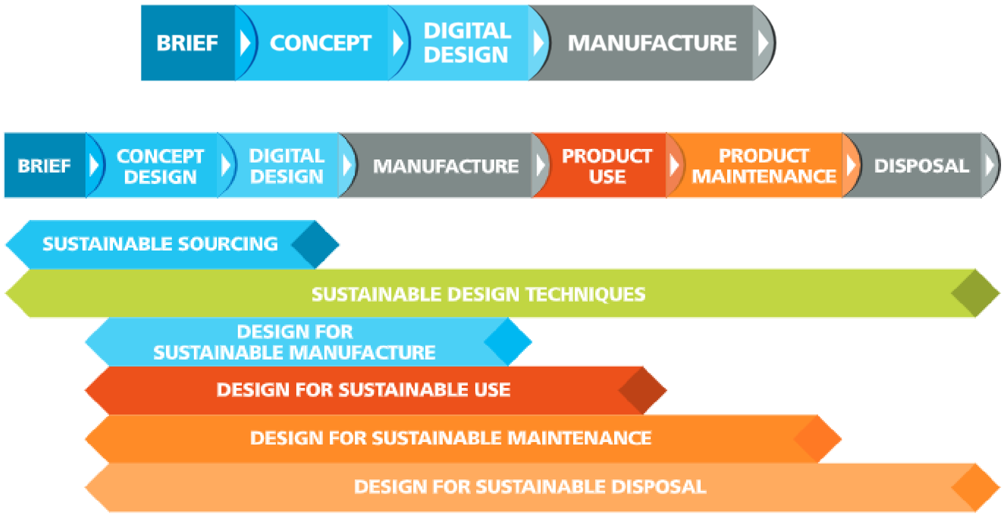


Figure 3: Classic design model (above) VS Sustainable Engineering Design Whole-Life Model (Below) (Johnson & Gibson, 2014)

Sustainability in Engineering: The second section of the lectures provided context for sustainability by defining sustainable development through the Triple Bottom Line. Again, sustainability throughout the product lifecycle was emphasized, however this time, metrics for sustainability at each stage were defined in addition to providing suggestions on how to reduce energy and cost expenditure at each stage of product development. The metrics were based on the value of the embodied energy at a particular stage, called a sustainable value (Johnson & Gibson, 2014). The metrics defined at each stage are illustrated in Figure 4. Ansys Granta was introduced within the lectures for eco-audits and robust materials/manufacturing process selection as well as to provide values for the metrics defined at each stage. The sustainability section of the lectures also covered drivers of sustainability in design such as regulations and legislation around the world, tools outside legislation for sustainable development and the financial and social drivers of sustainability. Strategic sustainable design was also brought into focus whereby the merits and application of the Triple Bottom Line (using case studies) was discussed along with the consumer's perspective of sustainable design.

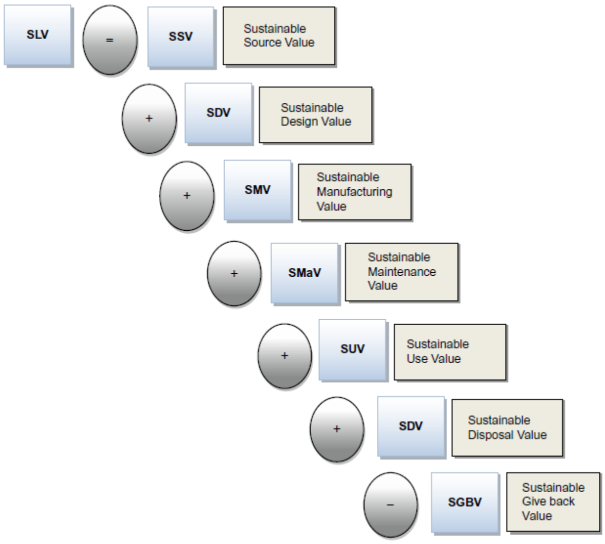


Figure 4: Sustainable Whole-Life Model (Johnson & Gibson, 2014)

The students were assessed via a product design project (50%) and an online examination (50%) at the end of the term. The product design project gave students a design brief to develop a motor driven product that can inflate tires, beachballs, air mattresses, etc and one of the constraints was that the client is interested in a low-cost product that will increase their product margin but not at the expense of the environment. The final submission for the project was a technical report that detailed all the phases of the product development from concept generation to a detailed design. An important aspect of the project in addition to inclusion of the conventional product development processes was the consideration for sustainability. Sustainability had to be considered throughout the product lifecycle but a separate section on sustainability considerations was also expected in the report to allow for the socio-economic impact of the product to be included. The marking criteria used for the product design project is given in Table 1.

Table 1: Marking criteria used for the product design project report

Product Design Project	
General Criteria	**Product Design Specific criteria**
General report structure	Introduction & Literature
Figures and tables	Concept design
Abstract	Detail Design
Conclusion	Materials and Manufacturing
References	Sustainability considerations

Interactive student-centred seminars were run in tandem with the lectures. The seminars focused on providing students with the means to communicate and apply the knowledge gained in lectures through instructor guidance, tutorials, and discussions. A flipped classroom was deployed in these seminars to allow the students to work on the product design project. Video tutorials on CAD design were provided along with tutorials on using Ansys Granta for the students to practice at home. A product design workbook was created and provided to students which covered a myriad of product development processes ranging from understanding the design brief to producing a final specification for the product. The students were provided the lectures and resources such as video tutorials in advance so that a discussion around the workbook could take place in the seminar. The activities in the seminar were further broken down into design phases namely Product Design Specification (PDS), Concept Design Specification (CDS), and Final Design Specification (PDS)/Product Specification (PS). The schedule for the seminar activities (Table 2) was also released to the students at the start of the term so they were aware of what to prepare for before attending the seminar discussions. The first 8 seminars took place online due to the governmental restrictions surrounding COVID 19. The discussions moved along via instructor probes, arguments from students and further aided by peer-to-peer discussions. A recurrent probe in all the seminars was the impact of a specific activity (design, sourcing, manufacture, etc.) on the environment, society, and profit to ensure the themes of the Triple Bottom Line were always considered at each step of the development of the product.

Table 2: Flipped classroom seminar schedule

Seminar	Activity	Gateway
1	CAD revisited & Research skills	Phase I (PDS)
2	CAD revisited & Research skills	
3	Design brief & Creativity/ Concept generation tools	
4	Evaluation and selection of Concept/ Concept design	Phase II (CDS)
5	Calculations / CAD model of concept	
6	Sustainability considerations / CAD model	
7	Materials and Manufacturing	Phase III (FDS, PS)
8	Design optimization/ costing/ sustainability	
9	Detail design/ GA drawings	
10	Finishing up and revisions/ Report writing	

The end of term examination was initially expected to be held in person, however, the unpredictability and restrictions surrounding the COVID 19 pandemic meant an online examination had to take place instead. As the examination was an online, open-book exam; two essay based, open-ended questions formed the exam that allowed room for discussion on the lines of the content taught in class. In the first question, the students were asked to analyse the evolution, current practices and future of engineering design and discuss the importance of engineering design in the context of sustainable development. The question expected the students to link the various tools and processes of engineering design such as design for total control, performance prediction and (or) smart manufacturing with principles, drivers, and legislation of sustainability. The second question was the application of the knowledge gained in class (demonstrated in Question 1 of the examination). The question asked students to propose the design of a product which had certain constraints and requirements. The students were expected to consider the entire life cycle (raw materials sourcing to disposal) and discuss how they would propose to design and manufacture the components of this product with the lowest possible environmental impact. The question expected design propositions in terms of sustainable sourcing, sustainable design techniques, sustainable manufacture, sustainable use and maintenance, and sustainable disposal while considering the constraints and requirements of the product provided in the exam question. The marking schemes for the examination questions are given in Table 3.

Table 3: Marking criteria used for the end of term online examination

Question 1 Marking criteria	Question 2 Marking criteria
General structure and flow of the essay	General structure, flow of the essay and use of high-quality sources
Principles, drivers, and legislation of sustainability clearly outlined	Proposed methods for sustainable sourcing
Design for total control considered providing a context for sustainable development	Proposed methods for sustainable design techniques
Themes of adoption of whole life approach clearly demonstrated	Proposed methods for design for sustainable manufacture
Strategic sustainable design and performance prediction given ample consideration	Proposed methods for design for sustainable use and maintenance
Critical thinking and relevance of arguments	Proposed methods for design for sustainable disposal
Use of high-quality sources	Consideration of the constraints and requirements highlighted

STUDENT OUTPUTS AND DISCUSSION

The aim of the two separate lecture sections was to provide students with a rounded view of product design from the perspective of the designer, the consumer as well as the company producing the product, covering all aspects of the Triple Bottom Line. An understanding of all three aspects has shown Triple Bottom Line to be a balanced and coherent construct of sustainable development (Epstein, 2008). As legislation and certification industry was also given attention, strategic sustainable design that catered to the societal, economic and environmental needs was evident from the student outputs. As an example, Figure 5 illustrates a student 's concept evaluation at a very early stage of product development. The evaluation and selection of the concept design already considers a myriad of socio-economic and environmental aspects such as, ease of maintenance, safety, market influence, etc. The concept selection clearly demonstrates an amalgamation of conventional engineering design principles with that of sustainable engineering.

Criteria	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Function	7	9	9	3	7	9
Cost	10	1	4	1	10	2
Sustainability	8	5	7	4	8	6
Reliability	8	9	6	10	8	7
Maintenance	10	10	6	2	9	4
Serviceability	8	5	6	2	8	6
Market influence	9	7	7	1	10	6
Ease manufacture	10	8	10	1	9	4
Safety	9	8	9	10	9	9
Limits	8	9	9	4	8	9
Aesthetics	7	7	7	4	7	5
Ease of use	10	9	9	3	10	6
Noise	6	5	6	2	6	3
Ergonomics	7	8	7	9	8	4
Weight	10	5	6	1	10	5
Total Scores	127	106	108	54	128	85

Figure 5: Product concept evaluation and selection. Evaluation table courtesy of Riten Patel (2021)

Some other student outputs to consider are the detailed designs produced (Figure 6) that clearly demonstrate forward thinking and modular designs that are easy to use and maintain, making them credibly sustainable. These designs are informed by similar concept selections as discussed.

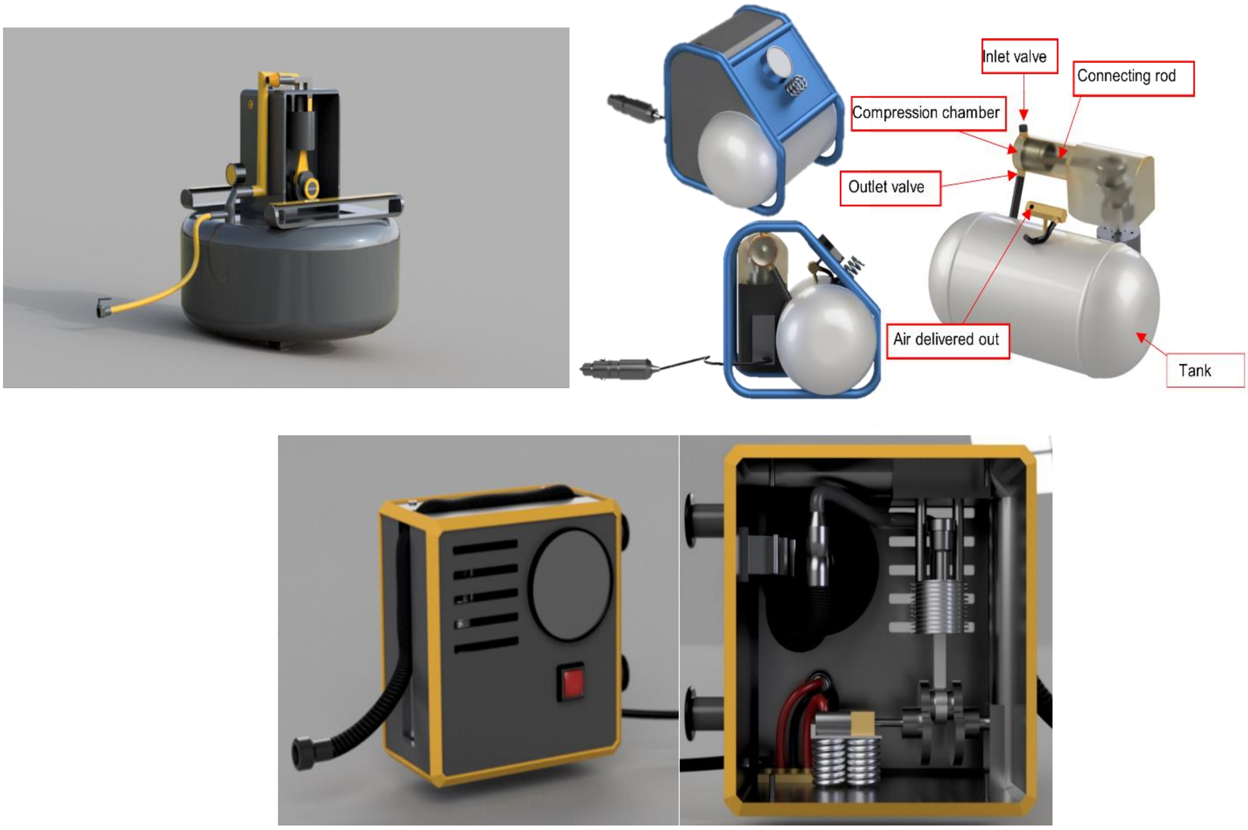
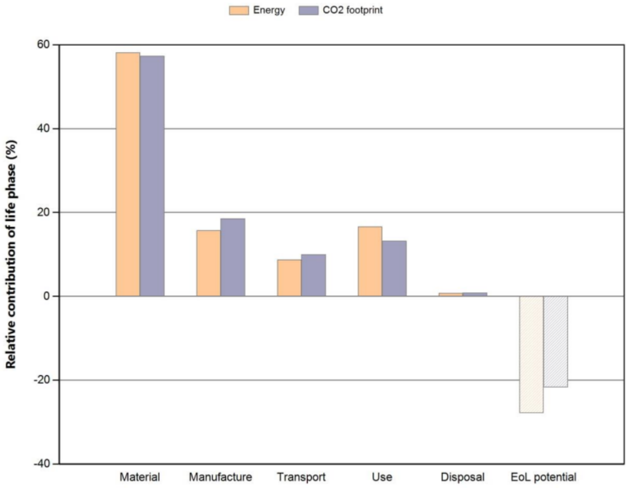


Figure 6: Detailed designs of the motor driven air compressor. Images top-left, top right and bottom courtesy of Sam Hunt (2021), Jarrod Greenwood (2021) & Jonny Cox (2021), respectively

In addition to considering socio-economic and the environmental factors for the concept and detailed designs, the students also conducted comprehensive eco-audits at various stages of the product development with several materials/manufacturing processes. The eco-audits helped the students define sustainability metrics that were illustrated in Figure 4. An example of a product eco-audits using Ansys Granta is shown in Figure 7. The objective of these eco audits was to minimize the energy consumption at each stage by as much as possible. Again, benchmarks for energy consumption/reduction were not prescribed, instead only methods such as sustainable sourcing, modular design and 4Rs end-of-life disposal methods were suggested (among others) during seminars for students to make an informed yet completely independent decisions.



Energy details   CO2 footprint details

Phase	Energy (MJ)	Energy (%)	CO2 footprint (kg)	CO2 footprint (%)
Material	25.1	58.1	1.55	57.3
Manufacture	6.79	15.7	0.501	18.5
Transport	3.75	8.7	0.27	10.0
Use	7.17	16.6	0.357	13.2
Disposal	0.34	0.8	0.0238	0.9
Total (for first life)	**43.1**	**100**	**2.7**	**100**
End of life potential	-12		-0.586	

Figure 7: Eco-audit of the product developed. Image courtesy of James Cree (2021).

Most students demonstrated a significant engagement with the design for total control approach and demonstrated clear adoption of the Triple Bottom Line framework throughout the product development lifecycle. This was further exhibited in the examinations where most students linked the various tools and processes of engineering design such as design for total control, performance prediction and (or) smart manufacturing with principles, drivers, and legislation of sustainability. These claims are backed by the high student attainment where 82% of the students achieved an Upper Second or First - Class grade that represent ‘very good’ and ‘excellent’ attainment, respectively. In the examination 90% of the students achieved an Upper Second or First - Class grade. These project and examination results are illustrated in Figure 8.

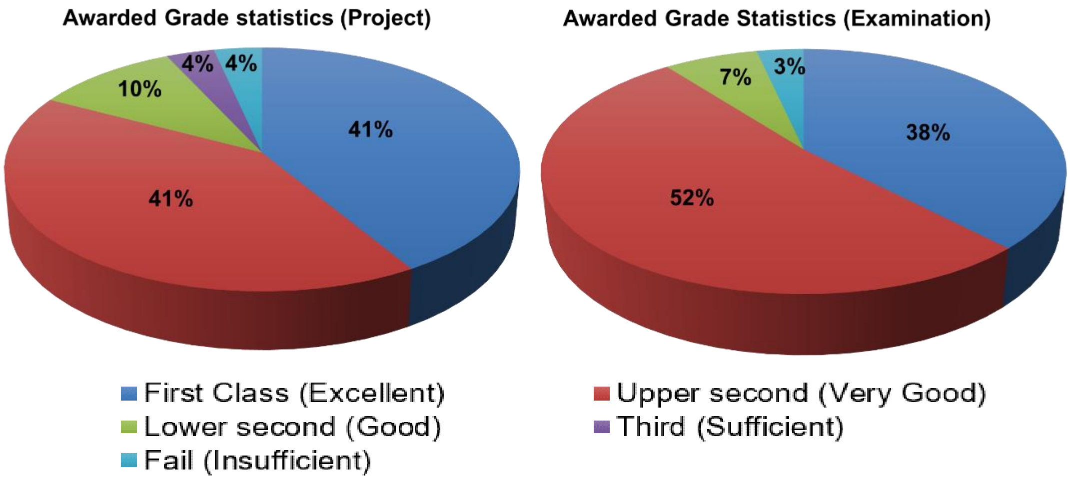


Figure 8: Student attainment in the project (left) and final examination (right)

Methods of embedding sustainability in engineering cannot be prescriptive as it is extremely subjective; tools and knowledge can be transferred, however sustainability in engineering design requires a change in mindset (Johnson & Gibson, 2014). As demonstrated, sustainability was not prescribed at end of life/disposal of the product, rather sustainability was encouraged throughout the product lifecycle. The focus was moved away from the rather dominant view of sustainability as an end-of-life consideration to a more holistic approach considered at each stage of product development. The probes during the seminars of how any aspect of design affected profit, people or planet at any stage reiterated the importance of being mindful of the Triple Bottom Line. This change was further reinforced by the exam questions that emphasized a whole life sustainability model.

The effectiveness of interactive lecturing for students with diverse science backgrounds has already been reported (Ernst & Colthorpe, 2007) and this was used for the current module. The in-class discussions and the variety of case studies allowed students to think critically and creatively while the flipped classroom seminars promoted active learning. Flipped classrooms have shown to encourage students to take responsibility of their own learning and engage in active learning (Lai & Hwang, 2016). Crucially, students have also shown in the past to appreciate flipped classrooms (Cronhjort & Wuerlander, 2016) as they can optimise the use of their time (Cheah & Sale, 2017) and work flexibly at essentially any location (McDonald & Smtih, 2013). The product design workbook was very well received as it provided opportunities for peer assisted and collaborative learning. It also provided an opportunity for the instructor to tune into student thinking; this has shown to make it possible to identify any misconceptions or lack of understanding (Cheah & Sale, 2017). The end-of-term module survey had very high scores of 4.7, 4.8, 4.6 and 4.6 out of 5 for student's *'Overall Satisfaction', 'Feedback on module teaching', 'Assessment and Feedback'* and *'Module Organisation and Resources'* which is a testament to the effectiveness of the teaching methods adopted. Most of the students had very positive and encouraging comments where some appreciated the skills learnt as in *"This module has proved the most valuable module so far across all years because of the skills learnt and their use in the world of engineering and product development"* while others appreciated the teaching methods, as demonstrated by the following comment: *"I like the focus on student interaction and questioning to help move seminar sessions along"*

CONCLUSION

The teaching and assessment methods adopted for a third-year engineering module at NTU have been presented here. The module is an introductory course for all engineering courses at NTU to product development and how to embed sustainability in design, with a special consideration of the Triple Bottom Line. CDIO standard informed the development of the module, specifically standards 1 – 3 & 5, 7 and 8 were demonstrated in this paper via module delivery methods and discussion of results. A key area of focus in the delivery was student engagement and active learning, ensuring that sustainable education was not prescriptive. Excellent feedback via module surveys and student attainment demonstrates the success of the module and the variety of tools used by students to integrate sustainable development in engineering design was confirmation that learning outcomes were met successfully. Despite the positive feedback, the module has room for improvement, specifically in replacing online examinations with a more conventional coursework that can perhaps test eco-auditing abilities of the students. The coursework could also provide an opportunity for a group project that can tie into and compliment the individual product design project while further encouraging collaborative learning.

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BIOGRAPHICAL INFORMATION

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FORMING 'BA' FOR ENHANCING ONLINE COMMUNICATION SKILLS BY CDIO APPROACH

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ABSTRACT

This paper aims to examine the applicability of the CDIO approach to online Project-Based Learning (PBL). Particularly, focusing on students' online communication skills, we examine the effectiveness of forming 'ba' for enhancing online communication skills. Due to COVID-19, our education has been forced to change a lot. Many classes were held online from 2020 to 2021. This paper introduces two examples of online PBL activities to discuss how those activities helped students to enhance online communication skills. To consider students' online communication skills, we will introduce the concept of 'ba', a concept that has been studied in organizational science. 'Ba' is a kind of space in which relationships are forged and human interactions take place. We also discuss the effects of applying the CDIO framework to those activities. By considering these activities conducted using the CDIO framework and considering from the perspective of the concept of 'ba', it was revealed that the CDIO approach helped students improve their online communication skills.

KEYWORDS

Online communication, COVID-19, Concept of 'ba', Project-Based Learning,
Standards: 3, 6

INTRODUCTION

This paper aims to examine the applicability of the CDIO approach to online Project-Based Learning (PBL). Particularly, focusing on students' online communication skills, we examine the effectiveness of forming 'ba' for enhancing online communication skills. Due to COVID-19, our society has been forced to change a lot. The same is true for education. Since on-campus classes were replaced by online-based classes, we observed that many classes had been held online from 2020 to 2021. As we can find in the proceedings of the 17th International CDIO conference, many practical reports regarding COVID-19 and online classes have been submitted at the international CDIO Conference 2021.

For example, Zapevalov et al. (2021) introduce a case of adapting the EduScrum methodology to their online teaching for software engineering program. They conclude that the implementation of EduScrum has ensured success in PBL. In another example, Manna et al. (2021) also introduce a case of a computer programming module conducted with flexible online teaching, virtual practical session, virtual CDIO sessions, and an online cafe. They conclude that flexible online platform encouraged students to be adaptive. Especially, their online cafe which is purely an informal chit-chat session for tutors and students provided mental support to the students who feel alone during the lockdown period. In addition, there are many other studies (e.g., Kuptasthien et al., 2021, Einarson & Teljega, 2021, or Chew et al., 2021) showing that online teaching methods such as online video instruction, online meetings, and so on have brought preferable outcomes of students.

As mentioned in these studies, students were required to study online. PBL, however, needs communicating and discussing activities. Thus, students are required to improve their online communication skills. This is the point we focus on in this paper.

This paper introduces two examples of online PBL activities to discuss how those activities helped students to enhance online communication skills and discuss the effects of applying the CDIO flamework to those activities.

At the same time, we will also introduce a concept being studied in organizational science to consider students' online communication skills. The concept is called 'ba', in which relationships are forged and human interactions take place.

First, we will briefly review the concept of 'ba' followed by case studies of PBL activities conducted from 2020 to 2021. After describing the cases, we will discuss how the CDIO approach is effective to enhance online communication skills for students.

THE CONCEPT OF 'BA': A BRIEF OVERVIEW

The concept of 'ba' has been studied in organizational science. Originally, it was introduced by Nonaka & Konno (1998) studying knowledge creation processes of Japanese companies. In Japanese, 'ba' means place, space, or field. They defined 'ba' as a shared space for emerging relationships in which human interactions take place. The examples of 'ba' typically would be meetings, working groups, project teams, and informal circles which are physical or tangible, but they emphasized that 'ba' is not restricted to something physical or tangible; "The concept of 'ba' unifies the physical space, the virtual space, and the mental spaces". A later study (Nonaka & Takeuchi, 2019) showed several examples of forming 'ba' online and virtual 'ba' in companies. They mentioned that creating a 'ba' online or a virtual 'ba' is extremely useful in today's network world in which numerous communities flourish online.

Although the concept of 'ba', the Japanese language, is originally derived from Japanese philosophy as mentioned by Nonaka & Konno, it is attracting worldwide attention as a great contribution to the study of knowledge creation processes in companies. Therefore, it is recognized that the concept of 'ba' is not just a Japanese concept, but applies to numerous companies (Creplet, 2000).

We will introduce two cases of PBL in the next section and consider how students acquired online communication skills. We will also keep in mind how ‘ba’ was formed online during the students carrying out the projects.

CASE STUDIES

A project to reproduce townscape online

The first example is a project to reproduce a townscape online and use it for tourism promotion, set in a local town in Hokkaido, Japan. The town of Shinhidaka, where the project takes place, has a population of about 20,000. The annual "Cherry Blossom Festival" attracts more than 100,000 visitors. However, the tourism industry of the town was damaged due to COVID-19.

8 students from the e-sports club of Hokkaido Information University (HIU) participated in this project. Their major activity is planning and managing e-sports events, however, their activities had been limited only to online activities due to COVID-19.

In June 2020, they started their project. Their idea is that they reproduce the townscape faithfully using the sandbox game "Minecraft" and develop some e-sports-like game in the virtual space. You can create your own rules for the game on Minecraft using its programming function. By July, the rules of the game were set to “collect the treasure chests that appear in the virtual town, and the player with the highest score within certain time wins.”

In September 2020, 5 students visited Shinhidaka to check the detailed streets, which cannot be seen on Google Maps and Street View. They also visited the town hall and discussed with the town hall staff which buildings to reproduce. They took photos of buildings and scenery in the town. Figure 1 shows the students taking pictures of the town. This was the only opportunity for the students to interact with the locals face-to-face. Based on the photos they took, they began reproducing the townscape. They gathered and discussed every weekend on a server on Minecraft.

Figure 1. Students taking photos in Shinhidaka Town.

They also used “Discord” for discussion. Discord is a chat application that they usually use in their club activities. They reported their progress and exchanged opinions on Discord. Discord has screen sharing and voice communication functions, therefore, they were able to share the photos and Minecraft screenshots they took on Google Drive. They were able to communicate with each other easily by using online communication tools and increased their online communication skills. Figure 2 shows Discord screens. The faculty members instructed that the students should report progress by uploading images and should create a list of productions. What the faculty members wanted students was to communicate spontaneously.

Figure 2. A faculty member interacting with students on Discord.

Their work was completed in December and the game was named “TREASURE COLLECT.” The students started preparing for the release of the game. Figure 3 shows screenshots of the game screens.

Figure 3. “TREASURE COLLECT” game screens.

In March 2021, “TREASURE COLLECT” was released at an e-sports event that was organized by the students with the cooperation of the e-sports organizations in Hokkaido. Figure 4a shows the event. The Minecraft server was also opened to the public.

Their works were exhibited at the tourist information center in Shinhidaka (Figure 4b), and the leaflet was distributed to visitors during Cherry Blossom Festival in May. The leaflet, shown in Figure 4c, includes screenshots of the townscape and cherry blossom trees created in Minecraft, as well as a QR code for a website that explains how to play the game. The townscape reproduction world created in this project was reported by the local newspaper.

By playing “TREASURE COLLECT”, game players can freely stroll around the townscape online and learn about the scenery of the town and the back alleys. Because it is released online, people from all over the world can see the townscape without visiting the town. The town hall staff and other local citizens expressed their desire to use this game for regional revitalization in the future. This was an example of a great contribution to tourism promotion using online technology.

Figure 4. (a): e-sports online event, (b): display at the tourism center, (c): leaflet design.

A Project to reproduce a library online

The second example is a project to reproduce local libraries online. Due to COVID-19, citizens lost their opportunities to visit libraries because local libraries were closed. Libraries wanted to stay connected with citizens, even when they were closed.

Figure 5. Students taking measurements in the library.

5 students from the 3DCG club of HIU participated in this project. They, like the e-sports club, were also affected by COVID-19 and all activities were limited to online. In March 2021, they began creating a reproduced world of the university library most familiar to them. Even though the local libraries were closed due to COVID-19, the university library was still available. The library of the HIU is located on the fourth through sixth floors of a ten-story building. The entrance is on the fourth floor. The students started by measuring the dimensions of the sixth

floor, where the space is large and easy to work with. Figure 5 shows the measurements made by the students.

From April 2021 to July 2021, they created 3D models of the shelves and tables in the library. For this project as well, they used Discord for reporting and confirmation, and Google Drive to manage the production. A spreadsheet was used to list the items that each student would create. They proceeded with the modelling process through the Discord screen. Figure 6a shows the progress report on Discord.

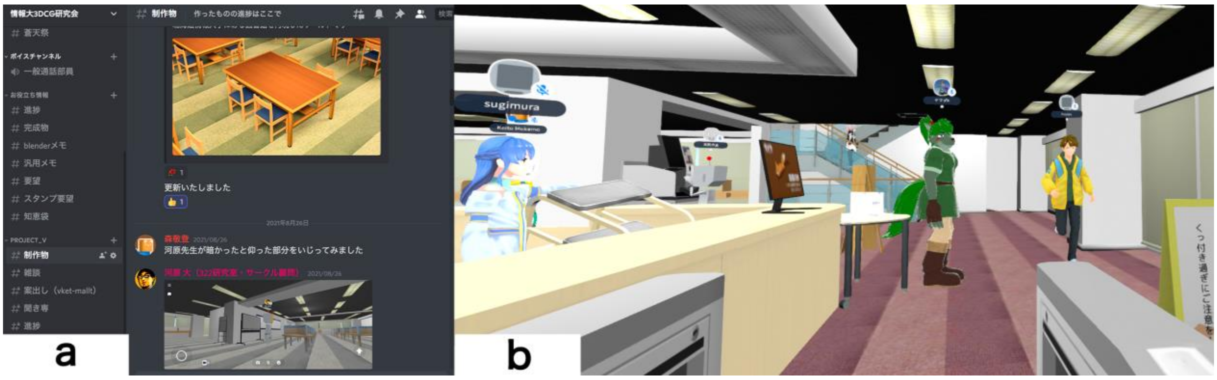

Figure 6. (a): Communicating on Discord, (b): Check the appearance in “cluster.”

In August 2021, they started building a world based on the model they created. The platform they used was the virtual SNS “cluster”. This is a platform that can be accessed from PCs, VR devices, and smartphones. They chose “cluster” because it is easy for anyone to use. Texture and other appearance adjustments were made in the world inside “cluster” shown in Figure 6b. On August 19, 2021, the library reproduced world was opened to the public as a beta version. It was accessed by the library staff and was well received. However, there were still some materials missing at this point, so the students continued with the modelling work and update the world.

During the creation of the reproduced library world, they conducted interviews with the library staff. They used the online conference tool “zoom” for the interview. As a result of the interview, they decided to add a mechanism unique to the online space. So, they added the “mascot character” and the “entrance to the library in Space” appearing on the library website. Figure 7a shows them in 3D modelling. They decided to place mascot character avatars as staff and guests in the world.

In December 2021, 3D modelling of the “mascot character” and the “entrance to the library in Space” were completed. In January 2022, the students met within the library’s reproduced world to identify problems. Figure 7b shows a meeting in “cluster”. The final update was made, and the library reproduced world, which was the original goal, was completed. In the future, they will increase the number of users and survey the functions of the VR library. Based on those results, local libraries will also be converted to VR.

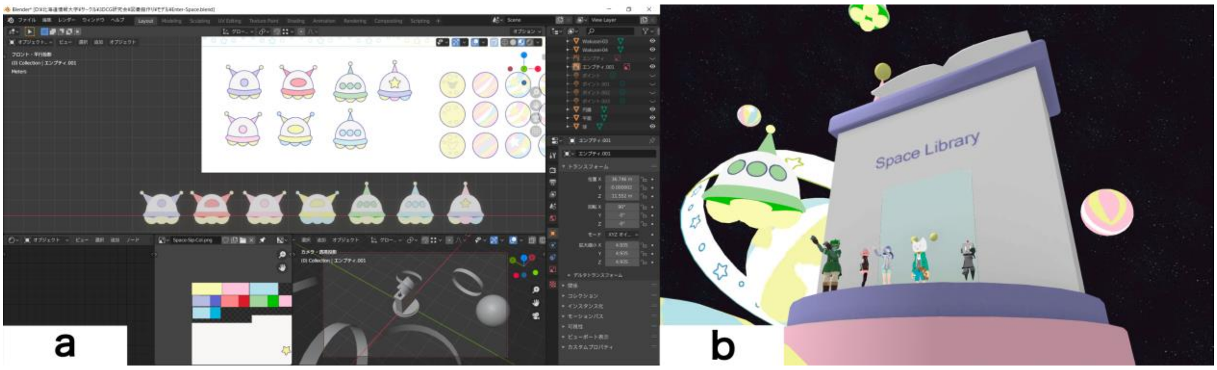

Figure 7. (a): 3D modeling of characters, (b): Meeting with students in “cluster.”

DISCUSSION

These 2 activities were designed and conducted with a strong awareness of the CDIO approach (see Table 1). We introduced the chat application Discord as a place for students to work. In other words, we prepared an online “Engineering Workspaces” [CDIO Standard 6]. Other Google services were used to visualize the progress check and data storage, providing an opportunity for everyone to be online and manage the project at any time. In addition, by gathering in real-time in the virtual space of Minecraft or “cluster”, we could prepare places for communication that were no different from offline [CDIO Syllabus 3.1, 3.2]. Over about 10 months, the students did almost all of the “conceiving - design - implementation – operation” online. Both projects were new challenges to solve the various problems caused by the impact of COVID-19 [CDIO Syllabus 4.1].

Table 1. The CDIO Approach for the projects

	The CDIO Approach	Contents of the project
CDIO Standard 6	Engineering Workspaces	Discord, a chat application as a place for students to work.
CDIO Syllabus 3.1,3.2	TEAMWORK, COMMUNICATIONS	Interaction as if you were offline, including conversations and progress checks.
CDIO Syllabus 4.1	EXTERNAL AND SOCIETAL CONTEXT	Resolve various problems caused by COVID-19.

The students set their goals by themselves as well as realize what they should do. In the first case, especially, they implemented the “TREASURE COLLECT” game to the public, designed the leaflet, and exhibited their work. Their activity contributed to the town tourism promotion. As Fukuzawa (2020) mentioned, education should not be unrelated to society or industry. Students must learn that projects are not realized by themselves, but only after considering their social value. The CDIO approach is quite a useful way to let the students experience real projects because that approach includes the Implement and Operate stages.

We also conducted self-evaluation questionnaires for the participating students after the projects had been completed. Figure 8 shows the results of each. The project to reproduce townscape online received high marks for “gained knowledge about the area” and “improved ability to collaborate”. Even though the activities were mainly online, they had a certain educational effect on knowledge acquisition and teamwork. However, the results for "understanding the problem" and "cooperation with the community" were low. The reason may be that they could not visit the site as they had expected due to COVID-19. The project to reproduce a library online received high marks for "improved ability to solve problems" and "cooperation with the community". We believe this is a good result of our increased approach to the people involved, based on the lessons from the previous project, reproducing townscape online. Unfortunately, "On schedule" was low for both projects. This may be the difficulty of managing online. The students tend to waste time because online activities do not need physical meetings. They may think they have plenty of time than they have.

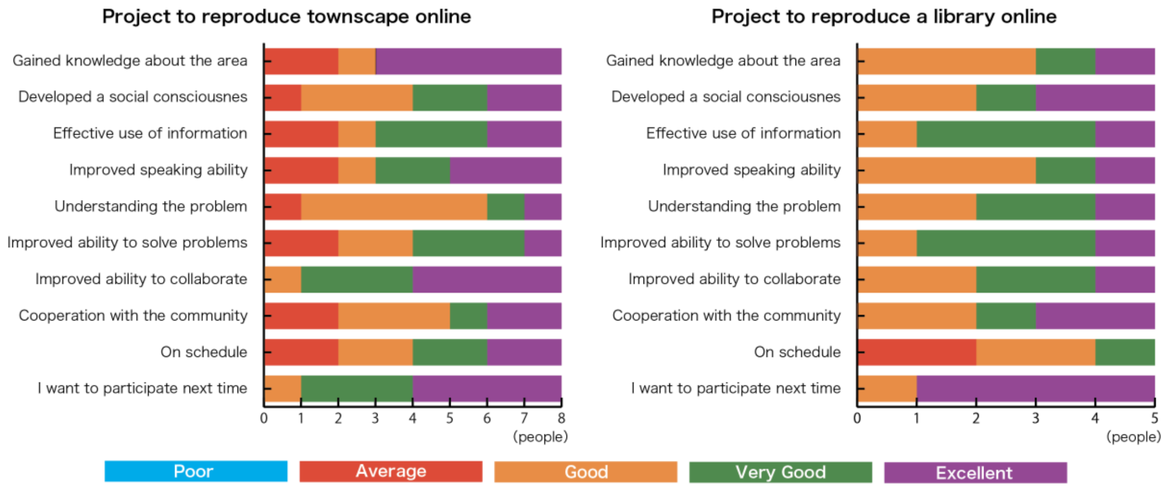

Figure 8. Results of the self-evaluation questionnaire for each project.

We could also observe that the students communicated with each other quite well using online tools. The students were able to deepen their understanding because they visited the town by themselves and reproduced the townscape, rather than only staying in virtual spaces. The students' ability to speak and the solving problem was improved in the 2 years as shown in Figure 8. It is revealed that if appropriate tools are given, it would help form useful 'ba', even if it is virtual space. As Nonaka & Konno (1998) stated, 'ba' is not restricted to something physical or tangible; it may be the virtual space. Here, we can reconfirm the significance of Nonaka & Konno's suggestion.

CONCLUSION

This paper introduces two examples of online PBL activities to discuss how those activities helped students to enhance online communication skills. Due to COVID-19, on-campus projects have been replaced by online-based activities. In the 2 activities, the students formed a community on the online chat application, Discord. Since the students got used to Discord, they smoothly conduct implementation and operation activities. Regarding the CDIO standards and syllabus, we believe that the quality was maintained online as well. This is the result of the students' adaptation to this pandemic situation. In addition, the students were mainly second-year students or above, who owned high-performance PCs and were accustomed to operating PCs. The use of online tools has made communication more visible and easier for teachers to evaluate. According to the questionnaire we conducted, we can confirm that the students have enhanced online communication skills, such as solving the problem and speaking through the project. In addition, we observed that if appropriate tools were given, it would help form useful 'ba', even if it is virtual space.

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CDIO FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT USING COMMON CORE CURRICULUM

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ABSTRACT

This paper describes an approach to integrate sustainable development into a program's curriculum using the CDIO Framework, with particular reference to the United Nations Sustainable Development Goals (UN SDGs). It proposes a set of guidance notes as "addendum" to the 12 CDIO Core Standards to provide further guidance towards how each Standard can be interpreted in all aspects of teaching and learning, from the learning context and learning outcomes, to integrated curriculum and various integrated learning experiences to learning assessment and program evaluation; as well as faculty professional development. This work is the direct outcome of a recent initiative in Singapore Polytechnic (SP) aimed at developing baseline emerging digital and human skills in students via a set of Common Core Curriculum (CCC). The CCC team works with all diplomas in SP to integrate these baseline emerging digital and human skills into their curriculum, using the UN SDGs as the learning context, where these skills will be deepened or applied in the domain modules. This paper firstly provides a brief overview of how CDIO had been used by the community to include the teaching of sustainable development, the state of involvement of higher educational institutes in providing education for sustainable development (ESD) in its programs. This paper also provides a short account on recent thinking about how best to deliver ESD for transformational learning; which is based on 2 key perspectives: that of behavioural change and empowerment of learners. The paper then explains what CCC is, in the context of educational landscape in Singapore, its key features and the integrated approach to the design and rollout of the CCC in Singapore Polytechnic. Next is the standard-by-standard explanation on how each standard can be interpreted through the lens of sustainable development, to provide guidance on how each can be used to support ESD. This is followed by a sharing of learning points from the recent pilot run of this approach and concludes with ideas of moving ahead in this endeavour to include ESD institution wide.

KEYWORDS

Common Core, Sustainable Development, CDIO Optional Standard 1, CDIO Core Standards 1, 2, 3, 7 and 12

NOTE: Singapore Polytechnic uses the word ‘courses’ to describe its education ‘programs’. A ‘course’ in the Diploma in Chemical Engineering consists of many subjects that are termed ‘modules’; which in the universities contexts are often called ‘courses’. A teaching academic is known as a ‘lecturer’, which is often referred to a as ‘faculty’ in the universities.

INTRODUCTION: THE CDIO FRAMEWORK AND SUSTAINABLE DEVELOPMENT

Various authors in the CDIO community had written on their efforts in using the CDIO Framework to address challenges related to sustainable development. For example, Borge, et al (2017) reported on their work that added sustainability to the INGENIA “Product Development“ course at Universidad Politécnica de Madrid. Later Uruburu, et al (2018) updated on the work done with a review of the initiative after 3 years and wrote on the challenge faced in contextualizing each INGENIA project so that sustainability is not perceived as something separate or without connection to the project to be developed. Earlier, Hussman, Trandum & Vigild (2010) wrote on the use of “Green Challenge” at the Technical University of Denmark to include sustainability in engineering education. The first author and colleagues also wrote extensively on sustainable development in the context of Diploma in Chemical Engineering in Singapore Polytechnic (SP), see for example Cheah (2021), Cheah (2014), Yang & Cheah (2014), Chua & Cheah (2013).

CDIO formally introduced Sustainable Development as one of its optional standards in 2020 (Malmqvist, et at, 2020), after the proposal was first surfaced in 2007 (Malmqvist, Edstrom & Hugo, 2017). Also well under way (at the time of this paper) to also release an update to the CDIO syllabus to capture skills and attitudes needed to support sustainable development. Earlier Rosen, et al (2019) had reported on their effort to map the CDIO syllabus to the UNESCO key competencies for sustainability. Their studies concluded that the CDIO Syllabus is rather well aligned with the UNESCO framework, however several opportunities for strengthening the Syllabus in relation to the key competencies are identified.

This paper shares an institution-wide effort in SP aimed at integrating sustainable development, in a phased approach, into all diplomas offered by the institution. This will be achieved via a set of modules that made up a Common Core Curriculum (CCC) for integration into all diplomas. The work reported here is derived from the collective experiences of the authors, based on a pilot run with 2 diplomas. Specifically, it aims to provide guidance how curriculum redesign for the teaching of sustainable development can be carried out for adoption by other diplomas in SP, as well as for the wider CDIO community.

HIGHER EDUCATION AND EDUCATION FOR SUSTAINABLE DEVELOPMENT

According to the United Nations, education for sustainable development (ESD), also called education for sustainability (EfS) in some parts of the world, is a key concept for education in the new millennium. ESD is a broad concept bringing a distinctive orientation to many important aspects of education on the whole, including access, relevance, equity and inclusivity. Thus, ESD is far more than teaching knowledge and principles related to sustainability. ESD, in its broadest sense, is education for social transformation with the goal of creating more sustainable societies. ESD touches every aspect of education including planning, policy development, programme implementation, finance, curricula, teaching, learning, assessment, administration. ESD aims to provide a coherent interaction between education, public awareness, and training with a view to creating a more sustainable future (UNESCO, 2012).

ESD empowers learners of all ages with the knowledge, skills, values and attitudes to address the interconnected global challenges we are facing, including climate change, environmental degradation, loss of biodiversity, poverty and inequality. Learning must therefore prepare students and learners of all ages to find solutions for the challenges of today and the future. Education should be transformative and allow us to make informed decisions and take individual and collective action to change our societies and care for the planet.

In recent years, higher education institutions are beginning to make more systemic changes towards ESD by re-orienting their education, research, operations and community outreach activities. However, despite the progress made and some signs of transition in parts of the academic community, there is still a long way to go to mainstream sustainability in higher education, and a paradigm shift from unsustainability to sustainability is still difficult to identify (Wals, 2014). Waas, et al (2011) opined that after more than two decades of debating and implementing sustainable development, to overcome arbitrary interpretations and reinforce the concept's action-guiding power, a better understanding of sustainable development and its implications for decision-making and policy-making is still needed.

More recently, Finnveden, et al (2020) reported on an interesting effort aimed at evaluating efforts in integrating sustainable development in higher education institutions (HEIs) in Sweden. The authors shared the findings commissioned by the Swedish higher education authority on behalf of the Swedish Government in 2016 to ascertain the progress of implementation after 10 years of following the introduction of the Swedish Higher Education Act in 2016, which mandated that all HEIs promote sustainable development in their programs. The study is unique in that all 47 HEIs in Sweden were involved, using a panel consisting of academics, students and working adults. Each institution is to complete a self-evaluation report consisting of 3 aspects: (1) Governance and organization, (2) Environment, Resources and areas, and (3) Design, implementation and outcomes; with 9 evaluation criteria. The panel studied each report and wrote its own evaluation report for each institution. The findings showed a mixed picture, in that while HEIs could give examples of programs or courses where SD was integrated, less than half of them had overarching goals for integration of sustainable development in education or had a systematic follow-up of these goals. Even fewer worked specifically with pedagogy and didactics, teaching and learning methods and environments, sustainability competencies or other characters of ESD.

CURRENT THINKING ON EDUCATION FOR SUSTAINABLE DEVELOPMENT

The approach of ESD seeks to empower learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society for present and future generations. It asks for an action-oriented, transformative pedagogy, which supports self-directed learning, participation and collaboration, problem-orientation, inter- and trans-disciplinarity and the linking of formal and informal learning (UNESCO, 2017).

Several authors had called for a new paradigm towards ESD, e.g. Barth & Michelsen (2013), Sterling (2010), Vare & Scott (2007). Sterling (2010) for example suggested a transformative education paradigm which he termed "sustainable education" which nurtures *resilient learners* able to develop *resilient social–ecological systems* in the face of a future of threat, uncertainty and surprise. An excellent summary on ESD was provided by Barth & Michelsen (2013), noting that it deals explicitly with values and separates itself from a point of view that sees the act of learning as a neutral process and learning as a self-evident good (Sterling 2010). ESD therefore takes the position between the two poles of indoctrination and value-relativism: at one end, education is seen as a tool to achieve certain social goals, hence is criticized and rejected as an inappropriate way of instrumentalizing education for political ends. At the other end, the nature and purpose of education is stressed as being always determined by human values, history, and changing patterns of power relationships. It can never be value-neutral, as the processes of education continually expose students to filtered experiences (Fien 1997; Grant and Zeichner 1984). ESD should be one that considers learners' underlying values and support the learner's critical reflection on them.

Such an outcome can be represented by Figure 1, adapted from the works of Læssøe, et al, 2009), reported in Disterheft, et al (2013). As can be seen, the approach is made up of 2 perspectives: (1) one on empowerment perspective that focuses on enabling students to become independent critical thinkers; and (2) the other on behaviour modification perspective that strives for changes in habits. Through such learning, young individuals will develop the abilities to make sound choices in the face of the inherent complexity and uncertainty of the future; and become active participants in building more sustainable societies, able to tackle real and relevant social problems. As noted by Vare & Scott (2007), long term future will depend less on our compliance in being trained to do the 'right' thing now, and more on our capability to analyse, to question alternatives and negotiate our decisions.

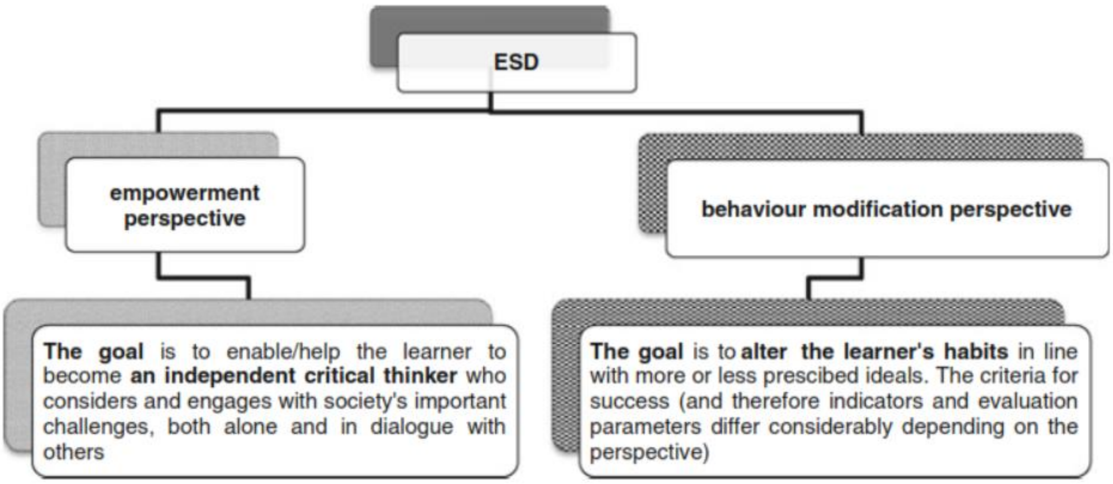

Figure 1. ESD with Empowerment and Behaviour Modification Perspectives

SINGAPORE POLYTECHNIC COMMON CORE CURRICULUM

The Common Core Curriculum (CCC) of Singapore Polytechnic aims to equip all SP graduates with foundational core skills that matter in a disruptive world.

Comprising 10 modules (Singapore Polytechnic, 2021), the CCC curriculum features skills that students would need to thrive in many industries that are facing or will face massive disruption. These skills include emerging digital skills like artificial intelligence (AI) and data fluency, and human skills like critical and digital communication skills. Among the 10 modules are also 3 modules that are constructed as hybrid modules – *Problem Solving with Creative* *and Computational Thinking*, *Persuasive Communication and Data Storytelling*, and *Sustainable Innovation Project*.

More importantly, the 10 modules are set in the context of UN SDGs. This is key in the design of the CCC as the curriculum would allow students to understand the wicked problems framed in the UN SDGs. The specific skills taught in each CCC module would expand students understanding of and allow them to think critically about various UN SDGs seen locally and globally. Students then consolidate their learning in the CCC by coming together in multi-disciplinary teams to ideate solutions to UN SDG challenges in Singapore in the module, *Sustainable Innovation Project*.

The CCC modules are designed to be baseline skills that are transferable across industries. Hence, to ensure that students are able to use and apply these common core skills to the field of their study, the CCC team works closely with all domain diplomas to integrate CCC skills into their curriculum. . This is done via featuring UN SDGs that are critical to key industries of domain diplomas in CCC modules and coming together to “pair” assessments such that assessment completed in CCC modules are done in partial fulfilment of another assessment in their domain diploma.

USING CDIO CORE STANDARDS TO GUIDE DESIGN OF ESD

SP introduced a pilot run of this CCC-integrated curriculum with 2 diplomas in Semester 1, Academic Year 2021/2022 which began in mid-April 2022 for its new cohort of Year 1 students. At the time of this writing, students from the 2 diplomas – Diploma in Optometry DOPT) and Diploma in Aerospace Electronics (DASE) – had completed one semester of study. When CCC is implemented fully across all diplomas in SP, most students will take CCC modules in year 1 and 2 of their study.

The 3 authors worked in various capacities along with a team of lecturers to bring the 2 pilot programs to fruition. The CCC team comprised of lecturers from the School of Life Skills and Communication (LSC) and the School of Mathematics and Science (MS). The second and third author co-leads the team in driving the CCC initiative. ; while the first author served as advisor on matters pertaining to CDIO and ESD, as he was at that time, also actively involved in reviewing the approach to ESD in the Diploma in Chemical Engineering (DCHE) where he is affiliated with academically. He was working closely with the DCHE team to prepare the diploma to come on-board in Academic Year 2022/2023 as the “second tranche” of programs to introduce CCC.

The first author reviewed and reflected on how he used the CDIO Framework to guide the curriculum redesign and distilled the key considerations on the approach that any diploma can take in the journey towards introducing CCC into the core domain curriculum and use the appropriate UN SGDs as learning context. The approach taken is that of a standard-by-standard explanation on how each standard can be interpreted through the lens of sustainable development. For the needed key competencies needed, references were taken from the CDIO Syllabus, and well as the CCC modules. The result is shown in Table 1.

Table 1. Guiding Principles for Curriculum Design for ESD using CDIO and CCC

Core Standard No.	Curriculum Design to include Sustainable Development
1. The Context	No change is needed for this standard. However, an emphasis can be added to highlight that the product, process, system or service should address one or more UN SGDs.
2. Learning Outcomes	Elaborate on the existing description: With reference to the CDIO Syllabus and the CCC, intended learning outcomes for key competencies for sustainable development – covered earlier in Cheah (2021) – are captured in module syllabus at course-level, and repeated in each integrated learning experiences at the task-level. The latter should be contextualized to the specific task and learning desired.
3. Integrated Curriculum	Enhance existing standard with the suggestion for achieving “dual-impact learning” approach via the 2 pathways of chemical process design and chemical product design (Cheah, 2021); with emphasis that sustainability principles can be used in both chemical plant operation and chemical product design using the same set of chemical engineering principles. Through thoughtful “pairing” with selected CCC modules, via both horizontal (reinforcement) and vertical (levelling up) integration to progressively develop knowledge, skills and attitudes required. “In-Module” integration can still take place for CCC modules that are designed to be standalone.
4. Introduction to Engineering	Supplement existing standard: Emphasize roles and responsibilities of professionals towards the discipline, as well as to society, with reference to the UN SDGs. Module such as “*Introduction to Chemical Engineering*” can be “unofficially paired” with “introductory” standalone CCC module “*Thinking Critically about the UN SDGs*”. This is also a good place to introduce specific UN SDGs as the focus areas of one’s profession.
5. Design-Implement Experiences	Include an added emphasis for project-based learning via a “project spine” themed after sustainable development, with projects from keystone to capstone (Cheah, 2014; Yang & Cheah, 2014) to support the product design track. However, the CCC module “*Sustainable Innovation Project*” will remain as standalone; so as to enable students from different courses to work together in a multi-disciplinary manner.
6. Engineering Learning Workspaces	No changes needed for this standard: students continue to use of learning workspaces in existing facilities. However, efforts such as energy-saving, water conservation, use of less chemicals, etc should be emphasized.
7. Integrated Learning Experiences	Include an added emphasis that these experiences should preferably address several UN SDGs within the same learning context, to reflect the interconnectedness of these 17 goals; and engage students is using a range of key competencies needed for sustainable development.
8. Active Learning	Emphasize greater use of collaborative learning with the help of technologies (such as Jamboard or Google Docs) to elicit different viewpoints from students in the context of appropriate UN SDGs to develop key competencies needed for sustainable development
9. Enhancement of Faculty Competence 10. Enhancement of Faculty Teaching Competence	The first author had developed 2 half-day workshops for help colleagues to first familiarize themselves with ESD and then to use the CDIO Framework when designing integrated learning experiences for their modules that are “paired” with the CCC modules: • What is Education for Sustainable Development? • Integrating Sustainable Development into Curriculum

	The first author also conduct sharing sessions featuring a case study based on his work done in the Diploma in Chemical Engineering
11. Learning Assessment	Include suggestions to carry out joint assessment where feasible for core modules “paired” with CCC modules, at least for the key competencies; focus in particular on the transformative aspect of an integrated learning experience or a design-implement experience; ensuring the usual constructive alignment is applied.
12. Program Evaluation	No change to this standard. This shall follow existing process as per SP Academic Quality Management System, with the added lens of the CDIO Framework. As will be elaborated in the main text, one consideration is to make use of self-evaluation rubrics of the CDIO Optional Standard 1 Sustainable Development

Although the guidelines are developed based on integration with CCC, which is decided based on SP’s educational needs, it is believed that the approach is useful and applicable to members in the CDIO community who wish to introduce ESD into their respective programs.

OUTCOMES OF PILOT RUN: CHALLENGES AND LEARNING POINTS

The CCC team conducted an evaluation of the pilot run of the CCC in 2 diplomas – Diploma in Aerospace Electronics (DASE) and Diploma in Optometry (DOPT) with a total of 150 students. The evaluation of the pilot run was done at the end of Semester 1 of AY21/22, with a focus on the learning experience of students. The evaluation comprised a survey and two focus group discussions.

The questions designed for the survey and focus group discussions aimed to find out:

(a) students’ knowledge of UN SDGs
(b) views on the usefulness of the CCC skills taught to their field of study and life
(c) perceptions about the workload in CCC modules

About 90% of the 150 students who were in the pilot run of the CCC participated in the survey and the team conducted two focus group discussions with 15 students. Some keys findings of the evaluation are as follows:

- Students gained useful knowledge (e.g. Un SDGs) and skills (e.g. digital communication skills)
- Students could also see the integration of the CCC into their field of study. Students saw skills taught in the CCC to be relevant to and could be applied to the industry of their field of study and even life at large.
- Students differed on their views on the workload in the CCC modules. Some felt that the workload was manageable while others wanted greater depth to the assignments.

Overall, students responded positively to the pilot run of the CCC. Even the Course Chairs of DASE and DOPT gave very positive response on how collaboration between the domain diplomas and the CCC gave students good baseline knowledge of UN SGDs and an integrated learning experience.

One key area of improvement that surfaced in the evaluation was the issue of communicating to students the requirements for assessments that were paired. Students received different instructions on these paired assessment. This issue had been resolved with discussions with the respective Course Chairs.

MOVING AHEAD

The learning points will no doubt be given due considerations when rolling out other CCC modules for Year 2, as well as for the next batch of diplomas. Plans are already in place for a next batch of diplomas, which besides DCHE as mentioned earlier from the School of Chemical and Life Sciences, will include another 10 diplomas from various other schools.

In the near future, the next natural step is to evaluate how well each diploma carried out the integration of sustainable development in its respective curriculum via the CCC. To this end, we can take reference from the work done in KTH Royal Institute of Technology, as reported by Rosen, et al (2021). These authors reported on the used the newly-introduced Optional CDIO Standard for Sustainable Development to carry out an institution-wide evaluation of a large number of programs at the bachelor and master levels, and concluded that, with some minor changes to the standard rubrics, the new standard is a useful tool for evaluating, promoting, and guiding integration of sustainable development, not only in programs with particularly high ambitions regarding sustainable development, but in basically any engineering program.

In SP, we can adopt a similar approach and adapt it for our own context. This can be on top of the usual sharing process via our Pedagogy Exchange platform; which is a monthly session organized by SP's Department of Educational Development. In addition, to more effectively learn from one another, we can also embark on some form of a peer-to-peer review process, in a manner similar to the ISO9001 Internal Audit, in that representative from say 2 schools undertook the review of the work done in another school. The other alternative is to engage a neutral third party, such as a member institution from the CDIO Community, in the form of some sort of a Peer-to-Peer Review, which is under consideration among CDIO Council Members.

Over the longer term, SP can consider actively promoting sustainability within its own campus, using the concept of "Living Labs". Verhoef & Bossert (2019) see Living Labs as new ways of innovation and are defined as user-centered, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real life communities and settings. This may provide the context for our students contribute to sustainable development through the CCC module *Sustainable Innovation Project*, where they work in multi-disciplinary groups to apply the design thinking method and tools backed by research and qualitative data, to tackle local issues mapped to the UN SDGs. As part of the CDIO Integrated Curriculum, students will get to use what they have learnt in the CCC modules that come before this module to create sustainable and innovative prototype solutions for real-life issues faced by a local community in need. In the process, it is envisioned that students undergo a transformative process where they not only felt empowered to contribute to sustainable development, but more importantly, developed a better understanding of themselves.

To this end, we can draw on the recommendations reported on earlier by Finnveden, et al (2020); some of which had in fact used by the team designing the CCC. Specifically, the authors recommend that higher educational institutions do the following:

(1) Decide on overall goals for integration of sustainable development and make sure that there are follow-up processes
(2) Create an organization for the work on sustainable development and make sure it has resources to work
(3) Let established definitions of sustainable development and Agenda 2030 be the starting point for higher educational institutions sustainability work
(4) Avoid solutions where only a part of the higher educational institution is involved
(5) Look for knowledge and engagement on sustainable development when recruiting leaders
(6) Create structures and "institutions" for sustainable development that are sustainable and resilient
(7) Support competence development of teachers and other staff
(8) Focus not only on content but also on ways of teaching, creating transformative learning environments and pedagogic expressions
(9) Create possibilities for interdisciplinary cooperation
(10) Support student involvement and collaboration with companies and the public sector
(11) Include sustainable development in Bachelor and Master theses
(12) Support cooperation between different higher education institutions

These suggestions can be further deliberated upon when more diplomas come on-board and implemented CCC into their respective curriculum. As noted earlier, SP had adopted a phased-approach in this new endeavour, and the process will necessarily be an iterative ones. There will be rich learning experiences from all involved, and collectively such learning can serve to improve the overall implementation towards education for sustainable development in SP.

CONCLUSION

This paper shared a broad approach that can be used by any program seeking to integrate sustainable development into its curriculum using the CDIO Framework. The approach comprises a set of common core curriculum serving to provide the foundational digital and human skills that can be infused into a program's domain core curriculum. The common core curriculum uses suitable UN SDGs contextualized to the key focus areas of each program, providing each program with its own unique integrated curriculum that allows students to use these digital and human skills not only in their respective domain areas, but also to contribute to sustainable development. This can be delivered through a series of integrated learning experiences, and a project-based learning module entitled *Sustainable Innovation Project*. A set of guidance questions based on the 12 Core CDIO Standards had been formulated to assist program owners to assist them in the curriculum redesign effort. Findings from the pilot run of this approach showed that students responded positive to this way of learning about sustainable development, and some ideas for future works are presented. Future papers may shares specific case studies of such an institutional-wide approach towards education for sustainable development.

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DEVELOPING STUDENTS' GENERIC SKILLS BASED ON OBJECTIVE EVALUATION

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ABSTRACT

We have been examining the effects of our educational improvements since 2014 at KOSEN (National Institute of Technology) Sendai College, Hirose campus. Our students are assessed annually with the PROG (Progress Report on Generic Skills), one of the standardized tests for generic skills assessment. We have previously reported on a survey analysis of GS (Generic Skills). In this paper, the GS growth characteristics of our students on this campus for the survey through 2020 are reported. In addition, the use of the results of the ongoing survey and the plan for a new pre- entrance survey and a follow-up survey after graduation will be discussed. Furthermore, we will collaborate with universities and companies to attempt to visualize the skills that are developed in different industries (fields) after graduation. In particular, the collaboration with universities will realize the potential for effective educational collaboration not only on academic performance (knowledge-based), but also on technical skills (skill-based). For collaboration with companies, on the other hand, this project will help companies to train their employees according to their needs and reduce the mismatch in career paths. From 2020, Hirose Campus will be promoting collaboration on GS research with the two universities of technology in Toyohashi and Nagaoka, both of which have a strong affinity with the KOSEN. We will report on the concept and future plans for academic improvement, including strengthening of collaboration, growth changes in students' behavioral characteristics through continuous analysis, collaboration from KOSEN to universities, and improvement of KOSEN education through feedback from universities.

KEYWORDS

Portfolio education, Collaboration between Parents and Teachers, Objective assessment of Generic Skills
Standards: 8, 11, 12

INTRODUCTION AND BACKGROUND

It has been recognized for a long time that in engineering education, in addition to the learning of specialized knowledge and skills, it is important to develop GS to apply the acquired knowledge and skills in the actual world. The Ministry of Education, Culture, Sports, Science and Technology (MEXT) has also indicated the importance of these skills, but has yet to propose specific evaluation methods using rubrics, as these are different from knowledge retention courses at https://www.meti.go.jp/english/policy/economy/human_resources/.

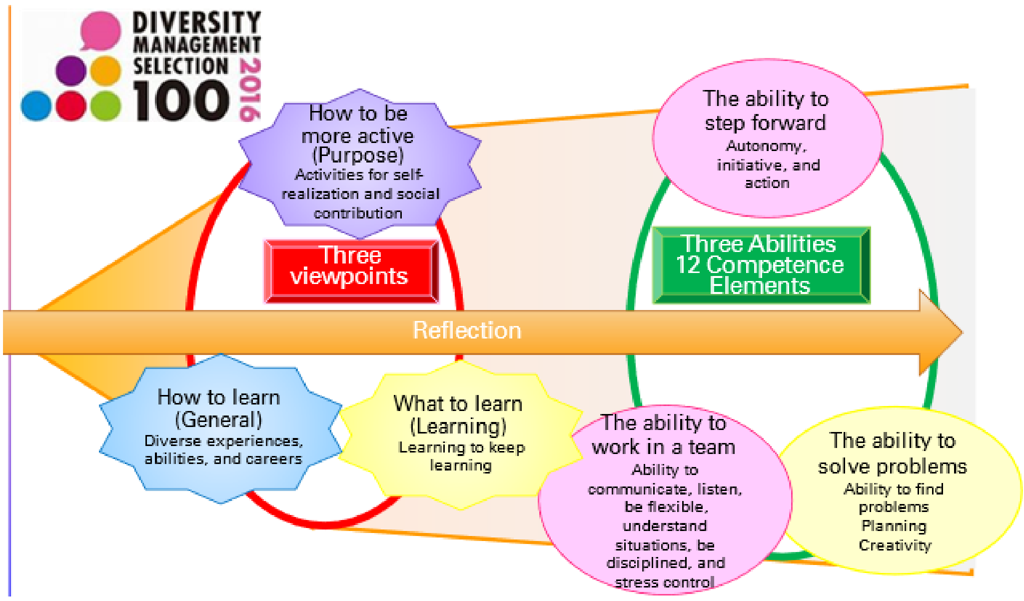

Figure 1. Improvement of generic skills for social workers

As well as GS development, portfolio education has been also emphasized by MEXT. As Zubizarreta (Learning Portfolio) and Seldin et al. (Teaching Portfolio) reported, reflection through portfolios deepens students' learning and improves teachers' teaching, thereby establishing quality assurance in education. The portfolio can be used not only to achieve short-term goals, but also to achieve long-term goals, and can be used to support students' careers.

At KOSEN Sendai College, Hirose campus, improvements of the classes and curriculum had been conducted by introducing Active Learning and PBL in 2014 and constructing the educational environment for effective GS development of students. Continuous assessments of students' generic skills had been conducted once a year using PROG, which is one of the standardized tests for generic skills assessment, in order to verify the effectiveness of our educational improvements. In 2018, we finished the 5-year continuous survey to identify GS growth characteristics from enrolment to graduation. Until 2018, the aspect of the survey was measurement, but since 2018, we have been focusing on the utilization of the results. The results of the survey to present and the utilization of the results (feedback to students and college, curriculum and class improvement based on the analysis results) have been reported at the 15th-17th CDIO International Conferences.

This paper reports on the GS growth characteristics of the most recent students on this campus, using the results of the survey through the year 2020, and introduces an overview of the utilization of the continuous survey results. Only briefing sessions based on PROG results were conducted for our students until last year, but a portfolio education program was started this year. By using the portfolio, students can reflect on their learning and set goals as well as record actions (club activities, qualification exams, etc.). At the beginning of the introduction of portfolio education, we did not focus on the priority of implementing a complex and complete portfolio system. We began by making sure that students understood the need for portfolios and having them fill out paper-based portfolios that were as simplified as possible. This is because paper portfolios can be viewed and recorded at any time, and we believed that this would make them more accessible to portfolio novices.

Next, we introduce our plans for a pre-entrance survey and a post-graduation follow-up survey as developments in the use of the results of our ongoing survey. In particular, an educational collaboration with universities and companies was proposed. By collaborating with universities and companies, we can evaluate and visualize the skills required for different industries, occupations, and research fields after graduation based on the same (unified) standards for the GS. As a result, enable effective educational collaboration can be achieved not only on the knowledge base of specialized fields but also on the skills base. In addition, this project will enable the construction of education that meets the needs of companies and guidance that can reduce the mismatch in the selection of companies and industries for students in career support. This will be possible by using the PROG evaluation standard to uniformly evaluate generic skills, which vary greatly from evaluator to evaluator. From 2020, we have collaborated with both Toyohashi and Nagaoka University of Technology, which have a close relationship with the KOSEN, to conduct surveys and discuss ways of collaboration. Since PROG is implemented in many KOSEN, and many students transfer to two Universities of Technology, and since PROG is implemented at the KOSEN, the goal is to develop students' humanity by linking information on humanity, which is different from grades, between the KOSEN and two Universities of Technology. In addition, by visualizing the progress of students, it will be possible to share information with universities (support for students transferring from KOSEMN, improvement of university life) and KOSEN (support for students transferring to universities, improvement of KOSEN life) and realize a cycle of mutual improvement. The concept of generic training and future plans will be introduced.

PROPOSE AND IMPLEMENT CYCLE ON CAMPUS

Implementation of student SFD(Small Faculty Development)

In the KOSEN Sendai College, students in grades 1-3 are required to take the PROG online at the same time in the computer room with the support of a few teachers. For 4th and 5th year students and advanced course students, the examination period is set (from mid-December to early December), and students take the examination at home or in the laboratory. What is GS? The school fosters not only academics but also human skills, including GS. 5-year career path (course selection, internship, lab assignment, career decision, etc.). We will guide them through the five-year process shown in Figure 2. In this guidance, the importance of GS, which is different from academic grades, was explained to acquire the ability to survive in society. However, since they do not know the details of GS, SFD will be conducted to help them analyze themselves and set goals while returning the PROG results.

Portfolio (visualization of 5 years of continuity)

Students write the results of the PROG on a sheet of paper as shown in Figure 3(a) and (b), making it part of their portfolio that includes a record of the changes in GS and self-analysis and self-development based on the results. Currently, both students and teachers have a little understanding of portfolios, so we are promoting paper records as part of the portfolio education for the whole school. The advantage of paper is that it can be checked and filled in at any time. Although there is a risk of lost items, we are using paper media to improve self-management skills as well. This is because if the students use digital media before they understand the necessity of the portfolio, the purpose will be to understand how to use the system, and the self-management effect of the portfolio will be weakened. As shown in Figure 3, it is possible to understand the current situation by transcribing the visualized values into a table by oneself. In many cases, students do not check the details when the data is visualized on a computer using the radar chart method. In addition, students can visualize their own changes by graphing the changes in each grade level for each skill.

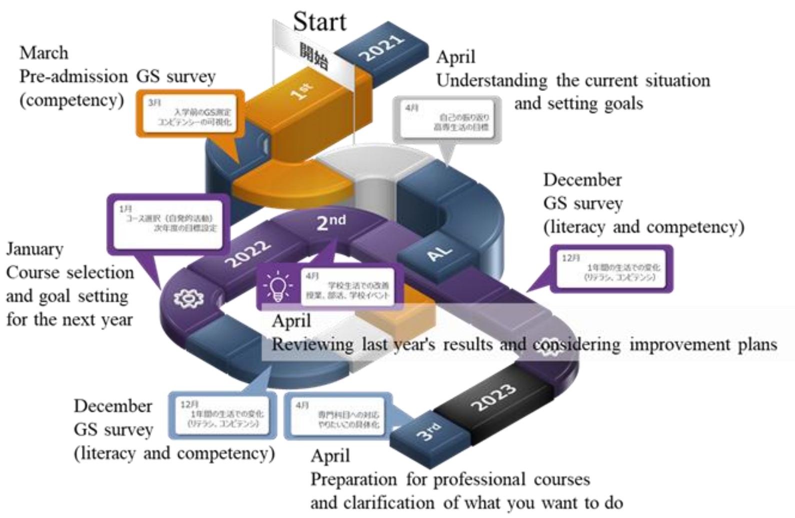

Figure 2. Career path at KOSEN Sendai College Hirose campus

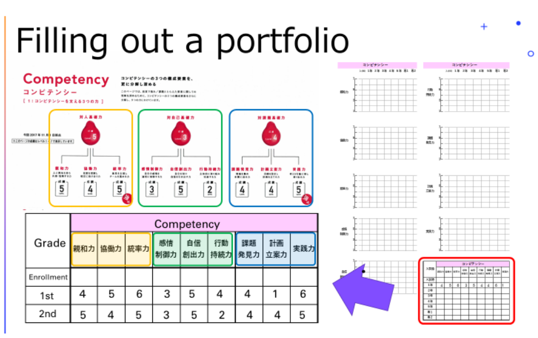

Figure 3. (a) Record competency results

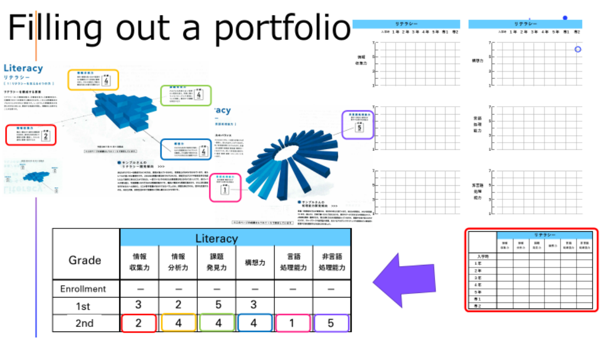

Figure 3. (b) Record literacy results

Considering that changes in GS are also influenced by changes in awareness, such as daily activities and qualification exams, recording them is also explained in the SFD. To add information to the portfolio, class teachers need to raise awareness through repeated announcements in HR. In addition to the quantification of each skill by the PROG, goals are set for further development based on comments on strengths, and goals for improvement based on comments on weaknesses. In the following year, they will be able to check the changes in their growth through the PROG values and strengthen their self-affirmation by reflecting on their actions.

Promotion of portfolio

In the beginning, changes in GS were used to investigate changes in students' behavioral characteristics due to changes in learning styles (passive learning → active learning) caused by the introduction of active learning. Every year students receive the results of their GS, but unless there is an explanation about the results, no improvement cycle based on them can occur. As mentioned earlier, SFD for students was conducted to promote the use of portfolios as a cycle of improvement through continuous reflection and goal setting over five years. What kind of skills are required? What skills will be required during the 5 years of student life?

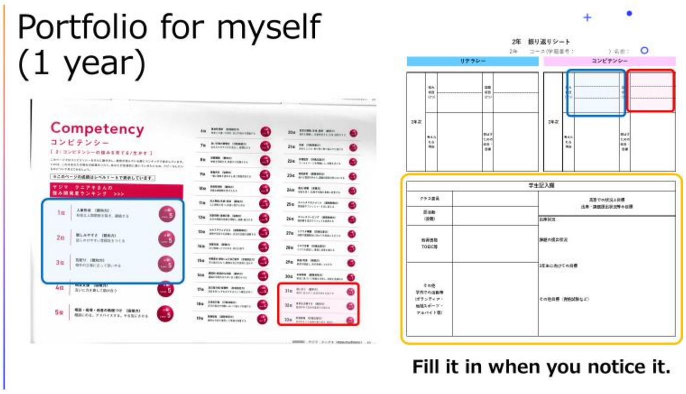

Figure 4. Career path at KOSEN Sendai College Hirose campus

Because GS is different from knowledge, a small score is not necessarily bad, but it can be made as large as they want it to be. Just as in pottery, where clay is kneaded to make a vessel, the size and shape can be changed as much as possible depending on one's goal setting and experience. As a teacher, if you are an adult and you fit into a certain field, it is very difficult to make the vessel bigger because it is already baked. As you improve one skill, the other goes down. We convey to our students that the overall strength of GS can be developed flexibly at SFD, and that the student days are very important. Currently, students take the PROG between December and January, which is the second half of the academic year. These explanations to students are given in February at the end of the academic year or around May of the new academic year. However, since students are not yet familiar with how to manage their own exams, it is necessary to devise a way to implement this at HR after each exam.

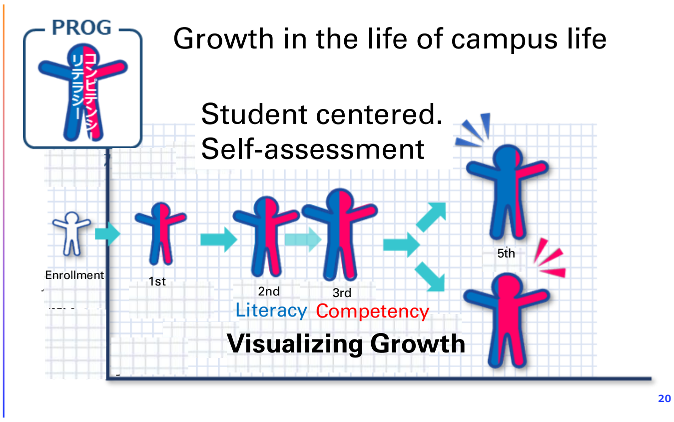

Figure 5. Growth of various GS configurations

Example of improvement

From the continuous survey, visualizations of the changes in the growth of GS across the campus were realized. The results show us that our students have some skills that have grown a lot and other skills that have not grown much. Rather than overlooking this as a characteristic of the college, it would be effective for the college and the students if we could assist their growth even a little in the curriculum. So, we called it a curriculum supplement to share GS trend analysis with the campus and improve the curriculum so that we can determine small targets in the curriculum to assist their growth.

As an example, the basic experiments for third-year students will be shortly introduced. Until now, the curriculum has been based on a schedule in which each group conducts experiments on prepared experimental themes in order in an omnibus format during one semester. In order to improve their ability to plan and carry out the experiments, the groups were asked to create and manage their own experiment schedules within the semester. Students had a start meeting at the beginning of the experiment to confirm the contents of the implementation and their individual progress. Before the end of the experiment, a closing meeting is held to check the progress of the day, confirm the contents of the next experiment, and reschedule if necessary. In addition to the experiment textbook, the teacher provided the students with tools to manage their schedules and check their progress. The teacher is responsible for checking and managing the status of these activities. In addition, in order to improve responsibility skills, we established a system of personal management of parts boxes necessary for experiments, and parts checking at the time of rental and return. In the students' self-evaluation (direct survey), the result that the intended skills have been improved was obtained. Unfortunately, with the current amount of data, it is difficult to analyze the correlation with PROG. In the future, it will be necessary to analyze the effects of this proposal together with PROG data to confirm the effectiveness of the curriculum supplement.

Student development in cooperation with universities

The flow of recording and utilizing the changes in GS growth as a portfolio over the five years of technical college is being established as a system. This cycle is also recommended by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) as a "career passport" for elementary and junior high schools. However, the details are left up to the schools, and the transfer and sharing between grades and schools is still being coordinated. The school is working on a project to develop students by collaborating with universities that allow transfer after graduation from technical colleges, not only for assessment of knowledge but also for GS.

In Japan, Toyohashi University of Technology and Nagaoka University of Technology are engineering universities that have strong ties with KOSEN. These universities were originally established for students graduating from technical colleges to obtain degrees and doctorates, and they have accepted many students as third-year transfer students. At the time of transfer, students' personal information and academic records are sent to the university. There is no information on GS for students of the College of Technology who come from technical colleges across the country. In other words, while information about grades is shared, there is no information about personal development, and students themselves need to create a new environment. After transferring to the university, students are assigned to laboratories and internships, and there is no way to know the nature of the students in detail. Therefore, since a year ago, we have been asking our graduates to take the PROG exam continuously to track their growth after transferring to universities.

We are promoting the follow-up of students transferring from KOSEN to the University of Technology, but due to COIVD-19, face-to-face active learning classes have been drastically reduced, making it difficult to continue GS skill checks. Table 1 shows the change in the number of schools taking the PROG at technical colleges in each region of Japan; before COVID-19, there was an upward trend, spreading throughout KOSEN, but after COIVD-19, it has been implemented in a limited number of KOSEN. One of the reasons given is that it is a GS test, and the survey itself is not being conducted because of the face-to-face paper-based mark-sheet group examination format. In addition, it was difficult to prepare for the PROG web-based examination because of the effort required for the remote class operation. This may be a problem unique to the Japanese, but in the case of web-based PROG examinations, it is difficult to trust the spontaneity of the students and there seems to be a strong concern that a fair judgment cannot be made due to the lack of support until the completion of the examination, relaxed examination (selection of the same marks), and differences in examination environments.

Table 1. Changes in the number of PROG tested by region

Year	Hokaido	Tohoku	Hokuiriku	Knato	Tyubu	Kousinetu	Kinki	Tyugoku	Shikoku	Kyusyu	Ratio
2014	1	1	1	1	0	0	0	0	1	0	9%
2015	1	1	1	0	0	0	2	0	1	0	11%
2016	1	2	0	3	2	2	3	2	1	3	33%
2017	1	3	0	3	2	2	3	2	2	7	44%
2018	1	4	1	5	3	2	2	1	2	7	49%
2019	0	3	1	4	1	2	1	1	1	1	26%
2020	1	3	2	4	1	2	1	1	2	0	30%

Currently, as an effective method, we are conducting a survey on PROG implementation at KOSEN, informing the University of Technology of the names of KOSEN students who have taken the PROG examination, and personally linking those who have taken the PROG examination with past PROG data. For this reason, the number of students to be surveyed is small, but in order to promote future collaboration between KOSEN and the University of Technology, the project was started last year as a project of each university of technology. Currently, the KOSEN Sendai college Hirose campus and both technical colleges are working together on each project. In the next year, we will be planning to develop this project as a nationwide project in collaboration with the head office of the National Institute of Technology. After that, the collaboration with other universities in Japan, where a student transfer is possible, will be scheduled.

By making continuous surveys possible, students will be able to learn about changes in GS that are different from those in KOSEN due to university transfer. The university side will be able to know the nature of the students and provide more effective guidance. In addition, KOSEN will be able to know what skills need to be strengthened for university transfer. Feedback from universities will enable KOSEN to improve its education. New collaboration among students, KOSEN, and universities using GS will become possible. In order to systematically realize these goals, we are currently studying the implementation method and adjusting the information sharing. Due to the Protection of Personal Information Act, it is currently difficult to efficiently share information across institutions, so as a countermeasure, we are asking individual students for their approval and proceeding with information submission from them. However, we do not plan to provide this information to universities and technical colleges in association with personally identifiable information. We plan to use this information as a result of trend analysis for school improvement. In the future, it will be necessary to consider a system that will enable educational improvement, including changes in individuals.

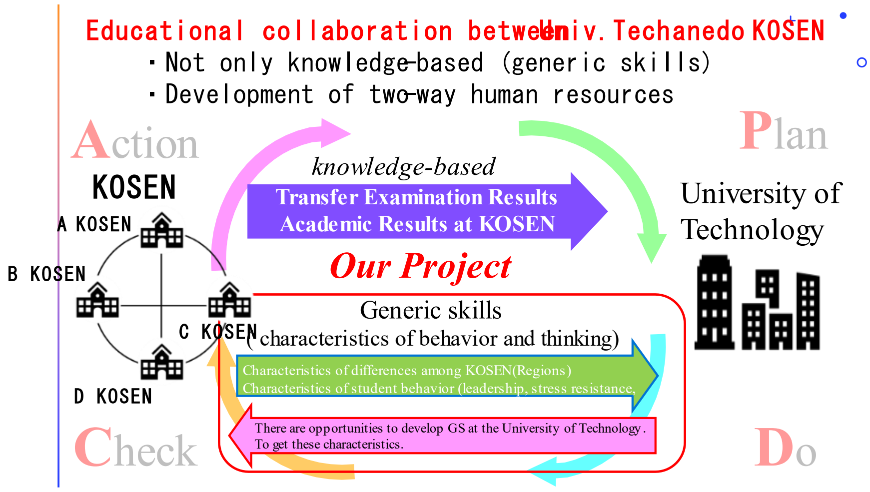

Figure 6. Growth of various GS configurations

CONCLUSION

KOSEN Sendai college is promoting the voluntary growth of GS by students using PROG with the help of portfolios. As for information sharing with universities after graduation, the current focus of student information is on grades and other indicators of knowledge retention. We reported on cross-institutional collaboration on efforts to foster students' continuous growth in human abilities by collaborating with KOSEN graduates. Within the constraints of the Personal Information Protection Law, a lot of ingenuity is needed in collaboration between KOSEN and University of Technology, coordination within and outside the institution to link PROG data, one of the GS evaluation methods, and sharing of individual student data, which is not described in detail.

Currently, the project is being promoted at the KOSEN Sendai college Hirose campus. In the second year of the project, students from other KOSEN have started to collaborate with each other, making it possible to conduct follow-up surveys and analysis: 1) changes in GS after transferring from the KOSEN (for students), 2) analysis and improvement of GS to be extended before transferring to the university (for KOSEN), 3) analysis and improvement of GS to be extended at the university (for University of Technology) and students. The cycle of improvement by the students themselves, feedback from the university to the KOSEN, and improvement of GS growth at the university will make it possible to continuously implement the cycle of improvement that has been carried out independently until now.

In the future, we plan to approach not only the University of Technology, but also the universities to which the students have transferred. We are also planning a follow-up survey of students who have found employment. By visualizing for current students what GS they need to strengthen depending on their field of employment, it will be easier for them to set specific goals for their five years at the college of technology, which will revitalize their student life.

We believe that if this project progresses significantly, it will significantly change the way student information is currently handled in educational institutions. While there is an importance of assessing the retention of knowledge, the human ability to cope with internal and external changes in social activities has a great impact. Although the importance of human resources is recognized, there are few reports on information sharing in collaboration within educational institutions. We hope that this will become a new type of student information collaboration in Japanese educational institutions.

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IMPLEMENTING PORTFOLIO EDUCATION USING OBJECTIVE DATA OF GENERIC SKILLS

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ABSTRACT

National Institute of Technology, Sendai College (Sendai KOSEN), Hirose Campus participated in the program of "implementation of portfolio education of 6 priority items for establishing quality assurance of education" of National Institute of Technology in the academic year of 2020 and we examined how portfolio education should be conducted and how we could implement it. In 2021, we started the first stage of portfolio education for younger (1st- to 3rd-year) students.

This paper reports the initial cases conducted at Hirose Campus in 2021 and introduces the future portfolio education plans. Among the initial concepts were "to reduce a load of students in the introduction of the portfolio," "to provide the appropriate guidance to deepen students' understanding of portfolio education," "to introduce objective generic skills assessment," and "to enrich the portfolio according to students' level of understanding." According to these concepts, guidance and portfolio creation workshops were held for younger students. In particular, we tried to include the results of objective evaluation of generic skills into the portfolio, which is a strength of Hirose Campus, and to practice effective portfolio education in cooperation with parents as mentors for life outside school.

KEYWORDS

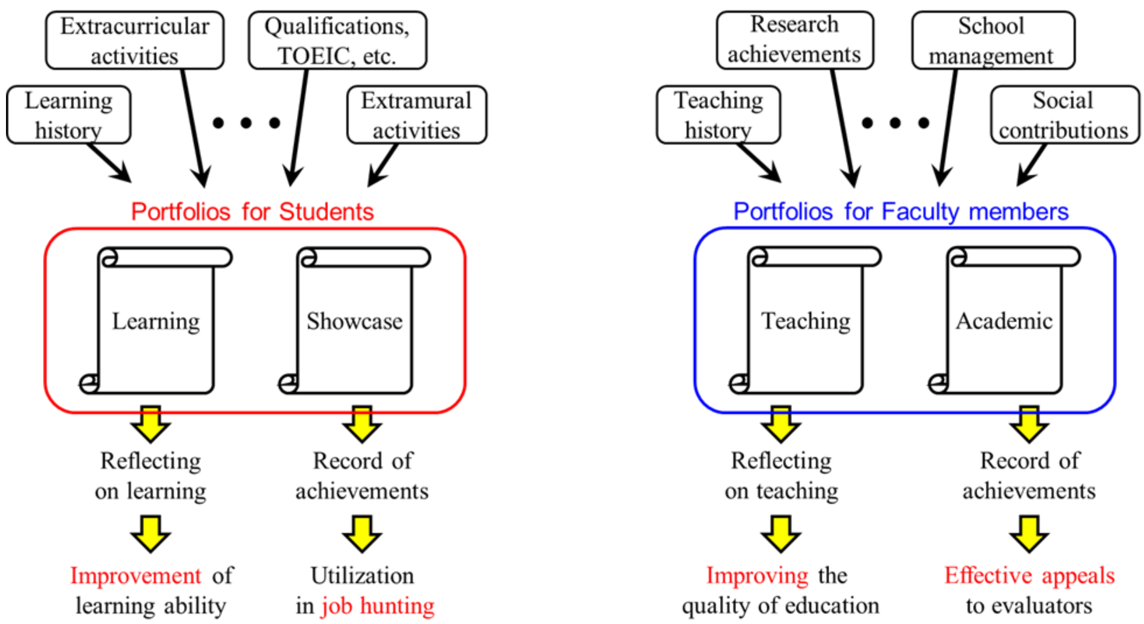
Portfolio education, Collaboration between Parents and Teachers, Objective assessment of Generic Skills
Standards: 9, 11, 12

INTRODUCTION AND BACKGROUND

Zubizarreta (2004) proposed that students' self-reflective practice with learning portfolios is effective in improving learning. On the other hand, Peter Seldin et al. (1993) demonstrated the effectiveness of teaching improvement by teachers themselves using teaching portfolios. For more effective lesson improvement, it is important that the two portfolios, the teaching portfolio by the faculty and the learning portfolio by the students, be organically combined. Fig. 1(a) shows an overview of portfolio creation and utilization by students. By creating a learning portfolio and reflecting on their own learning history, students can accurately recognize their own strengths and weaknesses and learn effectively to achieve their goals. In addition, students can be encouraged to take initiative in their own learning by clarifying their goals through the "showcase portfolio," which is a collection of their achievements. The showcase portfolio can be a powerful tool to prove their learning and strengths when applying for jobs or higher education.

On the other hand, portfolios are also very important for faculty members. An overview of the use of portfolios by faculty members is shown in Fig. 1(b). Teachers will be able to improve their teaching skills by recording and reflecting on their own teaching history in their "teaching portfolios." Furthermore, by summarizing the achievements of research and school management in an "academic portfolio," teachers can objectively grasp their current status and set goals for the next step. They will develop their teaching and school management skills through the creation of their portfolios.

As a result, faculties and courses in universities and colleges can use portfolios to guarantee and improve the quality of their education, as well as to improve the curriculum and lesson contents. In addition, portfolios will allow easy and effective connections to other educational institutions, such as high schools and universities.



(a) for student (b) for faculty members

Figure 1. An overview of portfolio creation and utilization

In Japan, portfolio education is just beginning, and many educational institutions are now trying to implement portfolio education in terms of its effective use for individual students and the way it can be reflected in their education. In 2020, the National Institute of Technology set the following six priority items for the establishment of educational quality assurance: 1) Implementation of portfolio education, 2) Implementation of visualization of experimental skills, 3) Implementation of cross-disciplinary competence (generic skills) development, 4) Educational improvement practices supported by data (evidence), 5) Implementation of peer supporter training, and 6) Consolidation and sharing of student information. Portfolio education is positioned as the first item, indicating that it is very important.

At Sendai KOSEN, we had had a common understanding of the concept of portfolios, but no substantial portfolio education had been provided. In the academic year 2021, however, portfolio education finally started at Hirose Campus. Since both students and teaching staff were new to portfolio education, the priority was to establish our awareness of portfolio education. First, we held workshops on what we intend to do through portfolios and how to use them, rather than using sophisticated and complex portfolios from the beginning. We then decided to complete the portfolios in stages over several years with the establishment of students' awareness.

In this paper, we will introduce a case study of the initial education for students who are using the portfolio for the first time at our campus, with the concept of drawing out students' independent learning. Specifically, we will focus on a practical plan for portfolio education based on the characteristics of our school, including 1) the development of generic skills and their assessment we have worked on using objective, standardized tests since 2014, and 2) the involvement of parents as mentors, taking advantage of the fact that many of our students commute to school from their parents' homes. And finally, we will explain the future plans for the development of the portfolio and how we plan to utilize it.

CONTINUOUS SURVEY ON GENERIC SKILLS AT SENDAI KOSEN, HIROSE CAMPUS

On our campus, we have been conducting a continuous survey of students' generic skills (GSs) since 2014. Progress Report on Generic Skills (PROG), which is a standardized test in Japan (Kawaijuku Group, 2021), has been used to evaluate students' generic skills. The reason for adopting the PROG is that we considered that generic skills cannot be accurately assessed by self-evaluation. Assessment by teachers using rubrics is also a possibility, but when one teacher assesses many students, accurate assessment is difficult, and on the other hand, assessments for the same student may differ among teachers due to their subjectivity. As an objective method, PROG can assess students' generic skills more accurately without the subjectivity of students and teachers. Moreover, PROG has been adopted by many universities and allows students to accurately recognize their own strengths and weaknesses by being able to compare their scores with the average score of university students. As a result, students can accurately reflect on and improve their generic skills.

Fig. 2(a) and (b) respectively show the years when the students took the PROG test and the overview of their growth characteristics. In Figure (a), circles "○" mean that students of every course took the test, triangles "Δ" mean that students of only some courses took the test (specifically, only students in two of the three courses in all were tested), and cross "×" means that students DID NOT take the test. Fig. 2(b) shows yearly changes in overall scores of the same students from their 1st year to 5th year in Literacy and Competency parts who enrolled in 2014 (red circles) and 2016 (blue circles). From Fig (b), it is observed that the Competency skills of our students improved with their grade progress, although some variability could be observed. As for Literacy skills, on the other hand, growth was observed as the grade progressed, but there was also a tendency to saturate when the score exceeded 5.0. Based on these questionnaires, we are currently working to improve the curriculum and lesson contents. Kawasaki et al. reported on the curriculum improvement at the IEEE Global Engineering Education Conference 2021(EDUCON2021), and Yajima et al. reported on specific improvements in lesson contents at the 17th CDIO International Conference (CDIO2021).

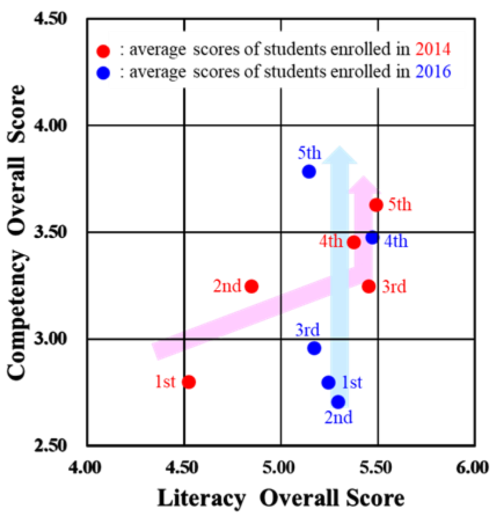
In this way, visualizing the growth of generic skills through annual PROG tests is effective for improving education. Furthermore, it is thought to be effective for individual students to improve their learning by incorporating it into their portfolios. In the PROG test, the assessment contents of the Literacy part are classified into six elements like “collecting information” and so on, and the Competency part consists of three categories of Personal, Interpersonal, and Problem-solving competencies, and they are classified into 9 contents and 33 elements. The detailed categorization of skills allows students to select the skills they need to achieve their individual goals, and taking the PROG exam and reflecting on it repeatedly promotes efficient growth of their generic skills.

Year	Academic Year						
	2014	2015	2016	2017	2018	2019	2020
1st	○	○	○	○	○	○	○
2nd	○	○	○	○	○	○	○
3rd	○	△	○	○	○	○	○
4th	○	○	○	○	○	○	○
5th	○	△	○	×	○	×	○

○ : students of every course took the test.

△ : ONLY students in two of the three courses in all were tested.

× : students DID NOT take the test.



(a) year of students who took the PROG test (b) the overview of growth characteristics f our campus students

Figure 2. Continues survey of the generic skills at Hirose campus

CONCEPT OF PORTFOLIO TO BE DEVELOPED

In this attempt, we started with the development of a learning portfolio, since it was the first time for both the teachers and the students to conduct portfolio education. In developing the learning portfolio, the development concept is shown in Fig. 3.

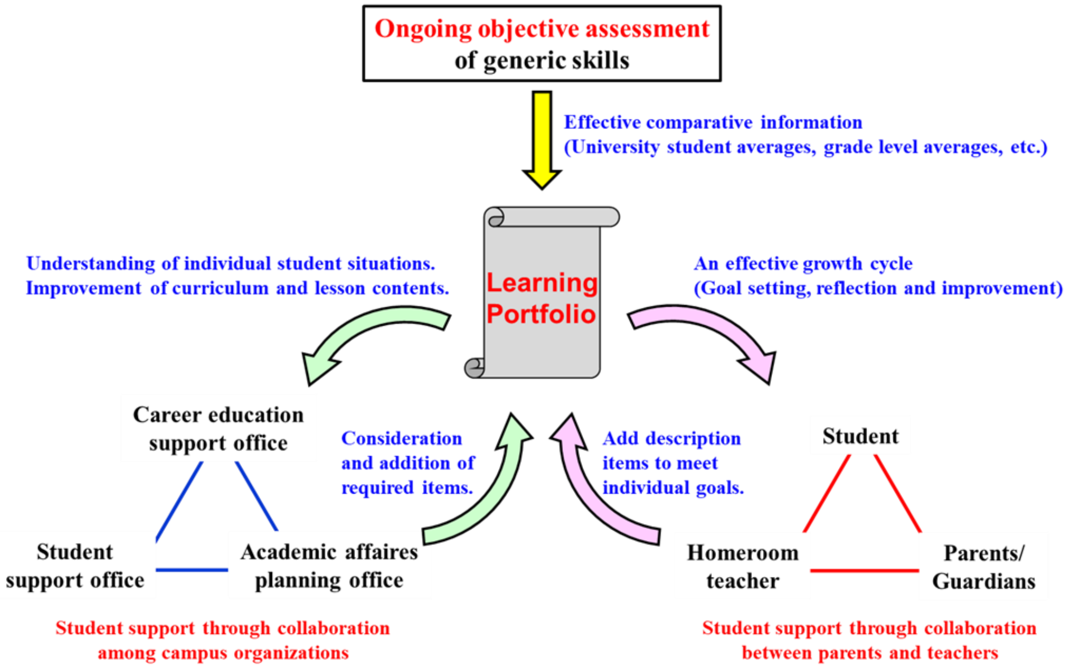


Figure 3. The development concept of the portfolio

Introduction of a voluntary improvement cycle for students through ongoing surveys of generic skills

Students will be able to reflect on generic skills, which are difficult to recognize accurately, based on objective assessment results. Furthermore, by comparing their score with the average score of university students and the average class score, students can identify their strengths and weaknesses. As a result, students can easily set short-term and future goals. By taking the PROG test regularly, students will repeat the improvement cycle and grow at their own initiative.

Introduction of support for students through collaboration between teachers and parents

The portfolio belongs to the student and is to be created by the student himself/herself for individual purposes. However, Sendai KOSEN has students between the ages of 15 and 20, including young students who have just graduated from junior high school. In addition, about 80% of the students commute to school from their homes. Considering these characteristics of our school, we thought that the involvement of their parents in portfolio education could make the education more effective. Therefore, we gave the parents a role as mentors outside school by including a section in the portfolio for parents to fill in as well. By sharing the portfolio with parents and homeroom teachers, we gave it the role of a tool to build a support system for students both on and off campus.

Introduction of education improvement through collaboration with existing organizations on campus

The portfolio allows teachers to understand each student's situation and to improve education as a whole school. By understanding the needs and challenges of individual students, we can enhance our individual and career support. In order to realize these supports, the Student Support Office, the Career Education Support Office, and the Academic Affairs Planning Office, which are existing organizations in our college, will work together to develop the portfolio education.

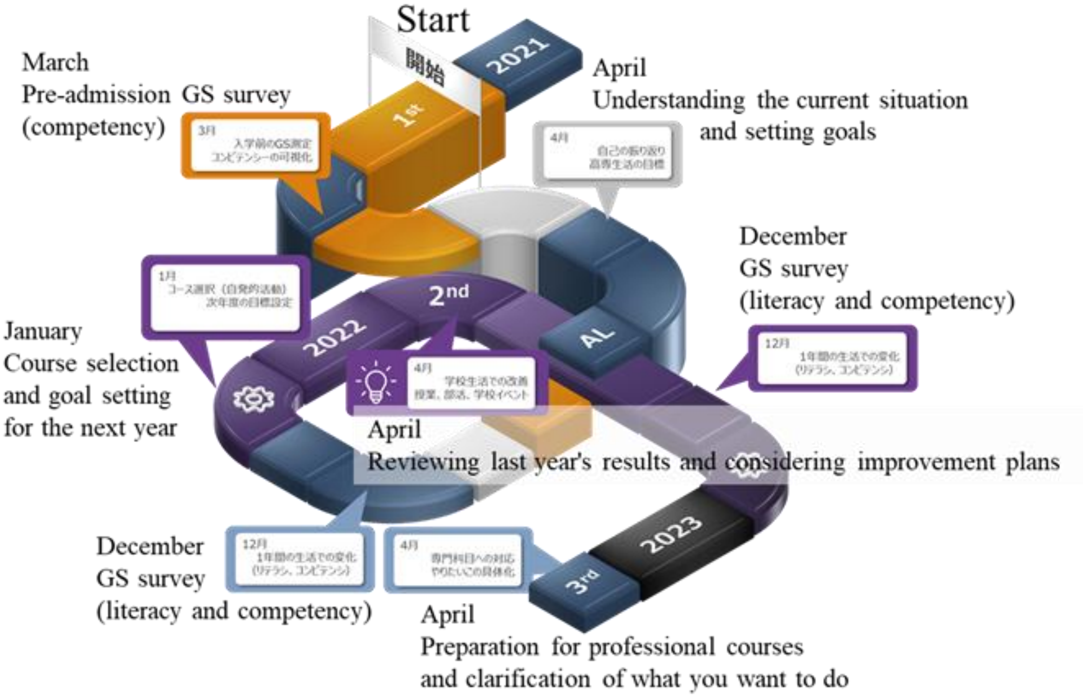
INITIAL APPROACHES TO PORTFOLIO EDUCATION

In implementing the portfolio, we emphasized the importance of students creating their own portfolios according to their own goals, rather than being led by teachers. In order to prevent the portfolio from becoming just a formality for students who are using it for the first time, we have made some efforts and attempts, which are described below.

First, we introduced a paper portfolio to reduce the students' load of starting the portfolio. The content of the portfolio was made easier to understand, and the range of content was not limited so that students could freely write anything they wanted. In order to make it even more fully individualized, it was decided that students could freely add items to the list according to their individual purposes.

Second, we provided regular guidance and portfolio filling workshop work to help students understand the meaning, intent, and use of portfolios. As an example, Fig. 4 shows some of the content of the first guidance and the workshop conducted for first-year students. In the guidance, the schedule from admission to graduation shown in (a) was explained, and students were made aware of the timing of important events leading up to graduation, such as course selection, laboratory assignment, and so on. And the preparations needed to achieve the purpose for each event were explained. In the second guidance session, the Career Support Office provided guidance on career activities, explaining the importance of preparation and the use of portfolios from the first year.

Third, as for generic skills which are difficult for students to recognize by themselves, we decided to use a portfolio to review, improve, and set goals based on objective evaluation results using the PROG results conducted once a year instead of relying on self-evaluation. In the workshop, we explained the characteristics of generic skill growth at our school and let them do individual work on self-analysis and goal setting using their own PROG scores. At the end of the academic year, we plan to hold a workshop using the scores from this year's PROG test. Fig. 4(b) and (c) show the scenes of the workshop.



(a) the content of the first guidance

(b) the scene of the guidance (c) the scene of the workshop

Figure 4. Guidance and workshops

Fourth, we decided to use the simplified portfolio until the students' own understanding of portfolio education was established. In addition, it was designed so that students could evolve it by themselves, adding items according to their own goals. In the meantime, the school will continue portfolio education, and existing organizations on campus will work together to select and add what is needed at each grade level.

THE FIRST PORTFOLIO AND FUTURE PLANS

Fig. 5 shows a part of the portfolio (for second-year students) that we developed. The portfolio consists of two parts. Fig. 5(a) shows the first generic skills development part of the portfolio, in which students use their PROG results. Students can visualize their own growth by filling in graphs of their scores on all six Literacy assessment elements and nine middle-leveled contents of Competency. As a result, students will be able to look back and consider ways to improve their skills and set goals based on the growth results.

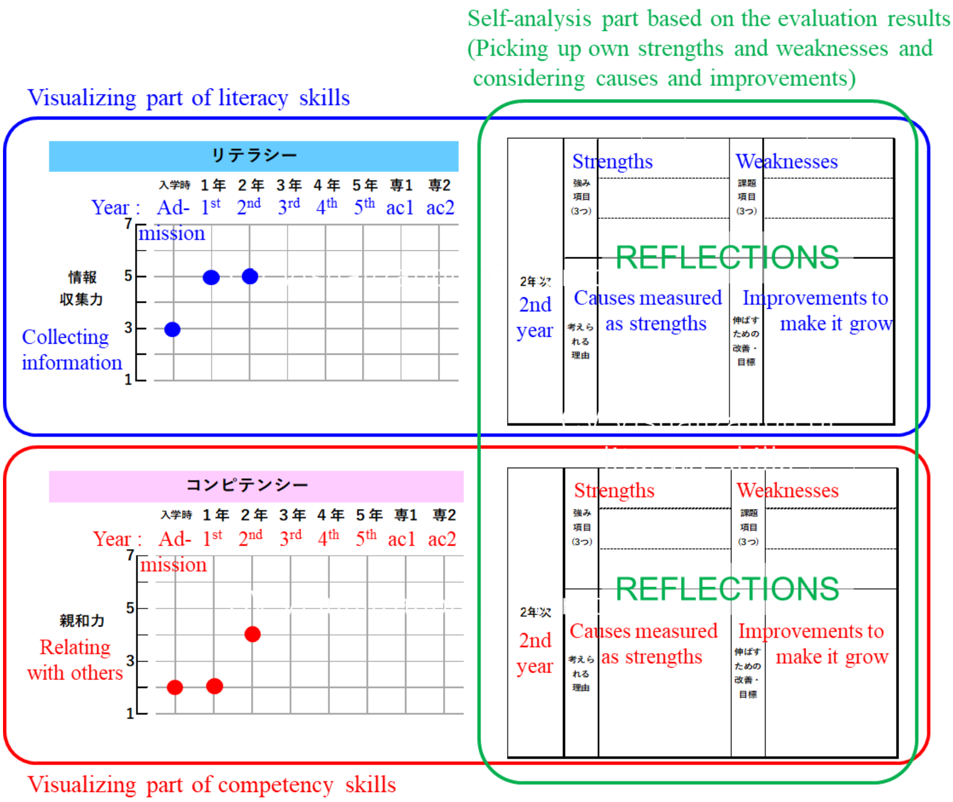
Figure 5(b) shows the second part of the portfolio, which records their achievements, learning situation and sets short- and long-term goals. The teachers try not to specify the items to be recorded so that the students could freely describe their long-term goals. In addition, the parents were given a role as mentors for life outside school by providing a parent comment box. This will build a collaborative student support system between parents and teachers through the portfolio, and as a result, an effective growth cycle for students can be expected.

The portfolio developed is a minimal portfolio with a low implementation load for students and faculty alike, in line with the initial concepts. As portfolio education becomes more prevalent among students, we plan to develop a more detailed portfolio. The specific plan of progress is shown below. The first step will be to fully individualize the portfolio. A fully individualized portfolio is realized by selecting detailed items of competencies necessary to achieve the goals of individual students and adding them to the visualization items of the generic skills development part. For the second part, we are currently considering ways to allow students to evolve the items to be collected in their portfolios and the perspectives of their reflections, based on their own ideas.

The second step is to digitize the portfolio in the next few years. For digitalization, an inexpensive and general platform that leads to lifelong learning must be established. Considering the development of a showcase portfolio, information dissemination to the outside world is also an important factor. Currently, we are considering using Microsoft Excel as a database and social networking services. For the showcase portfolio, we are also planning to build a creative environment (3D scanner, creating/editing videos, and so on) that will allow us to digitize the artifacts produced at our campus.

On the other hand, in order to allow teachers to understand the importance and use of portfolios, faculty development sessions and workshops on creating teaching and academic portfolios will be held. Through these experiences, teachers will be able to create and effectively use teaching/academic portfolios and reflect on their teaching skills and where they stand as teachers. In addition, by comparing the contents of their own teaching portfolios with those of their students' learning portfolios, teachers can improve their teaching more effectively by eliminating differences in perception between teachers and students. Portfolio practice for teachers must also be promoted in a way that is compatible with portfolio education for students, and we plan to start faculty development sessions and workshops in the next year. In addition, we will implement evidence-based lesson improvement by not only comparing and analyzing the learning and teaching portfolios but also by providing feedback on the generic skills test and growth analysis that are regularly conducted.

Using the completed portfolio, we will promote portfolio education with the final purpose of building close collaboration with universities, not only on the status of knowledge retention but also on generic skills. Yajima et al. will report on the concept and planes of collaboration with universities at the 18th International CDIO Conference.



(a) The generic skills development part of the portfolio.

学生記入欄	
クラス委員 Student Council	高専での状況と目標 出席・課題提出状況等や目標
部活動 (役職) Extracurricular activities	出席状況 Attendance Status.
取得資格 TOEIC等 Qualifications, TOEIC, etc.	課題の提出状況 Submission status of assignments
その他 学外での活動等 (ボランティア・ 地域スポーツ・ アルバイト等) Off-campus activities, etc.	3年生に向けての目標 Objectives for this year. その他目標(学外・将来的) Other goals (off-campus, future, etc.)

(b) Recording part of their achievements, learning situation and sets short- and long-term goals

Figure 5. A part of the portfolio that we developed.

CONCLUSION

Sendai KOSEN, Hirose Campus participated in the program of "implementation of portfolio education of 6 priority items for establishing quality assurance of educations" of National Institute of Technology in the academic year of 2020. We examined how portfolio education should be conducted and how we could implement it at Hirose Campus. In 2021, we started the initial implementation of portfolio education for younger (1st- to 3rd-year) students.

In order to prevent portfolio education from becoming a just formality, the initial concepts were defined as "reducing the burden of introduction for students," "providing guidance to deepen students' understanding of portfolio education," "introducing objective generic skill evaluation," and "enriching the portfolio according to students' level of understanding." We developed a portfolio, and provided guidance and portfolio writing workshops for first through third-year students. The portfolio we developed included reflections based on an objective evaluation of generic skills, a particular strength of Hirose Campus, and the role of parents as mentors for life outside school. Through these efforts, we will attempt to practice effective portfolio education. Future plans include digitalization of the portfolio and reflection of the results of the portfolio education in the curriculum and lesson contents. For the final goal of portfolio education, close collaboration with universities will hopefully be constructed using the completed portfolio.

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INTRODUCTION TO NEXT-GENERATION ENGINEERING: BEING HUMAN IN THE INFORMATION SOCIETY

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ABSTRACT

While adopting Information Technology (IT) may have been a goal in itself in the past, during the last decade the emphasis has shifted, and IT has instead become a tool that enables us to realize other needs. This also sets new requirements for IT education: skills in software engineering and computer science alone do not provide students with the professional abilities they will need after graduation. To answer this call, the University of Jyväskylä launched in autumn 2021 a new engineering B.Sc. and M.Sc. degree program in Information and Software Engineering with close ties to the Humanities. The degree program was established on three cornerstones: 1) the ability to implement IT systems, 2) comprehension of the expectations and needs set on technology, and 3) mathematical-logical reasoning. As an introduction to the multidisciplinary studies, the students take a course called Being Human in the Information Society at the very beginning of their B.Sc. studies. This course aims at providing an understanding of the multidisciplinary context in which technology will be developed and applied when addressing the complex challenges of the future. In this paper, we will present the planning process of the new course, and describe the intended learning outcomes, contents, and learning methods of the course. In addition, faculty experiences and student feedback of the first implementation are discussed and reflected upon.

KEYWORDS

Information Technology, Humanities, Social Sciences, Multidisciplinarity,
CDIO Standards: 1, 2, 4

INTRODUCTION

The future roles of engineering professionals are changing with societal and technological development. To be able to respond to the future challenges, the traditional 20th century 'how-to-do it' approach should be moving towards 'what-to-do' and 'why-to-do' engineering functions, addressing the needs of the digital, global, diverse, and rapidly changing society (Kamp, 2019; Sorby, Fortenberry & Bertoline, 2021). Accordingly, while adopting Information Technology (IT) may have been a goal in itself in the past, during the last decade the emphasis has shifted, and IT has instead become a tool that enables us to realize other needs. This also sets new requirements for IT education: skills in software engineering and computer science alone do not provide students with the professional abilities they will need after graduation.

It is widely recognized that graduate engineers need to understand the interaction between users, systems, and machines, and to be able to envision in multidisciplinary teams how novel solutions will outperform existing solutions. In addition, the future society calls for technology that can be widely applied and adapted to its fundamental needs. Bucciarelli & Drew (2015), Lantada (2020), Kamp (2021), and others discuss the importance of human literacy as an engineering competence. Engineering studies need to become more socially relevant, including topics in Ethics, Humanities, and Social Sciences. Empathy, communication skills, agency, and emotional intelligence should be guiding engineering graduates when solving complex societal problems together with experts of other fields.

To answer this call, the University of Jyväskylä launched in autumn 2021 a new engineering B.Sc. and M.Sc. degree program in Information and Software Engineering with close ties to the Humanities. To establish a broader view on technology, all students in the program choose their minor from a wide spectrum of other studies, such as education, psychology, communication, sports sciences, arts and humanities, and business & economy. The multidisciplinary research of the university as well as its Humboldtian tradition originating from the first Finnish-speaking Teacher Training College founded in 1863 sets a solid foundation for the chosen educational approach.

As an introduction to the multidisciplinary studies, the students take a course called Being Human in the Information Society at the very beginning of their B.Sc. studies. The course aims at providing an understanding of the multidisciplinary context in which technology will be developed and applied when addressing the complex challenges of the society of the future. This course alone does not cover all the aspects of the Introduction to Engineering course outlined by the CDIO Standard #4 (CDIO Initiative, 2021; Malmqvist et. al, 2019). Yet, it aims to stimulate students' interest in, and strengthen their motivation for, the field of engineering by offering insights into the impact of digitalization in human interaction and involvement, as well as the long-term individual, societal, and cultural effects of technological innovations.

In this paper, we will present the multidisciplinary planning process of the new course, and describe the intended learning outcomes, contents, and learning methods of the course. In addition, faculty experiences and student feedback of the first implementation are discussed and reflected upon. Based on our findings, it seems that while the concepts discussed on the course were unfamiliar to the students at the beginning, they were able to quickly grasp their importance for both the developers and users of technology. In their final assignment, the students were also able to critically evaluate the multifaceted and evolving impact of technology on society.

PLANNING THE COURSE

The Information and Software Engineering education at the University of Jyväskylä was established on three cornerstones: 1) the ability to implement IT systems, 2) comprehension of the expectations and needs set on technology, and 3) mathematical-logical reasoning. An essential element in reaching these goals is that the students gain an understanding of the fundamental principles and functions of the information society. To make this happen, they must be exposed to the multidisciplinary context in which technology will be developed and applied.

Many initiatives in introducing multidisciplinary elements to engineering studies include different project-based activities. For example, MIT (U.S.) initiated an interdepartmental project-centric academic program in 2016 (Crawley, Hosoi & Mitra, 2018). Enelund and Henricson Briggs (2020) discuss the Tracks initiative that creates pathways between degree programs by offering project-centered learning supplemented with short courses, online learning, self-study, and mentoring at Chalmers University of Technology (Sweden). The curriculum of the Information and Software Engineering degree program at the University of Jyväskylä also includes several phases during which the students work in multidisciplinary teams addressing different assignments and projects. However, it was considered important that the students also get an orientation to the Humanities at the very beginning of their studies and the development of their professional identities both as individuals and as a group of engineering students.

Designing the goals and learning outcomes of the Being Human in the Information Society course was a multidisciplinary, creative process, where participants from the different departments of the Faculty of Humanities and Social Sciences approached the topic from their own perspectives. The faculty has four departments with undergraduate degree programs, and representatives from each department took part in the planning process:

- Department of History and Ethnology
- Department of Language and Communication Studies
- Department of Music, Art and Culture Studies
- Department of Social Sciences and Philosophy

The aim was to ensure that each department would contribute in a way that would enable the students to catch a glimpse of the essence of the discipline, while also adhering to the common theme of the course. In the process of developing the course content, each department formulated a brief description of how their specific discipline approaches different aspects of technology. For example, the Department of Social Sciences and Philosophy wished to bring in the theme of digital life and approach it through age and aging, life trajectories, and intergenerational relations, as well as consumption and well-being. The common thread in their theme was the equal distribution of the benefits and challenges of digitalization. The different descriptions were then discussed together to fill in gaps and avoid overlaps. In the end, five learning outcomes were formulated. These were related to understanding the role of arts, culture, and communication in technological environments and their development over time, as well as the ability to critically examine the effects of digitalization in people’s activities and possibilities of participation in society. The course contents and intended learning outcomes are presented in Appendix 1.

COURSE IMPLEMENTATION

The course took place in the first period of the autumn term; the idea was to expose the first-year engineering students to topics in the Humanities from the beginning of their studies. There were two class meetings each week – on Thursday afternoon and Friday morning – and each week was devoted to a different topic. This made the course rather intensive. The course ran for seven weeks and had the following overall contents:

Week 1: Orientation and practicalities; social justice and cognitive accessibility
Week 2: Designing inclusive digital services; digitalization of consumption and lifestyles
Week 3: Technology-mediated interaction
Week 4: Music, art, and technology; digital culture and digital art
Week 5: The history of communications and technology
Week 6: Social anthropology of technology; digital ethnography
Week 7: Wrap-up and feedback; learning diary workshop

For each topic, there was a visiting expert lecturer from the relevant department. There was also a coordinating lecturer present in all class sessions, who took care of the online participants (Zoom) and assisted with lecture hall equipment, such as wireless microphones: the course was carried out in full hybrid mode, meaning that the students could decide whether they wanted to join in person or online via Zoom. All classroom activities were designed so that they could be done in class as well as remotely: we used, for example, breakout rooms on Zoom for group assignments. In addition, we used digital collaborative tools, such as Flinga, to collect the results of group assignments in class. To make full use of the hybrid setup, we also recorded each class to enable asynchronous participation. Each classroom meeting contained a lecture part as well as an activity or multiple activities on the topic. The activities were not recorded for later viewing.

The online learning environment Moodle was the digital backbone of the course: the Moodle workspace contained the course schedule, assignments, lecture recordings, background materials, a discussion area, and assignment return boxes. To pass the course, the students needed to actively participate in classroom activities, write a short essay on each week's topic, and produce a learning diary as the final assignment. The essays were graded pass/fail and the course grade (1-5) was given based on the final assignment. The final assignment instructions contained a set of questions for the students to guide their analysis of the course contents. The grading was based on the level of critical reflection, application of course contents, logical argumentation, and use of examples. For example, for a grade 3, the students had to show they had mainly understood the course contents, were able to critically evaluate at least some of the contents, and were able to connect the contents to the outside world using relevant examples.

Out of the 30 people who had enrolled on the course, 27 completed it. Out of the 27 students who completed the course, 24 gave consent for their learning diary to be used as data for this paper. We randomly selected 10 learning diaries to be analyzed. The diaries were anonymized prior to the analysis.

STUDENT AND FACULTY EXPERIENCES

To investigate the experiences of the students on the course, we used thematic analysis (Braun & Clarke, 2012) to analyze the learning diaries the participants turned in as part of their coursework. This method allowed us to systematically search for, interpret, and organize the threads of meaning we found in the diaries and use them to form broader themes. Our approach was mainly inductive and data-driven: we searched for the themes from the data rather than from a particular theoretical premise (Braun & Clarke, 2012, p. 58). Our aim was to discover how the students responded to and reflected on the course contents and whether they were able to connect the contents to their other studies and their everyday experiences as members of the information society, and whether there were any indications of change in their thinking.

We used Braun and Clarke's (2012) six-step model to conduct the analysis. According to Braun and Clarke, the steps of thematic analysis are: 1) exploring the data, 2) coding the data, i.e., marking points of interest, 3) searching for broader themes, 4) evaluating and making a final selection of themes, 5) defining and naming themes, and 6) writing the research report. We carried out steps 1-3 individually and 4-6 collectively. The examples from the learning diaries presented below have been translated from Finnish into English by the first author.

In our analysis, we found two main themes: 1) new perspectives into the digitalization of our society and 2) software development as the enabler of accessible and equitable society.

As to the first theme, many of the students mentioned that the course provided them with new insights into digitalization, their own backgrounds as users of technology, and the multifaceted impact of technology on society:

> **Excerpt 1**: Frankly, I was surprised at the number of different perspectives you can examine technology and its development from. For example, I hadn't previously considered that technology could impact culture, or that you could compose music using artificial intelligence.

Excerpt 1 shows that the course provided students with new or newly discovered old approaches to technology. Music is certainly familiar to all, but the course was able to open students' eyes to novel possibilities to connect technology and music.

Accessibility was a theme that many students brough up in their diaries. It was apparently something that many had not previously explicitly connected to technology. Excerpt 2 illustrates these views:

> **Excerpt 2**: I didn't think earlier that access to digital tools offered by public services could play such an important role in the equal treatment of citizens. It may be difficult to for a handicapped person, for example, to get information of public matters and social services concerning themselves. This problem could be mended with good planning and testing. This way one could ease the burden of public service personnel with matters that could be handled independently.

Excerpt 2 shows that the student had realized how certain groups may be marginalized in society when they do not have proper access to public services. The student also sees technology as one solution to the problem, as better planning and testing could save resources.

In the following excerpt, the student connects accessibility to broader issues of democracy and human rights, which shows how deeply some students reflected on the contents of the course:

> **Excerpt 3**: I was surprised to learn who much the accessibility of, for example, internet services affects democracy and human rights.

The students also recognized the importance of looking at the world through a wider lens, connecting technology and societal issues, and were able to position themselves within this wider framework in the future:

> **Excerpt 4**: The course brilliantly presented the side of things that is outside of working with computers. The reason why we learn to write code in the first place, or why new innovations

make the world a better place. The course gave me new, very interesting perspectives on real-world situations and things to reflect on in my own behavior.

The second theme that we discovered in the data was related to the role of software developers in making society more accessible and equitable. Although the students had only just started their studies, they were very aware of their responsibilities as future technology developers and saw the need to take all types of users into consideration when developing software products:

> **Excerpt 5**: I felt that digital inclusion, digitalization, and developing digital services were particularly important topics, because as future engineers, programmers, and web designers we need to understand the impact of digital technologies on society and be able to look at the digital products we develop from the viewpoint of regular people and consumers.

In the student as well as faculty feedback – which will be discussed next – one of the improvement suggestions was that the different topics on the course could have a clearer connecting theme. Nevertheless, the overall human perspective on technology seemed to come across clearly for the participants, as the following two excerpts show:

> **Excerpt 6**: This course taught me, above all, the importance of empathy, sympathy, and tolerance in the development of technology as well as the logic behind the development.
> **Excerpt 7**: The whole course of Being Human in the Information Society was a very eye-opening course.

To collect faculty feedback, we arranged two meetings with the faculty members that had taken part in the planning and carrying out the course. In the meetings, we discussed our work process and the teachers' experiences in planning and teaching the course. We also collected any suggestions for developing the course further. In general, developing the course had been a positive experience and each of the participants was willing to participate in the future, too. The participants felt that the hybrid system, with a coordinating teacher as a teaching assistant, worked well and that the amount of work associated with the course was feasible. Our aim is to develop the course iteratively, based on our own experiences as well as student feedback, and the improvement suggestions we collected after the first implementation include the following:

- A clearer common theme between the different topics on the course; for example, technological determinism or technological stratification
- Diversity in the weekly assignments – now, they were all short essays based on background reading
- Clearer picture of the other courses and activities taking place simultaneously for the first-year students, to increase cohesion.

In the spring term of 2022, we will arrange workshops to respond to these improvement suggestions and develop the course further.

CONCLUSIONS

Multidisciplinarity is a much-discussed topic, and its importance is widely acknowledged. It requires some effort – all participants must step out of their comfort zone – but it is necessary for the development of an inclusive information society. It is also evident that the society of the future places extensive expectations on technology: it must be widely applicable, accessible, and respond to the needs of the people. With the Being Human in the Information Society course, our aim was to answer this call.

For graduate engineers to develop technology in an efficient and usable direction, they need to understand the way society functions and be aware of the real-life contexts in which technology will be applied. Based on the feedback we received, the themes on the course were thought-provoking and gave the students new perspectives on everyday technology use. The feedback from both students and faculty will also allow us to develop the course further.

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APPENDIX 1 – COURSE DECRIPTION

The course description translated from Finnish to English from the Study Guide (Curricula 2020-2023) of the University of Jyväskylä (available at: https://studyguide.jyu.fi/2021/en/). Direct link to the original document: https://opinto-opas.jyu.fi/2021/fi/opintojakso/hytp5000/

BEING HUMAN IN THE INFORMATION SOCIETY

Course Level:	Basic Studies (B.Sc. in Information and Software Engineering)
Extent:	5 ECTS Credits
Grading Scale:	0 (failed) – 5 (excellent)

Summary

Human activity in the digitalized society from the perspectives of digital service systems, working life, communications, arts, culture, and history.

Learning Outcomes

After completing the course, the student:

- can critically examine the impact of digitalization on human activity and participation in different environments from the perspective of the distribution of well-being
- understands the importance of communication and interaction in changing technological environments
- understands the role of art and culture in identity and community building
- is familiar with the social and cultural implications of technological innovations
- understands long-term changes and continuities and their implications for individuals, communities and societies.

Contents

The course examines human activity in the digitalised society from the perspectives of digital service systems, working life, communication, art and culture, and history.

Digital everyday life is approached from the perspectives of age and ageing, the life cycle and intergenerational relations, consumption, and well-being. A cross-cutting theme is the fair distribution of the benefits and drawbacks of digitalization.

Regarding work life, the focus will be on digital interaction, intercultural communication, and multilingualism, as well as the links between these and organisational practices and, more generally, accessibility, inclusion, and well-being in today's society.

Music, art, and culture are approached as part of time, society, and humanity. Technology will be addressed from a cultural studies perspective, with a particular focus on the social and cultural implications of technological innovation. Games, music, images, and written expression are seen as key environments for learning, information processing, interaction, emotions, and social influence. The focus is on how art and cultural products are used to build identity and community, how art generates well-being, and how digital environments shape creative activity.

To understand today's digitalized society, it is also necessary to look at long-term changes and continuities from a historical perspective. This requires the adoption of a critical approach to historical sources and an analysis of the relationship between the present and the past. The aim is to understand why and how communities and societies have been formed as part of historical, often long-term, temporal processes.

IMPROVING TEACHING OF SELF-DIRECTED LEARNING VIA TEACHER MODELLING

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ABSTRACT

Self-directed learning (SDL) is a higher order competency that requires simultaneous development of a myriad of interrelated technical and generic skills, knowledge and attitude. The Diploma in Chemical Engineering (DCHE) from Singapore Polytechnic (SP) used the CDIO Framework to integrate development of SDL competency into its 3-year curriculum. Explicit teaching of SDL based on the SDL Model developed by SP was done in Year 1. SDL learning tasks were purposefully integrated throughout the curriculum to enable students to develop SDL with other core skills and domain knowledge needed. While we considered the integration effort to be generally successful from findings of the 3-year longitudinal study of the Academic Year (AY) 2018 cohort, we noted a disparate level of SDL readiness amongst students. Evidence of SDL transferability was seen as students progress from Year 1 to Year 3, although some students still faced challenges using SDL in Year 3. Most students surveyed in Year 3 displayed behaviour analogous to a self-directed learner during their final year capstone projects, and used SDL when they worked on their internship projects. The literature shows teachers can positively impact student learning and engagement through behaviour modelling where thought processes are verbalised hence made visible so they can be imitated by students. This paper shares the approach taken to further improve development of SDL competency through introduction of teacher modelling in a Year 1 practical-based module. In this pilot study, the teacher models how a self-directed learner approaches learning tasks in an integrated learning session. Students then use the same approach to complete similar learning tasks in subsequent session. Survey findings showed teaching modelling was useful and improved students' understanding of how SDL can be applied and most students were able to use the same approach in the second session. From qualitative responses collected, some students seemed unable to understand how to apply SDL and needed more guidance, indicating inconsistent development of self-directedness. More than half the students seem unable to manage the negative emotions that appear upon encountering challenges. The paper concludes by sharing future works to improve the teaching of SDL in DCHE students.

KEYWORDS

Self-Directed Learning, Modelling, Chemical Engineering, CDIO Standards 7, 8, 9, 10, 11

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to as "faculty" in the universities.

INTRODUCTION

This paper presents work done that strives to improve the development of self-directed learning (SDL) competency in Diploma in Chemical Engineering (DCHE) students in Singapore Polytechnic (SP). SDL is now made explicit as one of SP's six desired graduate attributes as it is recognised as an important competency needed for students to become lifelong learners. This work is built on the learning gained from past efforts from the last three years (Wong, et al; 2021; Cheah, 2020; Cheah, et al, 2019) where we used the SP-customised CDIO syllabus to define the underpinning knowledge (notable CDIO Syllabus sub-category 2.4.6) of what constitutes to SDL, and referenced the CDIO standards in the design of the various learning tasks. Findings from our previous studies, in which SDL was explicitly taught to Year 1 students indicated that not all students are able to demonstrate the level of readiness required of them at the end of their Year 1 study. We used the SDL Model promoted within SP for use by all diplomas within the institution. The model spelt out the key non-sequential steps students can undertake to become more self-directed in their learning: Plan, Select, Monitor and Evaluate. In addition, the model also highlighted two main factors students should consider when analysing their learning: metacognition and managing emotion.

The model is not without its limitations. Understandably, from the institutional perspective, it is necessary to introduce a model or framework that lecturers can easily identify with to encourage widespread adoption, and integrate SDL into all diplomas in SP. Another key finding of our previous efforts, is that a significant percentage (21.4%; n = 70) of students, from a longitudinal survey of the first cohort of students where SDL was explicitly taught in Academic Year (AY) 2018, reported they needed some help in applying SDL even as they are in the process of completing their Year 3 Final Year Project (FYP), i.e. Capstone Project, as well as their Internship Project and assignments (32.4%; n = 37). Some of the comments below highlighted the differences in terms of SDL-readiness among the Year 3 students on SDL in their FYP or Internship:

> "*There should be more guidance and resources available*."
>
> "*Guide them on which websites to find the articles needed*".
>
> "*Some prompts from lecturers would be very helpful. Since an issue with self-directed learning is that students often get lost and are not too sure what the best course of action would be. As such, lecturers could help guide students in the right direction without directly giving them the answers*."
>
> "*I think whatever was taught through the 2 years is adequate*."
>
> "*Students struggling with their understanding chemical engineering concepts have a need, whether self-acknowledged or not, to improve. Under the lens of SDL, these students would not be viewed as being "lazy" or 'stupid", but that they are simply using older, entrenched methods of learning that are not working well. The metacognitive tools of SDL would open these "weaker" students to using a range of learning tools - creating mental models, rehearsing the information etc. that could help them better than any peer mentoring program*."

In addition, we noted a fairly consistent percentage of Year 1 students in the subsequent two cohorts (i.e. AY 2019 and AY 2020) also reported that they had difficulty acquiring the skills from the various activities designed to help them develop SDL skills. These findings clearly showed that the students are at different level of SDL readiness, even as they progressed through Year 1 of study together, learning the skills of SDL, and taking part in the same learning tasks designed to develop their SDL skills.

The inconsistent level of SDL skills acquisition leading to different SDL-readiness levels can be, to a certain extent, attributed to students' socioeconomic background, and their varied motivational levels for learning Chemical Engineering. However, we also want to find out if there are other underlying factors that may have possibly contributed to these findings to further improve the teaching of SDL. As noted by Jossberger, et al (2010) the first step in learning how to be self-directed is to gain the skill to self-regulate one's learning activities and task performances. Therefore, for this study, we look into how lecturers can help students develop their SDL skills by modelling the behaviour of a self-directed learner, i.e. how a self-directed learner would approach learning activities and tasks.

LITERATURE REVIEW

This section provides a scan of the literature on SDL, looking into factors that can affect the development of SDL competency, in particular the different dimensions of SDL, and students' own readiness for SDL.

Factors to Consider in Developing SDL Competency

The development of SDL aptitude involves a complicated interrelationship of factors that make us human (Lord, et al, 2010). Everyone is capable of learning to be self-directed, but the extent to which self-directness develops to, will vary. This is simply due to the inherent difference in individuals, and their external influences, such as learning motivation, self-efficacy, self-esteem, conscientiousness, openness to experience, even intelligence (Cazan & Schiopca, 2014). This is echoed in another study done by Slater, et al (2017) who found that demographic, discipline and personality factors are associated with an individual's readiness for SDL. Suffice to note that to become truly self-directed, a myriad of these behavioural factors, coupled with the attainment of the mastery of a broad range of knowledge, skills and attitudes, are needed. Therefore, to support the development of students to be self-directed, it is important to balance these factors, and to provide the context when designing learning activities to engage students.

Patterson et al (2002) identified six competencies students need to become self-directed: self-assessment of learning gap, evaluation of self and others, reflection, information management, critical thinking and critical appraisal. Not unexpectedly, the authors cautioned that each of the skills are not mutually exclusive but are interrelated in such a way that simultaneous of all or a combination of some of them can be expected.

In order for students to have positive experiences in SDL, faculty must create learning environments that meet students' psychological needs and take into account their expectancies and values. Since SDL is primarily characterised by developing student autonomy, it can therefore be argued that it is important to consider students' view on self-directed learning. Silen & Uhlin (2008) found that students need to feel in charge, in order to take responsibility for their learning. Being in charge allows them to feel able to make changes to their learning situation, understand the rationale behind learning, and obtain feedback. Stefanou et al (2004) shared a framework in which student autonomy can be promoted at 3 different support levels – organisational, procedural and cognitive – with varying degree of student choice. According to Katz & Assor (2007), who based their analysis on the self-determination theory of motivation (Deci & Ryan, 2000), proposed that choice can be motivating when the options meet the students' need for autonomy, competence, and relatedness.

Bouchard (2009) highlighted the need to pay careful analysis of various dimensions of self-directed learning in order to determine whether our choices will promote or hinder the emergence of effective learning behaviour. This resonates well with the point made by Garrison (2000) who studied the theoretical challenges of distance learning; in that the teaching tasks normally associated with the role of a teacher in a formal setting must now be passed on to the learner in a self-directed setting. He offered the analysis from the perspectives of the learners in the choices they make during the learning process. Building on the work of Long (1992) who offered two fundamentals ways – namely psychological and pedagogical – where learning could be learner controlled; Bouchard (2009) offered four dimensions for analysis: algorithmic, conative, semiotic and economic. The first two are updates to Long's psychological and pedagogical ways; and the last two are new additions to represent changes in today's learning environment made available by technological advances to supplement traditional printed text (e.g. podcasts) and alternative forms of education (e.g. MOOCs). These have impacts of where and how learners choose to learn, and the perceived cost-benefit trade-off.

Role of Teacher in Developing Student SDL Competency

Candy (1991) noted the path to self-directed learning is dependent upon the individual's self-management skills in learning, his or her self-concept, and the learner's understanding of his or her own role and that of educators in the learning process. To enhance self-directedness, it is therefore not sufficient for the adult educator to simply provide the opportunity for learners to be autonomous. The approach can be counter-productive if learners lack appropriate skills or self-confidence or if they prefer traditional instruction. Raidal & Volet (2009) reported that students in formal education had been found to preliminarily need support and guidance for learning in the form of teacher-directed activities, so that they can become more self-directed over time. Likewise, Silen & Uhlin (2009) noted that becoming a self-directed learner is a learning process, and there is a strong need for teachers to take part in facilitating that learning. Teachers play a critical role in effectively promoting individual SDL development both through their instructional choices and their interactions with students. Studies by Douglass & Morris (2014) showed that while students acknowledged much of their learning was within their control, they did note that faculty do have a significant impact on their desire and ability to learn. Noteworthy are clear and relevant grading criteria, use of real-world cases or scenarios, and enthusiasm displayed by the faculty.

Hattie (2003) noted that besides students themselves, teachers are the second most important persons that can make large impact in student learning attainment. In the context of self-directed learning, Hiemstra (2013) suggested that many teachers employ traditional teacher-directed approaches because their views of behaviourism, often modelled after their own teachers and their own experiences as learners, are seen as the best method. Granted, indeed there are some teachers who still truly believe that their role is to "tell" students the knowledge they need to know.

Teachers also play an important role to equip students to become more self-directed. Grow's (1991) proposed Staged Self-Directed Learning (SSDL) Model (Table 1) suggest the evolution of the teacher's role to support students as they develop self-directedness.

Table 1. Grow’s 4-Stage SSDL Model

Stage	Student	Teacher	Examples
1	Dependent	Authority, Coach	Coaching with immediate feedback. Drill. Informational lecture. Overcoming deficiencies and resistance.
2	Interested	Motivator, Guide	Inspiring lecture plus guided discussion. Goal setting and learning strategies.
3	Involved	Facilitator	Discussion facilitated by teacher who participates as equal. Seminar. Group projects.
4	Self-directed	Consultant, Delegator	Internship, dissertation, individual work or self-directed study-group.

Another important reason why the role of teachers is important is that the capacity for self-directed learning have general components; and some are domain-specific and bound to the socio-material context (Candy, 1991). Some domain knowledge is necessary for learners to be able to take responsibility for their own learning (Bolhuis, 2003). The ability to learn in one domain cannot simply be transplanted to another. Knowledge domains have their own networks of meaning such as problem statements, concepts and rules that are expressed in a partly domain-specific language. Access to this knowledge is the main difference between experts and novices in a knowledge domain. An individual’s learning potential depends on expertise in the learning domain in three ways:

1. being knowledgeable of the problem statements and procedures of knowledge acquisition (i.e. knowing what and how to learn) in the domain
2. having access to a relevant knowledge base to build on
3. being motivated to learn in the domain; motivation to learn is domain-specific

The progression from novice to expert includes development of three interacting aspects: learning to learn, knowledge base and motivation. When competence in a domain increases, the learner begins to develop his or her own domain related goals, chooses and employs more strategies and shows increasing ability to operate independently (Bolhuis, 2003). It is therefore important to scaffold the learning process in such a way that the scaffolding and support are gradually faded over time. The key challenge is to balance the amount of scaffold and support against the needs of students, especially in a case whereby different students are at different stages of SDL-readiness. Azevedo et al (2004) suggested the use “adaptive scaffolding” which involved a delicate balance of providing support while continuing to foster a student’s own self-regulatory behavior during learning (e.g. planning, setting learning goals, and monitoring their emerging understanding). This necessitates the teacher to continuously diagnose students’ emerging understanding and provide timely support during the learning process. Francom (2010) offered the following suggestions to develop students’ SDL:

- match the level of self-directed learning required to learner readiness
- progress from teacher to learner direction of learning over time
- support the acquisition of subject matter knowledge and learner self-direction together
- have learners practice self-directed learning in the context of learning tasks

Teacher Modelling and Self-Directed Learning: Approaches

Since learning is a complex process influenced by a wide range of factors, and that “observational learning is an integral part of human development” (Bandura & Walters, 1963), Bandura, based on his social learning theory (Bandura, 1977) suggests that observation and modelling can play a fundamental role in the learning process. For Bandura, learning takes place in a social setting via observation. Such learning also involved cognitive processes, as learner internalise and make sense of what they see in order to reproduce the behaviour themselves. Jung (1986) suggested that an alternative formulation of the concept of role model emphasises the motivational, as opposed to the learning, function of role models.

Likewise, Gibbons (2002) noted that modelling is one of the ways to engage and motivate students to engage in self-directed learning. The teacher should be a model of the process – one who is committed to it and is actively employing it. Whenever a teacher demonstrates a concept for a student for example, when a math teacher works through a problem on the board, he or she is actually modelling how the problem is solved (Haston, 2007). Modelling is also used in numerous educational settings, particularly with performing ensembles, and interestingly, in art and design education (Groenendijk, et al, 2013). Role modelling is widely accepted as a highly influential teaching and learning method in medical education (Sutkin, et al, 2008). Teacher modelling is also a common element identified across academic reading programs, one of which is sustained silent reading (Methe & Hintze, 2003). Their study showed that teacher modelling of the process is effective in increasing student engagement.

When used appropriately, teacher modelling for student imitation is a useful tool. Student learning is enhanced when teachers verbalise their thought processes while simultaneously engaging students in learning activities. Cognitive thoughts normally not seen are now observable, and shown through the teacher's actions. Modelling can also be used as a scaffolding technique, where the teacher first model the task for students, and then students begin the assigned task and work through the task on their own.

From our literature review, there appear to be a dearth of studies on how teacher's classroom behaviours affect students' propensities towards self-directed learning. What we found are mostly studies related to more general aspects of teacher competency and behaviours, classroom management skills, etc., and the impact on student learning. We will not delve too much into these factors. Noteworthy to highlight is the work of Blazar & Kraft (2017), who reported that teachers who are effective at improving test scores often are not equally effective at improving students' attitudes and behaviours. Suffice to note that their study investigated the impact of "teacher effects" (which the authors explained as the "relationships between teaching practice and student outcomes") and the outcomes of self-reported self-efficacy in math, happiness in class, and behavior in class. Their results showed that teachers can and do help students develop attitudes and behaviours that are important for success in life.

Bandura (1977) suggested that the status of the model has a great influence on whether this person will be taken as a model or not. A "high-status" model can positively affect the perceived importance of an activity and can bring about a desirable behavioural response more readily by providing the observer with on-going visual feedback compared to a "low-status" model. Shahmohammadi (2014), in a study on importance of teachers' role in creating self-regulative behaviours in students, reported that the students' self-regulation has to a high extent correlates with the teacher's educational and social behaviours. The teacher's model and his/her respect toward the students' character encourages them in an effective self-regulation. In addition, the teacher's effort in explaining the lesson content is significant in increasing students' interest in self-regulation. In another study, albeit more limited in scope as it focused on classroom incivilities (and not related to students' self-regulation of learning), Stork & Hartley (2003) reported that students' perceptions about professors' behaviours generally fall into two domains: his/her competence and interest; and respect for the individualism of students. In addition, to further enhance students' modelling of teacher behaviour, Dynan et al (2008) proposed that a structured learning environment be employed. In a structured learning environment, students were given explicit and detailed instructions for completing each of their assignments and semester projects. In other words, their ability to self-define their work was intentionally limited. Students were asked specific questions related to their work each week. Their results showed that structure match enhances SDL skills and that courses designed to enhance students' readiness for SDL can do so.

OUR WORK DONE IN TEACHING SDL VIA TEACHER MODELLING

We used the model of student engagement as proposed by Bandura – that learning involved four different stages: (1) attention, (2) retention, (3) reproduction and (4) motivation (Horsburgh & Ippolito, 2018). The first stage is attention where learners need to be attentive to the behaviour to be learnt. They need to be able to see the behaviour that they want to reproduce or that others want them to reproduce. The second stage requires learners to internalise and retain what they have seen. This involves cognitive processes in which a learner mentally rehearses the behaviour or actions that are to be reproduced. In the third stage, learners need the opportunity to reproduce the modelled behaviour by converting the information obtained from attention and retention processes into action. Finally, in the fourth stage, learners need to be motivated to continue to imitate the behaviour they have observed.

Our earlier works on SDL since AY 2018 were already reported in past CDIO Conferences (see Wong, et al, 2021; Cheah, 2020; and Cheah, et al (2019). Very briefly, we introduced SDL into the module *Laboratory and Process Skills 2* offered to all DCHE students in Year 1, Semester 2. This module was designed to transition students from the more familiar laboratory work settings (i.e. laboratory skills) to the chemical plant work setting (i.e. process skills). SDL, and good thinking heuristics such as metacognition (CDIO Syllabus sub-categories 2.4.4 and 2.4.5) using Sale's Model of Thinking (Sale & Cheah, 2011), were explicitly taught in Week 1 of the module, and emphasised throughout all 10 activities (4 hours duration each) in the module. This allowed students to simultaneously learn, within the same activities, disciplinary knowledge in chemical engineering together with thinking skills and SDL skills to become more self-directed (i.e. CDIO Standard 7 Integrated Learning Experiences).

Studies showed that intentional curriculum design can potentially impact students' self-directed readiness and competence (Kraznow & Hyland, 2016). To deliberately introduce teacher modelling into the learning tasks, we focused on one of the integrated learning experiences centred on connecting laboratory skills to process skills based on the common set of chemical engineering principles, namely that on investigation on the use of sensible heat versus latent heat for heating/cooling applications (use of cold water or ice to lower the temperature of warm water). More specifically, we expanded the learning duration from one session to two consecutive sessions. This was made possible in an already-compact curriculum by removing another learning activity. We now have two 4-hour sessions in a 2-week period to firstly model SDL behaviour to students in the first session on how to use the SDL model in tackling the given tasks by verbalising the thought process through a series of "talk-aloud" questions. Students fill in a workbook (CDIO Standard 8 Active Learning) that we had prepared to scaffold the learning process, so that the thought processes of a self-directed learner are made explicit to students.

In the second session, and under observation by the lecturers, students use the same approach to complete similar tasks, with additional challenges to assess their understanding of the concepts learnt in the first session. More specifically, students now had to deal with binary liquid mixture (salt solution simulating seawater) instead of pure substance (pure water) used in the first session. Feedback was provided where needed as part of formative assessment, and students submit a group report on their work done along with a reflection journal on their learning experience (CDIO Standard 11 Learning Assessment).

The learning tasks were piloted in October 2020 for AY 2020/2021 and are summarised:

- Determine the different types of heat involved by measuring the thermal energies transferred when warm water is cooled using pure cold water versus using ice.
- Compare and contrast the relative merits of using ice versus cold water for cooling applications.
- Use the results to analyse the case of heating using superheated steam versus saturated steam, and investigate if there will be potential cost savings when heating using one type of steam versus the other.
- Repeat the same task to determine the thermal energies transferred when warm water is cooled using cold salt solution versus using ice.
- Relate the difference to the changes in properties (related to cooling) when binary liquid mixture is used instead of pure liquid.
- Use available resources to put together a cooling medium that is more effective than cold water, but easier to transport than ice.
- Extend learning to a case study simulating real-world application of using treated water versus seawater for industrial cooling application.

A short survey was conducted for 106 students to find out they were able to learn how to be more self-directed based on our attempt in modelling the thought process.

DISCUSSION OF FINDINGS, REFLECTIONS AND IDEAS FOR MOVING AHEAD

Results show that students agree or strongly agree that they were able to model the behaviour of a self-directed learner by planning (92.5%), referring to previously learnt knowledge (89.6%), monitoring and evaluating their work (86.8%) and seeking help from friends when needed (91.5%). We postulate that this can be due to the close similarities in the tasks given in the two sessions (P2 or practical 2 is the first session, and P3 or practical 3 is the second session) which allowed students to replicate the process fairly easily. Indeed, the following quotes from two students are quite typical of the responses obtained:

> *“After doing P2, I think I am able to do P3 really fast as they are similar experiments so I don't need more guidance and support.”*

> *“As P2 was very much similar to P3, thus when I fully understand P2 which I have already carried out. I would then be able to understand P3 much better and would be able to carry out the experiment more smoothly.”*

We are encouraged to find our attempt for lecturers to model SDL through verbalisation of the thought process using questions appeared to help students understand and apply SDL skills to tasks, at least for these two sessions. The second session also gave students another opportunity to reproduce the behaviour of a self-directed learner. Some students shared that:

> *“The rundown on how the model was used was crucial in bridging the gap between understanding and using it practically.”*

“There were a lot of questions in P2 which were guiding us and explaining in detail what each step is actually about, allowing me to understand more about SDL and I am then able to apply it to P3.”

“there were alot (sic) of questions to be filled up asking about my metacognition and thinking. and i could model the approach of being self directed in p3 by thinking and reflecting by referring back to what i wrote and reflected on what went wrong”

“… … Reflecting on the data and how it was derived helped to push me to research more on the variables that have to be taken note in an experiment. This meant that future calculation would be more accurate.”

“In practical 2, whenever I’m in doubt I will ask my group members. However in practical 3 I have learnt to ask myself questions and think in-depth to the question before asking my group members”

On the other hand, we still have students who wanted more guidance:

“I still need help thinking deeply on why is this the case etc.”

“We wish we knew more about the theory behind the procedure because at hat (sic) point we have not learned anything about it yet.”

More than half the students surveyed indicated that they were unable to manage their emotions. 52.8% agree or strongly agree that they get frustrated easily when they were unable to find the information needed or answer the questions.

Our findings may be due to the students’ grasp of domain knowledge (academic ability) which may have a correlation to their readiness to be self-directed, and how much they can relate their own competence level to the model’s (the lecturer).

Students who are academically stronger will naturally be more ready to take control of their own learning as they will struggle less to make sense of what they are learning, and therefore more confident to perform the learning task (Van Woezik, et al., 2019; Weimer, 2015). Since learning through modelling requires one to observe, follow through the process and make sense what is to be learnt, this approach can be challenging for learners if the model is unable to “break down” the information to the learner’s level of competency while modelling. When that happens, the traditional direct instructional approach where one simply needs to do what they have been told may be more beneficial to these learners. This observation is echoed by Gronenendijk, et al (2013), Braaksma, et al (2002) and Zimmerman & Kitsantas (2002). Gronenendijk, et al (2013) found that students who were naturally creative benefitted more from observing and self-verbalising the designing process and products compared to students with lower creativity levels. Braaksma, et al (2002) reported in their study of learners learning to write that writers who were weaker learn more from a writer model who was not as competent in writing while the converse is true for stronger writers. Similarly, Zimmerman & Kitsantas (2002) found college students performed better when they learn from a model who improved over time compared to a model who was fully competent at the beginning.

To our students, the lecturer is considered a mastery model. Therefore, students who seemed to have learnt more effectively to be self-directed, as shown from their responses, could have been those that are stronger academically. Academically weaker students may have found the lecturer's thought process challenging to follow and rationalise due to insufficient underpinning knowledge. As such, use of differentiated questions while modelling how to be self-directed or personalise guidance during learning may be one way to provide support to all students to learn to be self-directed. To do so, we will need to find out the students' academic abilities, and their baseline SDL-readiness levels. The former can be determined based on their grade point average (GPA) while the latter requires the use of a measurement instrument such as Personal Responsibility Orientation Self-Directed Learning Scale (PRO-SDLS) (Stockdale, 2003) to measure students' SDL readiness.

We are also mindful that these results, being all self-reported responses, may not provide a complete picture of whether students had become more self-directed since there is a likelihood for learners to to misjudge their own skill levels (Saks & Leijen, 2013). However, since self-reporting measures is still the dominant approach to evaluate self-directedness of learners in the literature, we will continue to use it and will triangulate with other evidence sources, such as knowledge transfer to perform tasks in other non-skill based modules.

Finally, we ourselves are not perfect as models. Models should be technically competent in knowledge and skills in their domain area but also adept and passionate in transferring this knowledge and skills to all students (Cruess, et al, 2008). Our teaching team may not yet have sufficient expertise to be able to effectively teach SDL through teacher modelling, and some of them may be in fact not comfortable doing so. There is henceforth a need for professional development in modelling SDL (CDIO Standard 9 Enhancement of Faculty Competence) as well as in designing integrated learning experiences and/or active learning lessons using workbook (CDIO Standard 10 Enhancement of Faculty Teaching Competence).

CONCLUSION

The overt teaching and intentional integration of SDL into a curriculum is a promising way to develop self-directed learners - findings from our 3-year longitudinal study indicated that students are able to attain SDL competency, but to varying levels. To further improve the teaching of SDL, we turned to the use of teacher modelling. In this pilot study, we found that most students seemed able to understand and independently replicate the modelled behaviour when asked to in a new yet similar context, but there are still some who requested for more guidance. In view of this, we plan to enhance the teaching of SDL via modelling by providing differentiated instructions during the modelling process based on their comprehension of domain knowledge required for the task, and readiness to be self-directed.

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HIGHER EDUCATION THESIS SUPERVISION - A NEW, HYBRID SUPERVISORY MODEL

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ABSTRACT

One of the final courses, if not the last course at university level in Sweden, and especially within the engineering programs, is a thesis course where the students demonstrate their accumulated knowledge and skills. One, or sometimes two students, identifies a topic of interest within his/her main field of study and is guided through the process by a supervisor. Preferably the supervisor has a lot of experience, both within the main field of study and as a thesis supervisor. Many times, however, the latter is not always the case. Hence, some form of recording of the supervisory process would be of importance, to be able to assess the supervisory competence of the supervisor. Through this recording, potential weak supervisory spots can be identified, and a special focus could be put on these.

In literature several supervisory models have been proposed over the years. The goal of this paper is to demonstrate, through a case study, how three of these models can be successfully combined to a hybrid model around the supervisory process building on grounded theory. A combination of the three models together identifies the individual supervisory process of a thesis supervisor. An analysis is then performed, and weak spots in the supervisory process of a novice supervisor can thus be identified and addressed. The results presented in this paper are based on a case where an experienced thesis supervisor was observed during a supervisory session. Hence, the case forms a baseline of what a “good” supervisory session looks like. By applying the hybrid supervisory model on a novice thesis supervisor, possible weaknesses in the process can be identified.

As both students and teachers are involved in a one-to-one teaching-learning activity during the thesis process, CDIO standards such as number 8 (active learning) is important from the students’ point-of-view, but especially standard number 10 (enhancement of faculty teaching competence) is of high importance as the competence of the novice supervisor, or the lack thereof, becomes evident and can be appropriately addressed through especially designed activities.

KEYWORDS

Student attitude change, Supervisory dialogue, Supervisory model, Supervisory management styles, Thesis supervision, Standards: 8, 10

INTRODUCTION

The student learning process at higher education is gradual and commences with students acquiring basic knowledge, competences, and skills within their specific main field of study through single, but interrelated, courses. Theoretical knowledge in the form of lectures is combined with practical skills in the form of, for example, laboratories, problem-based learning, or capstone projects. At the end of their studies, Swedish university students are faced with a professional thesis work where they need to demonstrate their acquired and accumulated abilities, ending with an oral presentation and a written report. The thesis work per se is usually realized by one or two students embarking a specific topic within their main field of study during the last semester where they, together with a supervisor, step-by-step and through multiple meetings reach a final goal that should comply with some predefined qualitative and quantitative criteria. The process towards the final goal is iterative and is highly influenced by the competence of the thesis supervisor. The thesis work is also the last opportunity for the students to acquire new knowledge, competences, and skills, on top of what they have already learned.

One of the main goals of a thesis on undergraduate, graduate, or postgraduate level, is for the student to acquire a set of skills in the trade of realizing a scientific work and present the results, both orally and in writing. These skills can be *discipline-specific*, for example, learning about graph theory or English 1900-century poets, or *generic*, for example, learning about scientific writing or time management (Mejtoft and Vesterberg, 2017) Related to these specific and generic skills are so called *conceptual threshold levels* that need to be crossed (Kiley and Wisker, 2009; Meyer and Land, 2003; Wisker and Kiley, 2018). After having crossed a conceptual threshold, a student is able to approach his/her specific theme with a new set of eyes. The characteristic stages and dimensions of conceptual threshold crossing accordingly to Wisker (2012) are:

- Liminality (stuck places and movements through)
- Praxis (integration of concepts and action, change)
- Dialogue (discourse of subject and research, dialogue between ideas and practice, people)
- Ontology (identity/identities, being in the world)
- Epistemology (knowledge-contribution to meaning)

The five stages, except for one, are solely in the hands of the student, meaning that the student needs to be in control of his/her own learning and be able to pass the thresholds on his/her own behalf. The exception being “dialogue”, where the supervisor has a one-to-one relation with the student. This is the main reason why supervisory meetings are of such importance to the student’s learning process during the progress of the thesis work. If correctly handled, the other four conceptual threshold crossing stages can be observed by the supervisor and adequately addressed during the recurring supervisory meetings.

The supervisor-supervisee process is complex and has been investigated and described by many researchers using so called supervisory models. This paper presents a composite supervisory model based on three supervisory models, that is, *supervisory management styles* (Gatfield and Alpert, 2002), *supervisory dialogues* (Wisker, 2012), and *student attitude change* (Aronson et al., 2010). Its usefulness is evaluated through the analysis of a realized supervisor-supervisee meeting during which both the experienced supervisor and the supervisees demonstrate a behavior that is well captured in the hybrid supervisory model. Applying the model during the evaluation of novice supervisors, their strengths and shortcomings as a supervisor become evident which means that especially adapted supervisory training activities can be developed and applied to increase the expertise of the novice supervisors.

The rest of this paper is divided in five sections. First, the research methodology applied in this paper is outlined. The second section describes the practical arrangements of the case of the analyzed supervisory meeting. Next, the theoretical background that the work is based on is presented. The three supervisory models that together constitute the composite supervisory model are presented. The fourth section examines the analysis of the composite supervisory model when applied to the supervisory case and the results from this analysis. The fifth and final section presents some conclusions of the work and argues why the hybrid supervisory model should be used by novice thesis supervisors to identify their shortcomings, or strengths, as supervisors.

METHODOLOGY

The research method applied in the work presented in this paper consists of a modified form of grounded theory (Glaser, 1992). In this paper it implies that a new theory is developed as a combination of previously developed theories and an analysis of the compiled data (that is, the sentences from the recording collected during the observation of the supervisory meeting and the coding of these). The presented grounded theory is inherently abductive (Reichertz, 2007) meaning that the observation data was first transcribed and coded (the inductive part) followed by a comparison with previously developed theories, the fitting of the transcribed texts within the theories (so called core categories) and the development of a new theory (the deductive part). The grounded theory process applied during the work presented in this paper consisted mainly of the following steps: (1) theory collection → (2) hypothesis formulation → (3) data collection → (4) data analysis → (5) theory building → (6) theory validation.

ANALYZED CASE

The results presented in this paper are based on the observations of a supervisory meeting on undergraduate level that lasted 30 minutes. Two computer engineering students realized a thesis work during a semester and the specific meeting took place relatively early in the supervisory process. The purpose of this paper is to demonstrate how changes in the supervisory style of an experienced thesis supervisor were captured by a composite supervisory model and how such recorded changes can be used by novice thesis supervisors to detect possible weaknesses in their supervisory process.

In continuation are presented the initial discussions with the supervisor before the supervisory meeting (pre-supervision), the observations during the supervisory meeting between the supervisor and the supervisees (observation) and the brief summing up after the supervisory meeting (post-supervision).

Pre-supervision

Before the supervisory meeting, the background of the supervisor was investigated. The supervisor was an associate professor at the Computer Science and Informatics department at Jönköping University who since 1999 had supervised some 50 theses at bachelor and master level. The supervisor considered himself to be more of the supportive type of supervisor, trying not to influence on the students' work too much. Based on the conceptual model by

Gatfield and Alpert (2002) (see Figure 1), the supervisor categorized his supervision style as being *contractual*, which implies the following:

- high structure and high support
- student highly motivated and able to take direction and to act on own initiative
- supervisor able to administer direction and exercises good management skills and interpersonal relationships
- most demanding in terms of supervisor time

Whenever possible, the supervisor sought to act both as a buddy and as a mentor, but it depended on how structured and dedicated he found the students to be towards the thesis work. Before meeting with a student for the first time, the supervisor prepared himself by trying to straighten out the problem picture of the thesis and to foresee the student's expectations on the meeting. When having to choose between the product of the thesis, that is, the quality of the written thesis report, or the process, that is, the student learning how to produce a quality report, the supervisor considered the process to be the most important, even though most students put their main interest in the observable part of the thesis, that is, the final report. Summing up, the five most important competences of a good supervisor, accordingly to the supervisor that participated in this work, are:

- scientifically knowledgeable (Hallberg et al., 2012)
- experience from similar development/research work (Love and Street, 1998; Philips and Pugh, 1994; Wisker, 2012)
- skilled at writing reports (Hallberg et al., 2012; Tynjälä, 2001)
- provides constructive critics (Philips and Pugh, 1994; Wisker, 2012)
- sees the bigger picture within a thesis (Adams et al., 2015)

Observation

The specific observation consisted of two students at bachelor level. According to the supervisor, the students were lagging in their thesis work. The meeting took place in a special meeting room and lasted 30 minutes. Both students talked during the session but one more than the other, where the less talkative student took notes on his computer. At the very start, the students put forward that they wanted to switch two sections in the report, but the supervisor explained that this would make the report lose in coherence. The learning process was also stressed in the initial stage of the meeting where the supervisor explained that the students had so far made a journey where they had learned about how and when to apply the methods they had previously chosen. After this "high-level" questions the discussion changed focus on more detailed aspects, but the supervisor never let the students lose the big picture of their work or get lost in intricate details.

Post-supervision

According to the supervisor, the students seemed to assimilate most of the comments made during the meeting. Nonetheless, the experience of the supervisor was that students often do not achieve this. Hence, he applied a method known as SWOT where he estimates the risk (of failure) at a given stage or situation during the thesis process by evaluating the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T) of the thesis work. He then takes preparatory actions based on the result from the risk estimation. This seems a reasonable method that through the reactive analysis of a supervisory meeting proactively prepares for the next meeting.

THEORETICAL BACKGROUND

The following section presents the theoretical background of three different supervisory models that have been applied during the supervisory meeting, namely *supervisory management styles, supervisory dialogues,* and *student attitude change*.

Supervisory management styles

The analysis that is undertaken in continuation is based on the supervisory management styles model by Gatfield and Alpert (2002) (also touched upon by Wisker, 2012). To create the model, the authors conducted a literature review including some 60 significant scholarly items related to Ph.D. supervision. The review made it possible to establish an array of variables that were deemed significant to the supervisory process at doctoral level. The authors identified some 80 elements that were deemed significant, which were further clustered into eight groups. Each of the eight groups were factored according to whether they were classified as *structural*, *support* or *exogenous*.

The *structural* factor was defined as those elements supplied principally by the supervisor in negotiation with the student. They are generally directive aspects and incorporate the variable groups of the organizational process, the accountability stages and skills provision. The elements of this factor assist in the management process of the thesis. (Structural examples: setting stages and goals, negotiated meetings or time management).

The *support* factor was defined as those elements supplied by the institution and supervisor that are non-directive, optional and discretionary. These include variables that can be grouped into areas such as pastoral care, material requirements, financial needs, and technical support. (Support examples: mentoring or positive feedback).

The *exogenous* factor does not contain neither structural nor support variables as the variables are relatively fixed. (Exogenous examples: organizational skills, interpersonal skills). The third factor was thus not incorporated into the model defined by Gatfield and Alpert. The result is illustrated in Figure 1. To make it easier to follow the transitions between the different supervisory management styles and how they are related to the observations made during the supervision meeting described further on, the different quadrants and the corresponding texts in the coming tables are marked using different shades.

The graphical representation of the supervisory management styles model consists of four quadrants, each representing a specific supervisory style. The supervisory styles and some related characteristics are outlined in Table 1. The contractual quadrant seems to be where most supervisors like to place themselves, according to results by Gatfield and Alpert (2002). Out of 12 interviewed supervisors, 9 were considered contractual while one was pastoral, one laissez-faire and one directorial. Gatfield noticed that the adoption of a preferred supervisory style was not defined solely by the supervisor's personal style or goals but was also influenced by the student's attitudes, the type and level of the thesis work, where in the process the thesis work currently was situated, etc. (Gatfield, 2005).

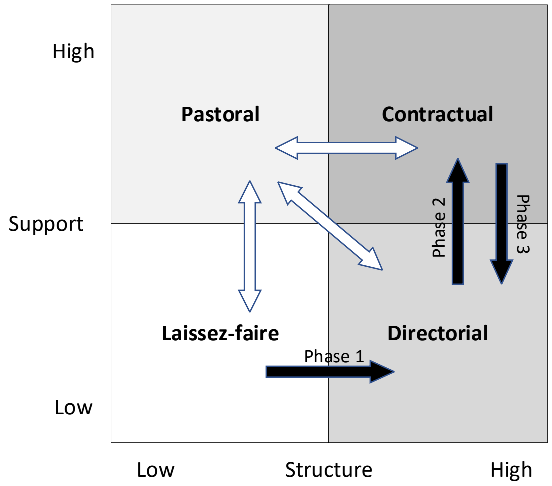

Figure 1. Supervisory management styles model and changes over time, Gatfield and Alpert (2002)

In their study, Gatfield and Alpert (2002) also noticed that the supervisory style changed over time (Figure 1, where the black arrows indicate different phases in a supervisory meeting while the white arrows indicate situations when a potential need for the supervisor to temporarily engage in the pastoral supervisory style is required which may occur at times of crisis, discouragement, or frustration on the part of the student). At the beginning of a supervision session, students generally have a limited focus and often search very broadly for a gap in the literature to discover a thesis topic. This usually involves very little structure and limited support, hence the term laissez-faire style. As the students advance, the thesis subject, research domain, and research questions usually evolve. In that situation the supervisor generally moves into offering more structure to aid in formally assisting the creation of the research design and aiding the methodological development.

Table 1. Characteristics of supervisory management styles, Gatfield and Alpert (2002)

Style	Structure	Observations
Laissez-faire	Low structure Low support	**Supervisee** has limited levels of motivation and management skills
		Supervisor is non-directive and not committed to high levels of personal interaction
		Supervisor may appear uncaring and uninvolved
Pastoral	Low structure High support	**Supervisee** has personal low management skills but takes advantage of all the support facilities that are on offer
		Supervisor provides considerable personal care and support but not necessarily in a task-driven directive capacity
Directorial	High structure Low support	**Supervisee** highly motivated and sees the necessity to take advantage of engaging in high structural activities such as setting objectives, completing, and submitting work on time on own initiative without taking advantage of institutional support
		Supervisor has a close and regular interactive relationship with the candidate, but avoids non-task issues
Contractual	High structure High support	**Supervisee** highly motivated and able to take direction and to act on own initiative
		Supervisor able to administer direction and exercises, good management skills and interpersonal relationships

Hence, the directorial supervision style becomes predominant. Next, the movement is towards the contractual quadrant. In this situation, most likely, the students will be engaged in data collection and analysis. In this phase, 'high' levels of support and 'high' levels of structure are most likely to be required from the supervisor. However, as the students move into the writing stage, that situation is not likely to continue. The students will possibly have reduced needs of support and yet still have high needs of structure. Hence, the supervisory style will occasionally move back to the directorial position.

Supervisory dialogues

In the book, the Good Supervisor (Wisker, 2012), chapter 8 (Supervisory dialogues), Wisker presents a set of supervisory questioning themes, or dialogues, divided into 11 intervention categories (from the supervisor's point-of-view). These are outlined in Table 2. The dialogues in the table constitute examples of situations when a supervisor interacts with a student. When, where, and how to use the different category dialogues depends on the supervisor, the type of student, when and where in the thesis process the dialogue takes place, and so forth. Thus, it is up to the supervisor to decide when to apply a specific category. An unexperienced supervisor possibly needs to be consciously aware of the need to change between the categories while an experienced supervisor, on the other hand, does this intuitively.

Table 2. Characteristics of supervisory dialogues, slightly modified from Wisker (2012)

Category	Supervisor	Dialogues
Tension-relieving	Relaxes	• Oh no! Not more of those bar charts! • How are you fitting all these interviews into your busy holiday schedule? • Is your daughter well?
Informative	Provides (straightforward information)	• It needs to be referenced - using the Harvard system. • Ramsden and Entwistle would be good researchers to follow up here.
Didactic	Teaches	• The abstract should be only 500 words and you must ensure it is concise clear, accessible to your examiners. • Look at these models and try to produce a draft version following one of them.
Prescriptive	Prescribes (a solution)	• No, don't cut the results part away from the discussion and interpretation. They need to be woven together.
Confronting Challenging	Provokes	• Really, how do you think you are going to access this sample • You have not yet made a realistic suggestion - there could be problems - how will you tackle them • The statistics so far just don't answer your question. You need to re-design the research for the next phase. • The results seem to suggest a contradiction to your hypothesis - what does that suggest for your theories and next steps.
Eliciting	Draws forth	• If you wanted to observe the children, how might you do this without affecting their behavior? • Could you just explore what these different interview categories suggest in terms of your argument about disclosure? What could happen next?

Category	Supervisor	Dialogues
Supporting	Encourages	• This is an impressive participation rate. • The work is going well, you have responded critically and evaluatively to the results of your interviews and fed these into changes in your proposal. Good.
Encouraging Facilitating	Drives	• I see you have written about how Virginia Woolf engages with inner thoughts. Is this just a formal experiment in your view, or is she saying something about self, experience, and the ways we perceive and express it? • You have shown how widening participation agendas appear in government documents and in university mission statements. Do you perceive any contradictions, paradoxes or problems with the equally popular comments about fee payments?
Summarizing	Condensates	• It seems you have found a range of themes here and have analyzed and discussed them according to the categories you have developed. • So, as you argue, Lacan's mirror phase is challenged from a feminist perspective by Kristeva's essays as quoted in your second chapter ...
Clarifying	Arguments	• Are you arguing, from your results in the two classrooms you observed, that it seems girls are more likely to tidy up than boys'? If so, you probably need to … • I'm not sure what you are saying here about the effectiveness of that procedure on re-growing coral - could you revisit the data and then explicitly link it to your argument? • What do you mean here by the term postcolonialism? Is it (a) in opposition to the colonial, or (b) after the colonial?
Collegial exchange	Invites	• This is a fascinating argument - have you looked at the work of Lave and Wenger on communities of practice, because it's absolutely central to what you are saying here. • 'There's a conference on the Gothic coming up in Liverpool in the summer - had you thought of giving a paper' • Yes, this is the same kind of result I came up with after running the experiment 12 times - what did you do to get over that problem about the water filter?

Student attitude change

The main responsible for a thesis, and the correct and timely development of it, is always the student. Hence, if a student has a negative attitude towards the thesis work from the very beginning, the effects could be detrimental to the thesis, and it is (mainly) up to the student to take notice of this and shift attitude. Ellis (2008) claims that attitudes influence learning. Attitude should not be confused with (lack of) motivation; while motivation is defined as those factors which influence behavior and give it direction based on underlying needs, Ajzen and Fishbein (1980) describe attitude as a learned predisposition to respond in a consistently favorable (or unfavorable) manner with respect to a given object. This suggests that learners' attitudes can be formed as a direct result of the conditions which exist within the teaching and learning environment. Hence, the supervisor can and must assist the student to take control of his/her learning process. This could be accomplished by positively influencing the student's cognitively based attitudes, for example, by making the student aware of the positive progress in the development of the report, and the student's affectively based attitudes, for example, by making the student feel positive about research work, both practically and theoretically (Aronson et al., 2010). The student attitude changes are strongly related to the supervisory management styles model and the supervisory dialogue model (see Table 3).

ANALYSIS AND RESULTS

The following section presents some reflections of the supervisory meeting that consequently led to the construction of the hybrid supervisory model. The results when applying the model are also outlined.

Supervisory style-dialogue-attitude observations

In the following section the observations during the supervision meeting are presented. Based on the analysis of the results, presented in continuation, and the strong resemblance between the models of Gatfield and Alpert, Wisker, and Aronson et al., a composite supervisory model was conceived (Table 3). The model was consequently validated applying the captured dialogues from the observed meeting.

The supervisory meeting lasted for 30 minutes, and it was possible to clearly distinguish three different main supervisory styles (Table 4). During the initial 18 minutes, between 19 and 24 minutes and between 25 and 30 minutes. During the 30 minutes, nine distinct discussions (marked Discussion 1 through 9 in continuation) could be observed. The students' questions and observations are presented as well as the supervisor's answers (minute 0-18) and questions (minute 19-30). The numbers in the table indicate the identified supervisory style-dialogue-attitude patterns (see Table 3). All texts were translated from Swedish to English, and some are presented in a condensed form.

Supervisory management style changes

Five phases could be observed during the supervisory meeting, each representing either a specific supervisory management style or a transition between different styles (Figure 2).

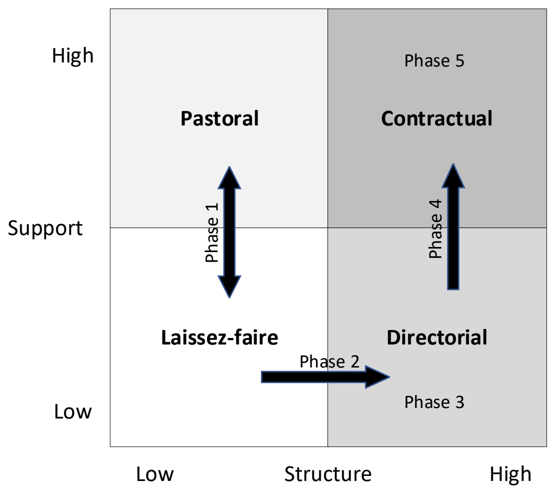

Figure 2. Five distinct supervision phases during the observed supervisory meeting

Table 3. Supervisory style-dialogue-attitude relations

#	Supervisory	Dialogue category	Student attitude change
L1	Laissez-faire	Tension-relieving	Cognitively based attitudes (weak evidence → strong evidence) Affectively based attitudes (weak evidence → strong evidence)
L2		Informative	
P3	Pastoral	Didactive	
P4		Prescriptive	
P5		Confronting and challenging	
D6	Directorial	Eliciting	
D7		Supporting	
D8		Encouraging and facilitating	
C9	Contractual	Summarizing	
C10		Clarifying	
C11		Collegial exchange	

- phase 1: The meeting started with discussions in the *pastoral* sector but moved between the *pastoral* sector and *laissez-faire* sector during the first 18 minutes of the meeting (that is, during Discussion 1, 2, 3 and 4)
- phase 2: After 18 minutes, the meeting style moved to the *directorial* sector
- phase 3: During minute 19 to 24, the discussions mainly had a *directorial* style (that is, during Discussion 5 and 6)
- phase 4: After 24 minutes, the meeting style moved to the *contractual* sector
- phase 5: During minute 25 to 30, the discussions mainly had a *contractual* style (that is, during Discussion 7 and 8)
- the meeting ended with a tension-reliever, thus moving back to the *laissez-faire* sector (that is, during Discussion 9)

The *discipline-specific* and *generic* conceptual thresholds that were touched upon during the supervisory meeting were:

- to understand the *content and place* of the various parts in the thesis report. (generic concept)
- to explain about *machine learning* and what is *technically possible* to achieve with a specific machine learning algorithm. (discipline-specific concept)
- how to perform *data collection* and the *preprocessing* of the input data to the machine learning algorithms. (discipline-specific concept)
- to understand the *relation* between the *expectations* of the project and the *achievable/attainable goals*. (generic and discipline-specific concept)

Table 4. Supervisory style-dialogue-attitude observations

0 – 18 minutes	
Discussion 1	
Students '*We want to move the theory section before the method section*.'	
Supervisor '*I have thought about that, and I don't think it's a good idea!*'	**P4**
Supervisor '*What you need is a section after the theory section where you describe how you have applied your methods.*'	**P3**
Supervisor '*The important thing is to describe the travel, the different choices that you have made.*'	**P4**
Supervisor '*You don't always write the theory section in a chronological order, in my point-of-view.*'	**L2**
Discussion 2	
Students '*What we have done can be backed up by theory.*'	
Supervisor '*Yep!*'	**L1**
Discussion 3	
Students '*Should we go into details in the algorithms, or … ?*'	
Supervisor '*No, you don't have to do that. What I mean is that the theory section is something that supports your work, things that we needed as well as the readers, to be able to understand.*'	**P4**
Supervisor '*But at the same time, it is necessary to have a "tree" of concepts.*'	**P3**
Supervisor *You need to think about the introduction section and the purpose of it as it often briefly introduces important terms.*'	**L2**
Supervisor '*You also need to refine your research questions to make the readers and examiner understand them.*'	**L2**
Discussion 4	
Students '*In other words, we can provide an overview of machine-learning and what it is used for?*'	
Supervisor '*Yep!*'	**L1**

19 – 24 minutes	
Discussion 5	
Supervisor '*Have you had time to look into related work?*'	**D6**
Supervisor '*It is important to describe what already exist.*'	**L2**
Supervisor '*Have you received any feedback from the company and are they happy with your results so far?*'	**D6**
Discussion 6	
Supervisor '*The information that you received from the company, was it structured?*'	**D6**
Supervisor '*Have you thought more about how to handle the input data?*'	**D6**

25 – 30 minutes	
Discussion 7	
Supervisor '*If you could motivate that it is impossible to realize (impossibility result), that would be an important contribution.*'	**C10**
Discussion 8	
Supervisor '*Could you imagine other types of input data, apart from the information that you already have?*'	**C10**
Discussion 9	
Supervisor '*How is the time plan for the remainder of your thesis work?*'	**L1**

The main problem when trying to observe the crossing of a conceptual threshold is that it is a process that occurs almost entirely in the head of a student, and it is mostly demonstrated *indirectly* through the quality of the results presented in the thesis report or from the answers provided by the supervisees during the presentation of the thesis. On occasions, though, an experienced and observant supervisor can *directly* detect a change in the students' behavior, reactions, body language or answers during a supervisory meeting, for example through expressions such as "ahaa" or "now I get it". The goal of the presented hybrid supervisory model is to alleviate the expectations put on a novice supervisor by making visible the potential shortcomings as a thesis supervisor.

DISCUSSION

As can be observed, the supervisory styles of the experienced supervisor moved from *pastoral* and *laissez-faire* (0-18 minutes), to mainly *directorial* (19-24 minutes) and ending as being predominantly *contractual* (25-30 minutes). The analysis of the supervisory meeting made it clear that the changes between the different supervisory styles happen on three different time scales: (1) very slowly, as the initial mindset (or attitudes, as described by Aronson et al., 2010) of students and supervisors change over time and the progress of the thesis, (2) slowly, between different meetings, as different stages in the thesis process require different supervisory styles (as described by Gatfield and Alpert, 2002), and (3) continuously during a single supervisory meeting, as the meeting progresses (as observed during the supervisory meeting). For an unexperienced supervisor, the changes in style would appear to be random and sometimes erratic, while for an experienced supervisor the changes would be planned or even realized on a subconscious level. The analysis also clearly demonstrated that the observed experienced supervisor started the meeting (0-18 minutes) having the students presenting their questions and resolving their doubts and ended the meeting (19-30 minutes) asking questions to the students forcing them to think differently on their work.

Regarding the students' attitudes, after having analyzed the recording of the supervisory meeting, it became evident that during the first 18 minutes the supervisor managed to fortify the students' *cognitively based attitudes*, by answering their questions (*laissez-faire* style supervision; *weak evidence* of improved *cognitively based attitudes*, and *pastoral* style supervision; *strong evidence* of improved *cognitively based attitudes*). After that, during the remaining 12 minutes, the supervisor managed, to some degree, to boost the students' *affectively based attitudes*, by asking relatively simple questions (*directorial* style supervision; *weak evidence* of improved *affectively based attitudes*) and by asking deep level questions (*contractual* style supervision; *strong evidence* of improved *affectively based attitudes*). As can be observed, it is usually more productive for a supervisor to ask (deep) questions, to make the students reflect, than to only answer the students' questions.

CONCLUSIONS

The purpose of the presented hybrid supervisory model is to make visible the progress of a single supervisory meeting and indirectly substantiate the quality of it. By repeating this process during various continuous supervisory meetings, a pattern can be identified. If handled correctly and in a structured fashion, a supervisor can graphically and textually establish his/her individual process as a supervisor as well as identify potential shortcomings. The identified shortcomings can consequently be addressed through directed supervisor training activities, either realized by the individual supervisor himself/herself or through planned and effected university activities. The hypothesis developed during the grounded theory building is that by analyzing several different supervisors during supervisory sessions, including both novice and experienced supervisors, and without having any external interference from the observers, it is possible to identify "good" and "bad" supervisory behaviors. The extension of this hypothesis should be further investigated in future research.

The supervisory process presented in this paper should only be regarded as an example of how the supervisory model could be applied. Still, the presented example illustrates the supervisory process of an experienced supervisor and could thus be looked upon as a good example of possible formulations applied during a supervisory meeting for the supervisees to progress in their thesis work process. By addressing standard 10 (through individual or university supervisory training activities), standard 8 will indirectly be addressed as well (through better implemented advanced student learning-activities).

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BIOGRAPHICAL INFORMATION

Anders Adlemo is an Associate Professor at the Department of Computer Science and Informatics within the School of Engineering at Jönköping University. He is involved in teaching at undergraduate and graduate level as well as doing research. In relation to teaching he received funding to develop and evaluate a new, hybrid supervisory model. His research has a focus on fuzzy logic solutions applied to a number of application domains related to decision-making, especially manufacturing relocation decisions.

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LOCAL RESILIENCE STRATEGIES FOR COVID19 – A PBL ENGINEERING CASE STUDY

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ABSTRACT

The increasing relevance of uncertainty and complexity provides ongoing and future challenges for engineers. Subsequently, engineers require competencies such as systems thinking, judgement and decision-making in the face of uncertainty or complex problem solving as part of their education. Already, these are part of e.g. the ABET and EUR-ACE standards and the CDIO syllabus. This aligns with emerging trends in engineering education, such as student-centred, active learning and problem-project-based learning (PBL). The aim of this paper is to present a seminar teaching concept and to examine to what extent scenario planning combined with active, PBL and collaborative learning can enable engineering students to develop resilience strategies. Here, resilience describes a system's ability to cope with sudden disturbances by adapting and learning, and resilience strategies represent the ability to design such resilient systems. Based on theoretical concepts of resilience, students had to apply these to a concrete and current problem. Following a PBL approach, an open and ill-defined problem was the starting point for a scenario planning project, where the students had to develop a resilience strategy with regard to the COVID-19 pandemic at a local level. The seminar aimed at developing competencies in resilience thinking and systems thinking. Findings showed that the teaching concept successfully enhanced especially these competencies which are characterized by a high level of complexity, such as reflection, analysis and assessment of resilience-related issues.

KEYWORDS

Resilience, Complexity, Scenario Planning, PBL, Active Learning, Standards: 8, 11

INTRODUCTION

Dealing with uncertainty and complexity are important challenges for engineers in the 21st century (Crawley et al., 2014; Goldberg, Somerville, & Whitney, 2019; Hadgraft & Kolmos, 2020). This requires new competencies such as analysis with uncertainty, dealing with complexity, judgement and decision-making in the face of uncertainty or systems thinking. These are already part of the ABET (2021) or EUR-ACE (2021) accreditation guidelines, but in particular in the CDIO syllabus, referring to 2.1–2.5 (Crawley et al., 2011). However, highly complex or chaotic problems, such as learning from past disasters, are seldom part of engineering curricula (Hadgraft & Kolmos, 2020) and there are shortcomings in terms of awareness of how to deal with and learn from failure (Edmondson & Sherratt, 2022; Goldberg et al., 2019; Pearson et al., 2018). Moreover, studies with engineering students showed that there is little knowledge and understanding about topics such as resilient infrastructures or risk management within their education (Chittoori et al., 2020; Contreras et al., 2020; Rokooei, Vahedifard, & Belay, 2022). Therefore, education needs to better embed the concept of resilience (Kharrazi, Kudo, & Allasiw, 2018; Pearson et al., 2018).

In the summer term of 2021, the seminar "Resilience and socio-technical systems" for engineers in the master's degree programmes in environmental engineering, civil engineering and industrial engineering was used to examine the extent to which student-centred learning approaches, as described in CDIO standard 8, enable students to design resilient systems. Based on the research on the concepts of resilience and different learning strategies, such as active learning and PBL, this paper shows to what extent a scenario analysis combined with an exploratory and collaborative learning approach can enable engineering students to develop resilience strategies on a local level. The teaching concept as well as the students' results are presented and discussed with regard to the learning outcomes.

RESILIENT SYSTEMS

Interdisciplinary and proactive solutions are required to deal with increasing extreme weather events, climate change and urbanization, but also the current pandemic. These need to go beyond safety or risk management which are mainly based on reactive approaches (Hollnagel, 2014; Levin et al., 2021; Park et al., 2013). Therefore, new infrastructures have to be created (informational, social and built), which increase preparedness and response to extreme events (Levin et al., 2021). Here, the concept of resilience applies, which refers to the adaptive capacity of systems or individuals to deal with sudden (unknown) disturbances or disasters. This becomes particularly relevant with regard to complex social-ecological systems, e.g., urban areas, which are based on many interactions of people and the environment (Berkes, 2017). In general, social-ecological resilient systems are characterized by the ability to absorb shocks and stresses, self-organization, learning and adaptation (Carpenter et al., 2001; Folke, 2006). In the face of extreme events, no matter what kind, an effective and adaptive governance with feedback learning and systems thinking is needed (Berkes, 2017; Carpenter et al., 2012; Levin et al., 2021). Moreover, there is evidence that flexible and adaptive processes to local needs build resilience, instead of rigid approaches with fixed procedures (Levin et al., 2021). In general, adaptive governance and adaptive management refer to ongoing problem-solving processes, which prioritize communication, collaboration, learning and adaptive strategies for moving forward (Berkes, 2017). Accordingly, learning from failure is a very important ability when considering resilience.

Dealing with uncertainty and complexity as well as designing resilient systems require corresponding competencies and especially a different way of thinking, which is described as "resilience thinking" (Folke, 2006; Walker & Salt, 2006). Competencies which go along with resilience are for example analysis with uncertainty, dealing with complexity, judgement and decision-making in the face of uncertainty or systems thinking (Francis & Bekera, 2014; Winkens & Leicht-Scholten, 2021). However, there have been few studies on teaching resilience and its underlying concepts and applications (Kharrazi et al., 2018; Plummer, 2010). These can be found especially in the field of environmental education, where Krasny and colleagues (2016; 2009) have been pioneers with regard to the connections between resilience and environmental education (Kharrazi et al., 2018; Plummer, 2010). According to Lundholm and Plummer (2010), education contributes to enabling the building of adaptive capacity regarding the resilience of social-ecological systems. Moreover, the integration of resilience in education can enhancing problem-solving and systems thinking competencies among students by critically analyzing systems' performance. With regard to the relevance of the abovementioned adaptive governance, there are several examples of inadequate educational practices, which mainly focus on students only studying established governance best practices, instead of enabling students to critically assess and maybe change these "best practices" (Nielsen & Havbro Faber, 2021). According to Nielson & Faber (2021), this is, for example, the case in governmental focus on the recovery phase after disruptive events, whereas rather a holistic and system perspective over longer time horizons is required.

However, it is crucial to consider the context in which resilience should be applied and how the concept is used, as resilience has various levels of meanings (Carpenter et al., 2001; Plummer, 2010). For doing so, at first, it has to be clearly defined resilience in terms of what to what and for whom (Carpenter et al., 2001; Meerow, Newell, & Stults, 2016). This makes it complex to teach and to integrate into the learning process. For this purpose, innovative teaching approaches are needed, such as active learning, collaborative learning and problem- and project-based learning (PBL) (Ban et al., 2015; Fazey, 2010). These emerging approaches are also used more often in engineering education (Hadgraft & Kolmos, 2020) and applied within the presented course.

TEACHING CONCEPT

Learning Outcomes and Course Description

The seminar “Resilience and socio-technical systems” takes place annually in summer semester and addresses master students of the study programs environmental engineering, civil engineering and industrial engineering at RWTH Aachen University. The course offers an introduction to current discourses on resilience. Starting with the definition and origin of the term resilience, various interpretations and interdisciplinary approaches are discussed and applied. In the summer 2021, the focus was placed on the current COVID-19 pandemic. This served as a case study to develop a local resilience strategy, thereby gaining competencies in resilience thinking and systems thinking.

Following constructive alignment and Bloom’s taxonomy, intended learning outcomes at course-level (see Table 1) as well as at lesson-level were formulated beforehand (Biggs & Tang, 2011; Bloom, 1956). Contents, teaching concept and assessment were derived from this (Biggs & Tang, 2011; Malmqvist, Edström, & Rosén, 2020).

Table 1. Intended learning outcomes at course-level

Level of Complexity	Taxonomy	Learning Outcomes
↑	Creating	Students develop local resilience-based approaches with regard to the COVID-19 pandemic.
	Evaluating	Students reflect on resilience-oriented approaches and ways of thinking in their future work as engineers. Moreover, they reflect on the relevance of resilience-oriented approaches to local and global crises.
	Analyzing	Students analyze different scenarios with regard to their resilience effects. They assess existing crisis management approaches regarding their resilience potential, especially using the COVID-19 pandemic as an example.
	Applying	Students apply resilience-oriented approaches to practice-related decisions.
	Understanding	Students outline, compare and contrast different interdisciplinary discourses regarding the concept of resilience. They understand the relevance of crises in the 21st century.
	Remembering	Students define resilience with its various conceptions.

Based on the intended learning outcomes, the course was divided into five topics with their respective problem statements. The selected topics were always related to the COVID-19 pandemic, as this was chosen as a concrete case for this semester:

Crises, disasters and shocks: Why do we have to be sensitized for global risks? Which global risks are increasing regarding their likelihood and impact? Students had to prepare this session by writing on a Miro board what resilience means to them in order to get an insight about their prior knowledge and associations with regard to resilience. Moreover, in this session, different disasters were presented regarding their different aspects of failure, such as the tsunami in 2004 or the Fukushima nuclear disaster.

Resilience and risk: How are resilience and risk related? How can risks be classified? How can resilience of systems be assessed? The concept of resilience was explained to the students, especially with regard to the misunderstandings that accompany it (Kharrazi et al., 2018; Walker, 2020). Furthermore, different types of risks were presented and the focus was placed on unknown risks, such as black swans.

Resilience Engineering: Which technical systems can fail? What relevance does this have for engineers? Students had to prepare this session by reading Park et al. (2013) in order to reflect on the relevance and responsibility of engineers with regard to the failure of technical systems. Based on Hollnagel (2014) relevant abilities of resilient engineering systems were discussed.

Urban resilience: What is the relevance of resilience for urban systems? What challenges does this entail? In terms of the practical application of the resilience concept, urban systems are particularly well suited for this. Based on the studies by Cariolet et al. (2019) and Meerow et al. (2016), the students had to discuss aspects to consider in a resilience assessment for different urban sectors, such as water and energy supply, IT and communication as well as logistics and transport.

Resilience Thinking: How do people perceive risks? What challenges does this pose for resilience? The last session dealt with individual resilience thinking and risk perception. Students had to reflect on their own resilience with regard to dealing with crises as well as their own biases in dealing with probabilities and risk perception. This was done with a special focus on the risk perception regarding COVID-19 (see Dryhurst et al., 2020) and a discussion about the risk communication in Germany.

Active Learning

The course is based on active and problem-based learning combined with collaborative learning, referring to CDIO standard 8 (Malmqvist et al., 2020). By applying active learning, students are required to engage in the learning process and actively reflect on what they are doing, which has shown to positively effect learning outcomes and students' performance (Felder & Brent, 2016; Freeman et al., 2014; Malmqvist et al., 2020; Prince, 2004; Prince & Felder, 2006).

Individual sessions were based on think-pair-share, as this includes individual thinking and therefore leads to greater learning (Felder & Brent, 2016). For doing so, students had to prepare the sessions by reading a paper on their own with a specific question assigned to them. In class, they had to discuss the results together with others. At the end, the group results were presented to the plenary. As the course was conducted online, the group work was organized in breakout sessions using a creative mind mapping tool. In addition, further discussion questions and challenges were posed in the individual sessions, which sometimes had to be answered in the course, others again in small group work by sharing their responses afterwards. This enabled a continuous exchange among students, gaining insights into other perspectives and opinions.

Students were able to voluntarily submit a critical reflection related to each session, which improved the overall grade. However, only a few students made use of this, which is why they are not listed and evaluated here any further.

Problem-based Learning

PBL is a teaching method to engage active learning, which is based on problem orientation and is used to provide the context and motivation for the following learning (Edström & Kolmos, 2014; Prince, 2004). Following a PBL approach, a complex, open-ended and ill-defined real-world problem was the starting point for the course, which was based on a given case. The previously described learning content should guide students to use the provided material, methods and concepts relating to resilience strategies, which promote students' motivation and comprehension (de Graaff & Kolmos, 2003; Prince & Felder, 2006). As there are different PBL practices at the course level, which was studied in a literature review by Chen et al. (2021), the current problem fits both to project-led PBL and PBL for practical capabilities. Furthermore, this could also be framed as challenge-based learning according to Malmqvist et al. (2015). The duration of the course was one semester and students had to work in groups of five. The collaborative team-based learning is important, as the learning process is a social one, where students not only learn from each other, but they also gain competencies in teamwork, communication and collaboration (Edström & Kolmos, 2014). The level of achievement of the intended learning outcomes was assessed via team reports and presentation as well as peer assessment.

Students received the assignment and the case at the beginning of the semester and were able to work on it during the course. During the semester, the students had the opportunity to be advised, ask questions and receive feedback on their previous work.

Case Study

As students should learn resilience and systems thinking by applying scenario planning, an open ill-defined problem is required (Edström & Kolmos, 2014; Jonassen, 2000). Thereby, the COVID-19 pandemic was chosen as a case in order to refer to a current and real-world problem. Within the case, students had the task of developing a local resilience strategy, referring to an adaptive governance, explained in the background section (see Box 1). Thereby, they had to assume the role of a crisis team that is to advise municipal policy. For this, they had to take on different citizen stakeholder perspectives, such as students, service sector employees or nurses. At the same time, the students were given different unknowns to deal with it. For example, it was unclear whether a new (fictitious) mutation of the coronavirus could be transmitted via drinking water. Moreover, some requirements of the governance were given on which students critically had to reflect on regarding their relevance for resilience.

Note that the case is based on the German regulations that were valid during the COVID-19 pandemic. The case was developed in March 2021, the seminar started in April. At that time, tightening measures, such as lockdowns, were linked to incidence, which were set out in a phased plan (see CoronaSchVO, 2021).

Scenario Planning

As it is important for engineers to be able to identify the critical performance measures for a system and not just for a single aspect (Hadgraft & Kolmos, 2020), the task required them to set up different scenarios involving different local stakeholder groups.

Box 1. Case Description

It is May 2021. The third wave has flattened out, retail, outdoor dining, theatres and museums have reopened across the board. No more appointments or negative test results are required. Schools are back in attendance, with high school graduation exams to be written next week. However, a new mutant, R.E.S.21, has recently been discovered in California that is three times more contagious and it is foreseeable that the situation will worsen drastically again in a very short time. It is possible that the new mutation can also be transmitted via groundwater. So far, there is no scientifically proven factual basis for this. More than 60% of the population have been vaccinated, but it is unclear whether the vaccination is effective against the new mutation. Here, too, there is still no scientific evidence.

The federal government has introduced the principle of subsidiarity, according to which the municipalities can decide completely autonomously which measures they take to cope with the crisis. According to the decision of the Federal Constitutional Court, municipalities can even intervene in the fundamental right as long as they are limited in time, purposeful and justified.

Within the framework of a newly appointed crisis team of the Aachen district, various actors meet to discuss the further course of action. In order to strengthen the involvement of the citizens, interest groups from different areas are included. They now have the task of jointly developing a strategy that will have a decisive influence on the next few months. The district will implement your strategy in any case. You will have to put yourself in other perspectives and think through different scenarios to achieve the best possible outcome for everyone.
The following actors are involved:

- two staff members of the Resilience Research Department (mandatory)
- three more stakeholders from different areas, e.g., one school representative of a grammar school, a retail salesperson, a caterer, a nurse etc.

(With the exception of the staff of the Department of Resilience Research, you can choose three other interest groups whose perspective you must represent consistently).

However, your discussions are unfortunately repeatedly interrupted by incoming calls from the City Region Council, which makes the following demands:

1. Every affected industry should receive financial support should you consider a lockdown again.
2. There should be a clear step-by-step plan at which incidence which measures should take effect.
3. It insists on face-to-face teaching and in-presence baccalaureate examinations.
4. an app should be developed, which should contain the functionalities of the Corona App as well as up-to-date information on local retail.
(Think about what you answer and what recommendations you make).

Basically: The focus is always and exclusively on Resilience Thinking! It is not about a medical impact analysis, accordingly, do not get lost in details of medical implications.

To enable resilience thinking among students, several authors recommend the use of scenario planning methods combined with theoretical foundations (Carpenter et al., 2012; Kharrazi et al., 2018). Scenario planning is a suitable method for enhancing creative, critical and systems thinking about possible complex and uncertain futures, based also on different interest groups (Amer, Daim, & Jetter, 2013; Peterson, Cumming, & Carpenter, 2003; van der Heijden, 2005): "In a situation of uncertainty planning becomes learning, which never stops" (van der Heijden, 2005, p. 16). By applying scenario planning the resilience of a system can be explored to various factors (Carpenter et al., 2012). Possible future alternatives are to be considered, which can help to deal with uncertainty. Moreover, it enables to critically question the future and which outcomes are desirable. Therefore, scenario planning provides a holistic perspective on a system with all its interactions and dependencies. Using this approach allows educators to illustrate different probable and yet undesirable futures (Amer et al., 2013; Kharrazi et al., 2018).

As described above, students were given both facts and unknowns. Thereby, students had to identify alternative possible solutions, which often can have different implications for resilience (Carpenter et al., 2012). This enables the students to better understand the dynamics of a system for deriving possible recommendations for action in order to enhance resilience.

RESULTS

Students had to prepare a recorded screencast, in which they present their results to the City Region Council. Here, too, they had to take on the role of the crisis team. To understand the learning process and the resilience strategy of the students in detail, a team report had to be handed in. There, the students had to justify their entire procedure and document the results from their group meetings. After submission, the students had time to view the screencasts of the other groups. In a discussion session, the individual group members were then mixed and tasked with evaluating the results of the other groups with regard to their resilience strategies. In total, four groups (1–4) of five students each submitted a screencast and a report.

The following assessment criteria were applied by the researcher: motivation by explaining the relevance of their resilience strategy, creativity (Did the students deviate from the given guidelines? Did they go beyond the visible reality?), argumentation (Do they justify their strategy? Are they able to convince the audience?), resilience thinking (Did they consider any resilience-related aspects, such as flexibility, worst case scenarios or learning? Is there any longer-term perspective for dealing with such crises?) and reflection (Did they reflect on their own work? What are the weaknesses of their strategy? What would they do differently next time?).

Case Results

The students' results were ambivalent. The work of groups 1 and 2 was overwhelming positive, as they developed a detailed, comprehensible and coherent resilience strategy. Their screencasts, i.e., the presentation for the City Council, were presented in a meaningful way, consistently considering the perspectives of the different stakeholders. Particularly noteworthy were the parts on the development process of the strategy, which show considerable reflection and engagement with the topic. Moreover, they made appropriate assumptions, either based on scientific literature given in the course or on further researched studies by the students. They considered resilience-related aspects, such as flexibility, redundancy, learning and monitoring and multidisciplinary thinking. The students clearly refuted the first two demands of the governance and argued based on resilience why those requirements are not in the sense of learning and flexibility. Both groups performed scenario planning in their work by identifying different alternative solutions with resulting implications for resilience.

Groups 3 and 4 show weaknesses regarding the abovementioned assessment criteria. Their scenarios were based on the chosen requirements of the governance, which characterizes a deductive process. Those were not explained or justified regarding the relevance for resilience or learning. Their strategies focused on robustness rather than resilience, as they did not consider any aspects of flexibility, learning or adaptive capacity. Here, partly, the starting point of their strategies can be considered as scenario planning, but in general they did not follow up on different alternatives and solutions. Furthermore, group 4 closely mirrored the real restrictions and regulations in Germany at that time, with only minor changes to parameters.

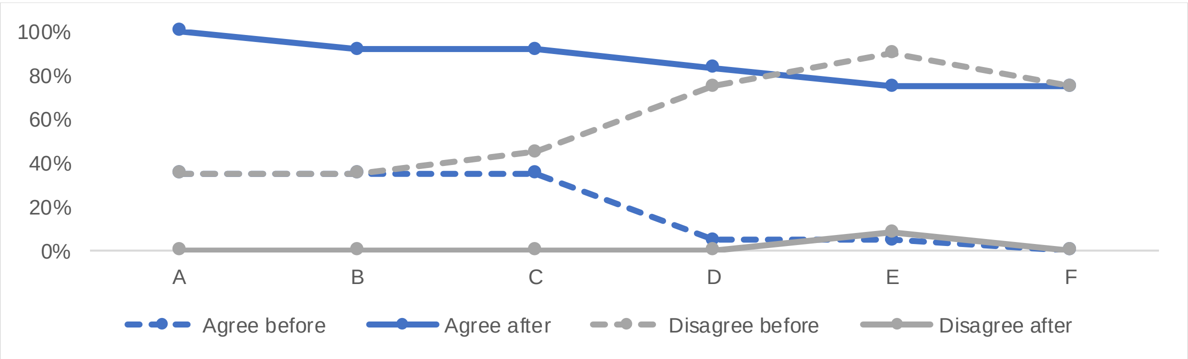
Peer-Assessment and Reflection

In the discussion session, students had to critically reflect on the work of the other groups. They had to discuss strengths and weaknesses of the individual resilience strategies. Moreover, after this session, they had the opportunity to integrate the discussed weaknesses in their final report in order to refine their strategy. Thereby, students not only learn about designing resilient systems, but also on an individual level about learning and learning from failure. By doing so, students could reflect on their learning process and consider what they would do differently.

The results of this peer-review session highlighted that there were significant discrepancies concerning the understanding of resilience. Groups 1 and 2, with a well thought out resilience approach, were criticised by their peers for not having adhered to the prescribed step-by-step plan. So even after having been confronted with resilience for a term, having been explicitly asked to challenge some of the underlying assumptions and being confronted with alternative viewpoints, there was still a deep aversion against deviating from what was seen as the established and expected approach. More so, groups 3 and 4 which primarily presented a robust and stable scenario without further justification did not take up the – justified – criticism in the subsequent reflection. However, the discussion showcased that a justified point of criticism for groups 1 and 2 was that they had not sufficiently thought through transparent (science) communication to the local population. This aspect was taken up and elaborated critically in the subsequent reflection in the report.

Self-Assessment and Learning Outcomes

To follow the CDIO standard 11, a self-assessment survey was conducted in order to measure the extent to which students achieved the intended learning outcomes (Malmqvist et al., 2020). Thereby, the previously targeted learning outcomes of the course were translated into a self-assessment survey for students to complete before the course started and at the end. Students were asked to self-assess (*strongly agree, agree, disagree, strongly disagree, neither*) the following competencies: *I know the concept of resilience and related methods, I understand the relevance of resilience with regard to global risks and crises, I understand the relevance of resilient systems for my work as an engineer, I am able to apply the concept of resilience to different situations, I am able to analyze scenarios with regard to their implications for resilience, I am able to evaluate existing crisis management approaches regarding their potential for resilience.*



A – Knowledge of resilience, methods and tools
B – Understanding the relevance of crises and global risks
C – Understanding the relevance of resilient systems for engineers
D – Applying the concept of resilience to different situations
E – Analyzing scenarios with regard to their implications for resilience
F – Assessing crisis management approaches regarding their resilience potential

Figure 1. Self-assessment results before and after the course

Figure 1 shows the results of the self-assessment before (n=20) and after (n=12) the course. The results are expressed by cumulative percentages of each (strongly) agree and (strongly) disagree. Evidently, after the course all percentages increased. Note that competencies D–F, which are based on a higher complexity level (see Table 1), are consistently rated lower before the course. Moreover, regarding those competencies, students perceive a stronger subjective improvement than at the lower levels A–C.

The results of the self-assessment are only of limited significance and not representative, as not all students completed the second survey and only students' perception is covered. However, the results display a trend concerning competences acquired through the course.

Evaluation

The evaluation of the course took place within the framework of a session in which the students were able to discuss the seminar concept and their acquired competences in groups. They were also asked to record what their personal key takeaways were. The respective results were recorded anonymously, whereby the students could decide which aspects they would discuss again in plenary.

The overall feedback was very positive. The understanding of resilience, dealing with uncertainty, self-reflection and collaborative working were highlighted. The relevance of adaptation and learning and the understanding of resilience as a continuous process were also mentioned. The students appreciated the systematic approach to non-technical problems and especially the topic of urban resilience was positively emphasized, as here concrete and practical case studies could be presented. Beyond urban resilience, however, they wished for more case studies in the other subject areas as well since resilience was understood as a very complex and partly abstract concept. Likewise, the students wished for more time for group work during the sessions. Overall, the feedback session confirmed the improvement of the self-assessed competencies which was surveyed.

DISCUSSION

Kharrazi et al. (2018) found several common misconceptions to the concept of resilience in education: value judgement, adaptability and trade-offs. These result on the one hand from various definitions in literature and the difficulty in measuring resilience and on the other hand from confusing it with the term of robustness and stability (Walker, 2020). Although these were all taken into account in the development of the teaching concept, the students' case results still show deficits, for example with regard to the scenario planning. As explained in the background section, it is crucial to always discuss the resilience of a precise system's function to a precise disturbance (Carpenter et al., 2001; Kharrazi et al., 2018). Moreover, adaptive governance is crucial to dealing with extreme events. In the frame of this course, students had the task to dive into the perspective of this governance. Thereby, students were enabled to critically assess and theoretically change the current COVID-19 management practices in Germany. However, students' results partly do not show detailed analysis of the system's performance. Instead, they concentrated more on stability and robustness.

At the same time, the opportunity to get feedback during the semester was only used by groups 1 and 2, which – perhaps correspondingly – produced strong results. Groups 3 and 4, whose results showed more weaknesses, did not make use of feedback opportunities. The option of supervising was not mandatory, as in PBL it is important that students are the owner of their learning process (Edström & Kolmos, 2014). In a similar pattern, the groups which were already performing very well used the feedback of their peers to further refine their concepts, whereas the weaker groups disregarded it. In summary, in this case study, voluntary feedback and learning opportunities served to further already strong work but had little effect of less well performing students and groups. This aligns with research about students' inability to benefit from assessment feedback by failing to make use of the offered feedback, as there is often a gap between receiving and acting on feedback (Evans, 2013). In future courses it should considered whether feedback sessions are to be mandatory, in an attempt to bridge the gap between achievement levels. As resilience and complexity are difficult to teach (Hadgraft & Kolmos, 2020; Kharrazi et al., 2018), a current, comprehensible and real problem was chosen as the case. However, it also cannot be ruled out that the COVID-19 pandemic, as an event that affects everyone personally. On the one hand, this might have made it difficult to have an objective perspective with regard to resilience perspectives and to break away from current regulations for some students. One the other hand, the case might have contributed to the motivation of the students – in some cases with excellent results.

The results of the self-assessment surveys show a positive trend regarding the development of the intended learning outcomes. The results indicate that especially competencies with a higher level of complexity with regards to resilience were not pronounced before taking the course. At the same time, these competences have developed the most through the course, which suggest a success of the active learning and PBL teaching approaches. However, the considered case presents only a single course. CDIO Standards 8 (Active Learning) and 11 (Learning Assessment) were implemented into the teaching concepts by using PBL. But, as stated by Hadgraft & Kolmos (2020), competencies such as complexity or systems thinking must be embedded in curricula in order to educate engineering students for this purpose. The students' results show that there is a need for enhancing their abilities to deal with complexity and uncertainty, especially in the context of resilience. As it is not possible to provide these abilities completely in a single course, a more systematic and holistic perspective on engineering curricula is required (Hadgraft & Kolmos, 2020; Pearson et al., 2018), which can be provided by a systematic implementation of the CDIO standards.

CONCLUSION

This paper shared the design and results of a student-centred teaching concept, based on active learning, PBL and collaborative learning. CDIO standards 8 (Active Learning) and 11 (Learning Assessment) were implemented by using a PBL approach. Implementing this teaching concept enhanced engineering students' competencies relating to complexity, uncertainty and systems thinking or more concisely: resilience. This is substantiated by students' self-assessment of competence acquisition during the course, whereby in particular those competencies, which refer to a higher complexity level, were marked as developed within the course. The results indicate that the teaching concept and the implementation of active learning and PBL were successful.

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QUALITY ASSURANCE IN ELECTRONICS-ICT ENGINEERING EDUCATION

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ABSTRACT

This paper outlines a system of internal quality assurance and its concomitant education support services for the teaching staff and study programme committee of the electronics-ICT engineering education at the faculty of Engineering and Architecture of Ghent University. Living up to the Ghent University credo 'Dare to Think', this system is a fully-fledged quality culture, in which all stakeholders naturally strive for continuous quality assurance as well as quality enhancement. It offers information on our study programme's unique selling points and on its strengths and weaknesses with regard to quality assurance.

Our study programme carries out annually a critical self-reflection on the following two features: programme-specific content and quality culture, meanwhile explicitly following the CDIO guidelines. The responsibility lies with our programme committee, also in charge of generating and cultivating the engagement of all relevant stakeholders: students, lecturing staff, professional field, alumni, international peers and experts. Since in the new system the programme-specific content plays a more important role, guidelines to facilitate embedding the external perspective are developed. Quality performance tools are essential to promote a qualitative and systematic reflection process. Therefore, an education monitor is used as a team site and document management system. A manageable set of programme-specific operational objectives have been integrated into this education monitor, are easy to assess and linked to the data made available through our business intelligence system. This education monitor is data-driven, with a proper dashboard function. In summary, the above-mentioned quality performance tools enable us to draw up an annual quality improvement plan. In this paper, all parts of the quality assurance system are described, supported by the CDIO standard programme evaluation.

KEYWORDS

Quality Assurance, Programme Evaluation, Standards: 1, 10, 12

INTRODUCTION

The improvement of quality by higher education institutions is not only important for the optimisation of the limited financial resources, but also as a responsibility of educating future professionals in a high-quality way. The electronics-ICT engineering study programme educates people who dare to think about tomorrow's challenges. In order to assure the quality, an attitude of data-driven critical reflection and systematic follow-up of improvement actions is installed. It consists of the implementation of monitoring instruments that will enhance quality reflection. This quality assurance system is built on four principles:

- trust in the expertise held by all courses of our study programme;
- shared ownership by facilitating and stimulating self-management. After all, all courses of our study programme are the principal engine for generating and monitoring quality;
- continuous improvement by furthering a positive quality culture, in which our study programme is stimulated to continuously improve (the quality of) our education;
- by offering a set of efficient 'quality performance tools', the existing quality assurance procedures is supported and policy-making is substantiated.

We focus on systematic quality reflection on our education policy. It is based on the PDCA-circle (Plan-Do-Check-Act) of Shewhart and Deming (1939): establishing objectives (Plan), carrying out them (Do), gathering data and results (Check) and improving the process (Act), restarting the entire circle. This reflection results in appropriate improvement measures on the level of individual lecturers and study programme (committee), augmenting the overall quality.

In this paper, the previous and the actual Ghent University system are described, followed by the implementation within the electronics-ICT study programme. A next section discusses the critical view by externals. The section thereafter handles the lessons learned on the implementation of this system on continuous quality culture. The last section finalises with the conclusions.

GHENT UNIVERSITY SYSTEM

In this section, the change in quality assurance and enhancement at Ghent University is described. We will start with a short description of the old system: portfolio, which is followed by an extensive description of the new system: education monitor, based on both a data-driven critical self-evaluation and a quality improvement plan.

Old System: Portfolio

For many years, the quality of higher education institutes was validated by accreditation bodies, organised by the Flemish government. The development of such accreditation bodies, national or international, tried to ensure that quality was in place. However, the focus was most of the time on quality assurance and not on feedback and putting important steps on improvement. Therefore, all participants saw this as an obliged process with a restricted outcome: a list of quality criteria obtained positive (or negative) checks, but with no indication for quality enhancement. It also resulted in lengthy documents including as much information as possible.

A decade ago the government transferred the quality assurance to the higher education institutes themselves. At that time Ghent University installed a different monitoring process: at study programme level, at faculty level and at the level of rectorate. The accreditation bodies remained responsible for checking if all higher education institutes were in control of all quality.

At that time, we used for every study programme a digital portfolio, as an online repository and giving a complete view on every aspect of the study programme. The main part was the description of the vision and operationalisation, as a translation of the different learning outcomes (Verhaevert & Van Torre, 2019). It also consisted of an overview of the continuous approach to assure quality within the own study programme. It also gave a description of the day-by-day processes and practices of the internal of the study programme. This digital portfolio formed the basis for peer learning visits by other study programme leaders. The focus was on the exchange of best practices across disciplinary boundaries and on learning from each other. The written report serves as a proof that the own institution is in control of the quality.

When implementing this system, also major drawbacks appeared: the evaluation of 55 processes and more than 100 indicators resulted in an unclear view and a too static instrument. Although the peer learning visits focused on learning from each other, the overall feeling was that scores by the peers in the written report resulted too much in window dressing and that the entire process was very time-consuming. Preparing the portfolio itself and writing a report afterwards take up a great deal of time.

New System: Education Monitor

Taking all the experiences above into account, a new Ghent University quality assurance system has been developed, called the education monitor. The focus is now on the systematic self-evaluation. It is based on the PDCA-principle, as an iterative management method used for continuous quality enhancement. First, opportunities are recognised (Plan), changes are tested (Do) and test results are analysed (Check) and, finally, actions are taken (Act) and it is started over again. It results in adequate improvement actions at different levels: the teacher, the study programme, the faculty and the higher education institute itself. All 4 levels are handled below.

- The teacher has an attitude to critically reflect on the own teaching and evaluation, based on the annual course feedback given by all students. In order to support and to encourage this reflection, several initiatives on further professionalisation are available (e.g. individual and classroom training offers, online tutorials...).
- The study programme performs at least annually a critical self-evaluation. The study programme takes the input of other stakeholders into account: students, lecturing staff, professional field, alumni, international peers and experts. The focus is on the check of the programme-specific content, based on a clear set of guidelines to facilitate the embedded external perspective.
  At the level of study programme, a set of 39 different operational objectives are defined. As a dashboard function, every objective is directly coupled with one or more inputs of the business intelligence system, making the education monitor entirely data-drive.
  To improve the quality and the systematic of this reflection process, some quality performance tools are used: the education monitor as a data-driven document management system, which is based on Microsoft SharePoint acting as dashboard. This monitor contains several small operational goals at study programme level. The business intelligence

system is entirely integrated in the education monitor. The entire self-reflection on a PDCA-cycle results in an annual quality improvement plan.

- The faculty is a key-player in the education support and the monitoring of the education quality assurance. At faculty level 28 operational objectives are defined and also here SharePoint is used (with coupling possibilities with the study programme monitors). The faculty board carries out an annual critical self-reflection based on a PDCA-cycle. Afterwards, a constructive consultation is held between faculty members and members of the rectorate. In that meeting feedback and feed-forward in both directions are discussed.

- The rectorate focuses on the attitude of an annual critical reflection, based on university-wide education policy, the general quality assurance culture and several operational goals. From a helicopter perspective, the quality assurance culture is monitored and secured. It is now based on trust and the focus is on having a clear view on the actual quality assurance and the ability of improvement, rather than a critical view of externals (which will be discussed further in this paper).

The whole process at all 4 levels results is visualised on a public web page. It describes the main strengths and weaknesses, opportunities and threats of each study programme, in combination with a realistic timing when the bottlenecks will be eliminated.

In the education monitor the study programme reflects on a regular basis all operational objectives: which objectives are acquired and which ones need to be improved. The education monitor consists of 3 major parts. In part one the study programme's vision, mission statement and context are commented. Here the learning outcomes, the curriculum and the assessment are monitored and if required, concrete improvement actions are scheduled. In part two the policy on quality assurance is discussed. Part 3 is for the Ghent University strategic education objectives, partly overlapping with parts 1 and 2. It contains the following university-wide objectives: 'Dare to Think' and 'Multiperspectivism', education based on excellent research, internationalisation of students and lecturers in the study programme, staff and student talent development and stakeholder participation. All items are analysed as a PDCA-cycle:

- Plan: For every item concrete objectives are established and described in order to deliver the required results.

- Do: The objectives described above are carried out, divided in several steps and described here.

- Check: In the Check phase, from the business intelligence system the most recent data, together with an evolution over the years, are directly fed into this lemma. If necessary, also own indicators can be added. It is followed by a reflection and evaluation on the obtained results, gathered from the Do phase. The result of every indicator is colour coded: red (insufficient), yellow (sufficient), green (good) and blue (excellent).

- Act: Depending on the obtained results in the Check phase, improvement actions are defined and followed up after different loops. It is in this phase that the overall quality of the study programme is improved, supported by the Do and Check phase above.

IMPLEMENTATION IN ELECTRONICS-ICT

The old system with the portfolio gave an entire intersection of the study programme: from vision to implementation, combined with the way the quality was assured. It resulted in a document of more than 100 pages. It was not only an extensive task to define the important parameters and to acquire all correct information, but it was also very time-consuming to keep the portfolio up-to-date. A rather small, but necessary change in the study programme resulted in changes in the portfolio on several places. The overall feeling was hence almost avoiding that change.

The education monitor as a new system of quality assurance was welcomed within the study programme Electronics-ICT. Microsoft SharePoint as a dashboard platform is more user-oriented, is more convenient and straightforward to change items and to keep track of all these changes. Because of the clustering of the different goals, less data is required. It results in a very focused and hence short set of documents, which is very convenient. It is also less time-consuming to write and keep up-to-date, compared to the former portfolio. The direct coupling with the Ghent University business intelligence system makes the education monitor truly data-driven and it is very obvious to include all relevant data to assure quality. Unfortunately there is no easy way to transfer the existing data from the portfolio to the education monitor. But we saw this fact as an opportunity to reorganise and to restructure all relevant information and to make everything more straightforward.

In order to start this process, the programme leader clustered all objectives in 6 different collections. Mixed working groups are formed: lecturing staff in charge of several courses (as core members) are put together with lecturing staff only teaching one course, with technical staff and students. The working group chair was selected/appointed to have a limited direct connection with the study programme, resulting in a fresh outsider view on the study programme. Every working group was asked to extensively discuss one collection of objectives. As input for the discussion the data (student and lecturer survey results, enrollment numbers...) from the Ghent University business intelligence system was used. The working group chair was asked to report by providing the required texts for the education monitor and to couple it via live links to the latest available data of the Ghent University business intelligence system.

All documents were discussed within the study programme committee, where all working group chairs and most of the core members were present. This resulted in a combination of documents giving a complete and correct helicopter view on the entire study programme. It also resulted in a quality improvement plan, combined with an accurate timing. Thanks to the implementation within Microsoft SharePoint, it is very convenient to extract relevant documents as input for a discussion.

Every year when new survey results and enrollment numbers are available, the education monitor needs to be updated. At the same time, the quality improvement plan with timing is also actualised: some items are in-control and can be checked, where some new items need to be added. The education monitor combined with the quality improvement plan acts as a dashboard for the education policy at study programme level and makes it very convenient to detect the strengths and weaknesses.

Table 1. CDIO Programme Evaluation

#	Standard	Score
1	Adoption of the principle that product, process, and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education	5/5
2	Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with programme goals and validated by programme stakeholders	5/5
3	A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills	4/5
4	An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills	4/5
5	A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level	5/5
6	Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning	5/5
7	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills	5/5
8	Teaching and learning based on active experiential learning methods	4/5
9	Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills	4/5
10	Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning	5/5
11	Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge	5/5
12	A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement	5/5

CDIO Programme Evaluation

The CDIO initiative also suggests a quality assurance and quality enhancement based on Standard 12 - Programme Evaluation. This Standard evaluates the study programme on 12 CDIO criteria and gives feedback to all stakeholders (faculty members, lecturing staff, students...) (Kontio, 2016).

When discussing the study programme and when filling the education monitor, we also performed a CDIO self-evaluation at the same time. The survey results available in our business intelligence system were very helpful and resulted in the scoring on the different CDIO standards as can be seen in Table 1 (CDIO Standards 2.0, 2022). All these standards gave us input for the discussion, while keeping the focus on enhancing the quality of the educational programme for the engineers of the future. In contrast, the education monitor - as a quality assurance system - is made available for many different study programmes of Ghent University and is indeed very general. Hence although the format is different, we can conclude that in the study programme of electronics-ICT engineering the same strengths and weaknesses appear, compared to the earlier described education monitor.

CRITICAL VIEW BY EXTERNALS

The self-evaluation described earlier in this paper is used in a learn-and-inspire way by an extensive and critical view by externals (Bennedsen & Schrey-Niemenmaa, 2016), (Kontio, 2016), including the broad community of engineering educators from around the world.

Within the CDIO framework a critical view by externals is not directly required or strongly encouraged. However, in the CDIO community experiences on improving engineering education are shared during e.g. international CDIO conferences. As is described in Clark, Thomson, Kontio, Roslöf, and Steinby (2016), Bennedsen and Schrey-Niemenmaa (2016), Kontio (2016), McCartan, Hermon, Georgsson, Björklund, and Pettersson (2016) and Rouvrais, Audunsson, Saemundsdottir, Landrac, and Lassudrie (2016), institutions of higher education are working closely to share all kinds of information of self-evaluation, cross-evaluation and critical friendship during site-visits focusing on enhancement of quality.

The goal of the set of actions accords with 3 different criteria:

- Each study programme checks the content component to the broad community of external stakeholders: the professional field, alumni and international peers. At least the learning objectives, the assessment and the exit level are analysed.
- The study programme committee discusses annually the programme-specific survey results of the professional field or other structurally involved stakeholders. Also the surveys of recently graduated students and alumni are reviewed by them.
- Every 4 years (or in the context of a curriculum revision) a programme review is carried out by at least 3 international, independent, academic peers as international authorities with a broad view on the study programme.

The different external stakeholders provide another perspective and expertise. Selecting them needs to be done carefully in order to obtain at the same time a broad and deep view:

- Regional versus international: the professional field combined with alumni mostly give an anchoring at regional level, whereas peers from other higher education institutes give an international view.
- Job market versus academia: the perspective on the job market is given by the professional field. They can import information on the employability and professional aptitude of the graduates, whereas academia members mostly focus on the academics.
- Feedback versus programme review: Collection of feedback in a structural way by the professional field and alumni is expected. In contrast, international experts are in charge of a thorough content-based programme review and of checking if the entire curriculum is sufficiently evidence-based.

For the critical view on the electronics-ICT curriculum by externals, we proposed the following:

- We established a committee with different external stakeholders. This advisory board contains all kinds of members from the professional field, mostly graduated several decades ago. They can draw attention on professional trends and on strengths and weaknesses of recently graduates. They meet annually and discuss one or more topics on quality assurance. We also organise an alumni event, where both alumni and advisory board members are present. There are presentations of the recent changes in the study programme and about an attractive and interesting topic by one of our graduates (e.g. the new DAB+ broadcast network in Flanders). All present lecturers and the advisory board members meet afterwards at a network reception for an informal chat. In the near future a more structural and formal survey is planned.
- Every master thesis in the electronics-ICT study programme is obliged to have a direct connection with the industry or non-profit organisation. It can be as follows: (partly) supervision by an industry member, advice for valorisation or evaluation, delivering use-case or data and/or as jury member for assessment. Students get hence acquainted with industry-relevant research questions and the study programme also acquires input of the professional competence and employability.
- Internships of students are partly supervised by an internal promotor and partly by an industry member as internship mentor. When assessing the tasks performed by the student, at the same time the skills of the student are evaluated (and hence the preliminary courses taken by that particular student). It gives us information about insurmountable substantive gaps within the study curriculum.
- Students going abroad and students from abroad provide us with interesting information about their stay. During an individual conversation direct information on good practices is made available. Also comparison between both study programmes can be instructive.
- The student survey results are also discussed in focus group sessions with a selection of the students that participated in that survey. It gives the opportunity to deepen the survey

results and to focus on particular topics of the open questions. We are obtaining in that way interesting and more nuanced information on the strengths and weaknesses of the study programme. For the bachelor programme focus group, the selection of voluntary master students is straightforward. Combining the focus group for the master programme is more challenging, because the graduates have their focus on their newly acquired jobs. However, when doing this immediately, during the study period or immediately afterwards and on a regular basis, it incorporates the tradition of quality assurance and an attitude of problem solving, as is described in Leander Zaar and Andersson (2020).

There are some ideas in the pipeline, waiting to be implemented:

- Evaluation of a selection of master thesis by international peers, during or directly after the student assessment.
- Dedicated parts of quality assurance are evaluated by international partners from a research project or during/afterwards an international congress. For instance: structural alignment of one set of courses or a selection of learning outcomes can be discussed.
- A (online) meeting with international peers to evaluate the complete study programme, sharing best-practices and improvement opportunities.
- The organisation of a fair with posters where students present (preliminary) master thesis results. Not only relatives are invited, but also externals from the industry. Afterwards a (online) survey or a focus group meeting with the industry members can be organised to keep track of essential trends in the industry.
- Also students - as directly involved partners - can have valuable and meaningful comments when discussing structural alignment and/or learning outcomes.

LESSONS LEARNED

The whole process was very fruitful for all participants. The formation of the different working groups (with a mixture of colleagues and students) resulted in groups with a broad and sometimes challenging and critical view on the study programme. Colleagues learned each other in another way. The discussions in the working groups and in the entire study programme committee brightened understanding of the strengths and weaknesses of our study programme.

Because all courses are taught in Dutch, also the education monitor had to be written in the same language. This is now a challenging opportunity for obtaining critical views by externals, and especially for finding international peers. Also although window dressing (during the visit of an accreditation body) disappeared and a more realistic view on the study programme is given by the education monitor, the threat is now that it has a certain level of non-commitment and a lack of obligation.

CONCLUSIONS

The quality assurance of the electronics-ICT study programme at Ghent University is in this paper discussed. After a period of visits by the accreditation body, the portfolio system was very time-consuming and it was challenging to keep the evaluation of 55 processes and more than 100 indicators up-to-date. In the new system, installing a quality culture is performed at 4 levels (teacher, study programme, faculty and rectorate). This education monitor offers important information of the study programme's unique selling points and its strengths and weaknesses with regard to quality assurance. For 29 operational objectives there is self-evaluation using the PDCA-cycle, based on survey and other results originated from the intelligence business system. The use of Microsoft SharePoint as document management system resulted almost automatically in a quality improvement plan, including both programme-specific content and quality culture, meanwhile explicitly following the CDIO guidelines. The self-evaluation is combined with a critical view by stakeholders. Working together as a group of teachers and students, all in charge of the quality improvement, resulted in ameliorated dynamics and interaction and - as we believe - in a high quality in our electronics-ICT study programme.

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BIOGRAPHICAL INFORMATION

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A CDIO-ORIENTED TECHNOLOGY PRODUCT DEVELOPMENT COURSE FOR ELECTRONIC ENGINEERING STUDENTS

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ABSTRACT

This paper describes a one-semester course, given to third-year Electrical and Electronic Engineering (EE) students at Shenkar College of Engineering, Design and Art, since 2011. The course was developed in accordance with CDIO standards. This integrative course is delivered by two co-teachers, one from the EE Department and the other from the Industrial Design Department. Each year a different topic is chosen for the course. Throughout the course, students plan, research, design, develop, implement, and present a product prototype. The prototype must be a physical and functional model that effectively communicates the proposed idea. Students are expected to use the tools and experience gained during course sessions, including basic aspects of industrial design and prototyping. The course provides an opportunity to implement both theoretical and practical knowledge acquired through previous EE core courses along with elements of industrial design. In the course, students integrate interdisciplinary knowledge elements to conceive, design, implement, and operate real-world systems and products. Looking forward, this active learning experience forms a basis for carrying out challenging capstone projects, and for future successful integration into the engineering industry.

KEYWORDS

Design Thinking, Engineering Problem Solving, Teamwork, Innovation, Industrial Design, Standards: 1, 2, 3, 5, 7, 8

INTRODUCTION

The typical engineering curriculum nowadays still consists, essentially, of a multitude of frontal lecture courses, augmented with a capstone project that is carried out during the last year of study. However, this way of knowledge transfer is insufficient: it is often too abstract, and in many cases, lacks on aspects of knowledge implementation. These limitations motivated the development of the CDIO framework some two decades ago (Crawley, Malmqvist, Lucas, & Brodeur, 2011). The CDIO approach emphasizes the importance of learning experiences where products that meet customer needs are developed through a process of conception, design, implementation, and operation (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014).

The current paper is about a CDIO-oriented course (module), named "Technological Product Development" (TPD) that was developed and is being taught in the Electrical and Electronic Engineering (EE), at Shenkar college in Israel, since 2011. The course is a single-semester, project based, interdisciplinary, knowledge-integrative course, guided together by two teachers- one from the EE department, the second from the Industrial Design (ID) department. As such, this concept (to be detailed below) is aligned with the institutional mission and vision at Shenkar College, in which engineering and design studies co-exist, with an aim to find joint areas of activity. In fact, the course was inspired by an annual Hackathon-like event at Shenkar, called MERKACHA (jam, in Hebrew), in which students and staff from the Engineering and Design departments collaborate on projects, within a specific, common, pre-defined theme, which changes each year. We have written about this Engineering-Design "fusion" event, and some of its implications on engineering education, in previous papers (Furman, & Weissman, 2019), (Furman, & Weissman, 2020).

The need for such a course, and its suitable position within the curricular flow of knowledge transfer, has become clear over the years of teaching engineering, EE in this case. As illustrated in Figure 1, the course follows several core EE courses, in which students accumulate theoretical knowledge in variety of subjects, particularly in electronics and coding. These courses are followed by a series of EE labs on various subjects, in which the main theoretical subjects are demonstrated in a pre-defined set of experiments, using a suitable dedicated lab equipment. Notably, these labs include subjects such as electronic circuits, communication techniques, micro-controllers, and others.

These courses and labs provide sufficient basis for building simple systems, but they often lack the provision of a wider context to the proper way to use the acquired knowledge in the process of developing these systems. Thus, it became clear that what was further needed is a project-based learning (PBL) course, at about midway of the study path (beginning of 3rd year), that would precede the capstone project, would provide context, and would interconnect the theoretical subjects with the practice of designing products. This is where the course discussed here fits in.

The product development process generally involves skills and competencies that are beyond the core topics of EE theory, so engineering education must fulfil many and varied tasks dictated by modern trends. For example, technological innovations, changes in business models, and changes in consumer habits require not only business trend awareness, but also innovative practices of self-management, time management, teamwork and problem solving (Eppinger, & Chitkara, 2007). Added to this is the transition from a traditional learning methods to an attitude of creativity, design, and planning of new alternatives (Zika-Viktorsson, & Ritzén, 2005). In addition, based on the various approaches on design thinking, common basic principles have been identified that successfully allow dealing with contexts such as: user focus, problem framing, visualization, experimentation, and presentation (Leavy, 2010). These additional skills and competencies, which are part of the CDIO syllabus (Crawley, Malmqvist, Lucas, & Brodeur, 2011), enable future graduates to be more competitive in the labor market. Studies on preparing engineering graduates for industrial careers appear often in the industrial and academic literature (Cerezo-Narváez, Bastante-Ceca, & Yagüe-Blanco, 2018). As shown in Figure 1, three additional competencies are reflected during the course: Acquaintance with principles of design thinking, b. development of soft skills, c. experiencing prototyping tools, particularly the use of 3D printing.

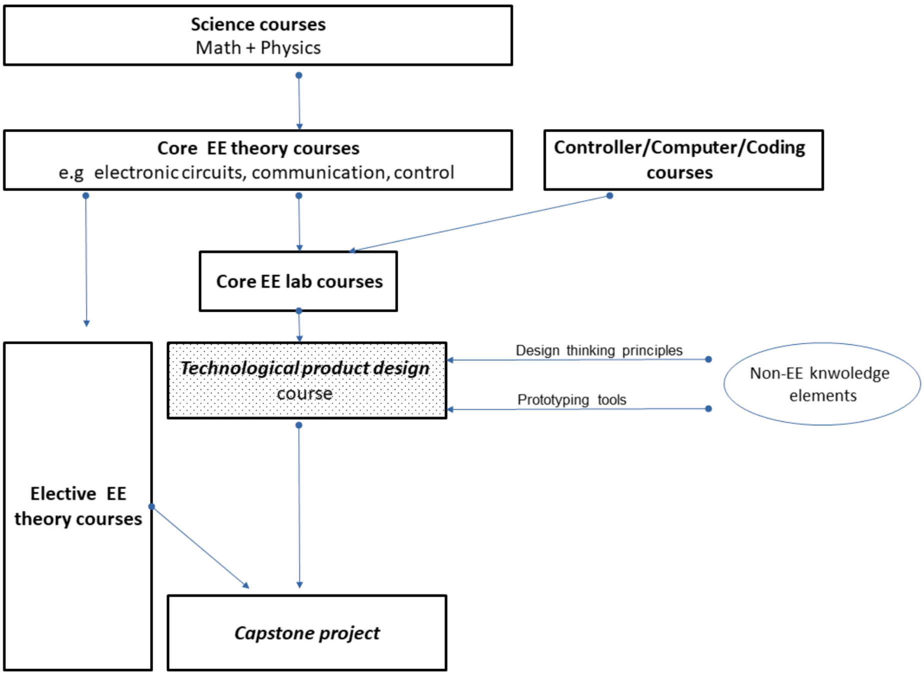

Figure 1. The curricular structure at the EE department. The dotted-pattern course is the subject of the current study

The methodology of integrating all these components into a useful course is detailed in the following section. The aim of this study is to describe the design and process of this CDIO-oriented course and reflect on their impact on the EE curriculum and on its pedagogical effectiveness.

COURSE DESCRIPTION

As indicated above, the course (or module) is normally taught during the first semester of the 3rd year. Each year, before the semester begins, a theme is chosen by the two co-teachers, one from the Electrical Engineering (EE) department and the other from the Industrial Design (ID) department. The theme is broad enough to facilitate a sufficient variety of feasible products. The theme should match the common knowledge of a typical 3rd year student. Two examples for such themes in recent years are energy harvesting devices, and innovative musical instruments.

Upon course debut, the students are assigned into teams of 2-4 participants. The aim was to try and ensure a reasonable balance between teams, and in particular disperse the most talented students equally among all groups.

The next phase is brainstorming for ideas. After the brainstorming session in the class as a whole, each team would be free to choose a product based on the ideas raised in class.

Once the teams had chosen an idea, they are asked to conduct a short market research. Throughout this research, they have to explore three similar products and conduct focus group interviews (as commercial companies regularly do, as part of their market research). The interviews take place within the classroom, and the focus groups are their peer students.

At this stage, the groups have gathered enough insight and can start defining a functional specification – main product features and use case scenarios.

The next phase is hardware design. Based on EE core knowledge acquired throughout their studies thus far, each team prepares a block diagram containing the electrical components which are needed to build the prototype. In order to save precious delivery time, components are borrowed from the college or bought in local electronics stores, rather than being ordered online.

From this time on, the course proceeds to the "Practical, Hands-on" phase. This takes place during the second half of the course and lasts seven weeks long. The work format in this phase is that of a workshop: Each student team works separately, and the co-teachers guide the groups, one by one.

As soon as the main components are acquired, the ID team moves into a higher gear. The ID team is led by the ID co-teacher, and a 4th year ID student, who helps with building the physical 3D models, into which the electronic sub-system is inserted.

In parallel, each team assembles its respective electronic circuit and starts coding the software that would run on the embedded microcontroller, which constitutes the core of most systems designed in the course. Software writing skills, as well as physical assembly of electrical circuit skills, are acquired in previous core EE courses.

Then, all the elements are integrated into the final model, which is to be presented in front of the class in the last lesson of the course. Alongside the functional prototype, the students are requested to prepare a one-pager, and a PowerPoint presentation.

The final presentation is held during the last lesson of the semester, the forum being the students, the co-teachers, and a "jury". The jury is comprised of staff members from Shenkar College and of external visitors from the hi-tech industry.

Several examples from recent years are shown in Figure 2. In Figure 2a, an electric fin is shown, which is a surfboard that powers LED stripes with the energy of sea waves. Figure 2b shows a milk saxophone, in which a standard milk carton is used as a resonance box. Figure 2c shows a solar sunflower, that absorbs solar energy during the day and turns on LED lights during the night. Finally, Figure 2d shows an electronic Hang, an electronic version of the acoustic hang musical instrument.

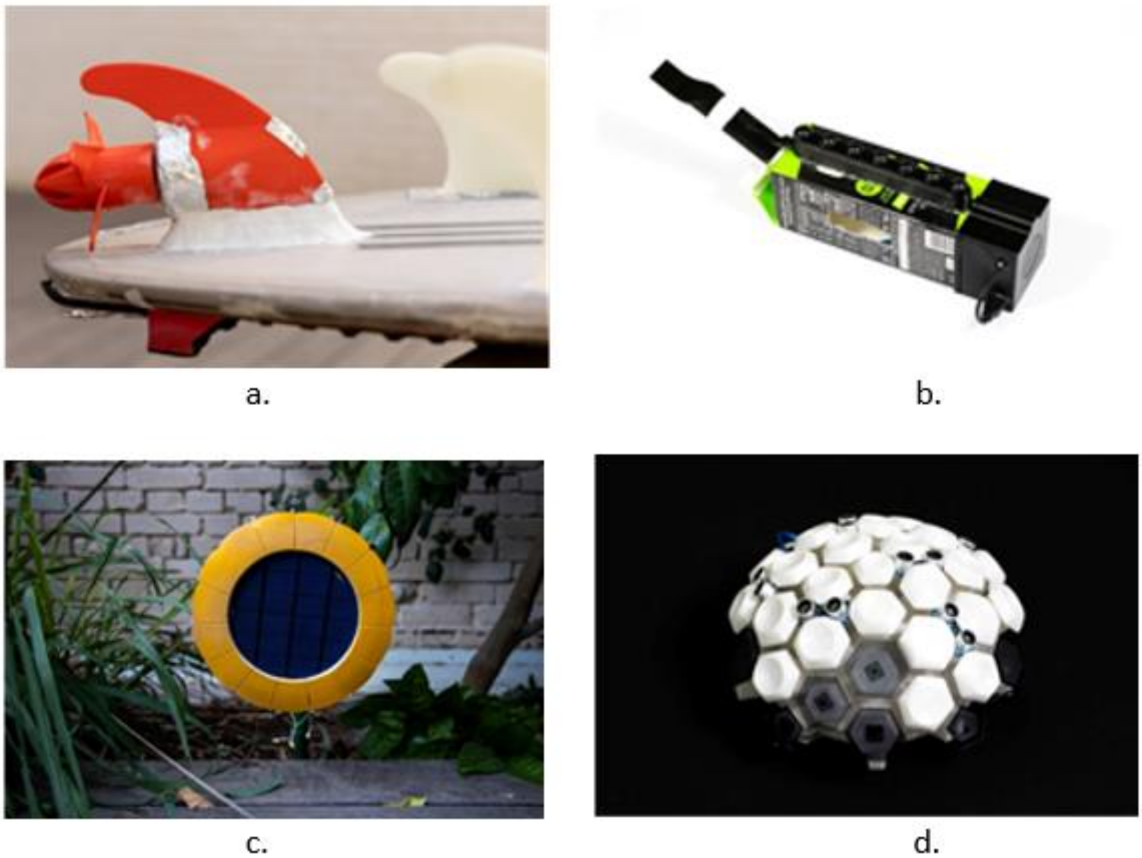

Figure 2. Examples of products developed in the TPD course over the past few years. a. Electric fin, b. Milk saxophone. c. Solar sunflower, d. Electronic Hang

DISCUSSION

In this section we consider some of the relevant issues with respect to the TPD course.

The first issue is the interaction of the course with the preceding core EE courses, that “feed” this course with relevant engineering concepts and methods. Namely, we ask: to what extent does this course provide a framework for students to implement previously acquired engineering knowledge? And, conversely, may the course provide useful feedback with respect the content of some of these preceding courses? We first note that in most cases, for the types of products implemented in this course, there are mainly two relevant elements of such knowledge: hardware coding, and basics of electronic components and circuitry. Preceding the TPD course, among many other core courses, there are: a. courses in C & Python languages, b. labs that focus on Arduino and Raspberry pi, and c. basic courses in electronics, that deal with amplification, sensing, actuating, etc.

The elements of knowledge acquired in these preceding core courses are typically the most useful ones for the TPD course. Among them, perhaps most useful is the knowhow of using the Arduino microcontroller and (to a lesser extent) the Raspberry pi miniature computer platforms. These are the backbones of most products designed in the course, and the respective knowhow, both hardware-wise and software-wise, provides a needed flexibility for realizing reasonably functional (though, arguably, not too complex) products. Notably, theoretical knowledge acquired in other core courses is considerably less implemented in the TPD course. Further, the TPD course also benefited from changes made in some of these core courses. Specifically, some five years ago, when the microcontroller lab course switched from teaching the concepts on an older TI micro-controller card, to using the more ubiquitous and user-friendly Arduino platform, the projects in the following TPD courses stepped up their levels of functionality.

A second aspect that deserves attention is the effect of the TPD course on the subsequent, final year, capstone projects. Meaning: to what extent the course facilitates more challenging capstone projects? This has not been studied methodically, yet it is reasonable to say this course serves as a useful introduction to the capstone project in more than one way. Most important, the course provides some basic skills for a project, by guiding the students through the main phases of the process of product development, and by training them in using some newly acquired soft skills. Although the scope of the TPD products is more limited than that of the end-products of the capstone project, these newly acquired skills make the progress at the capstone phase somewhat smoother.

A third aspect to discuss relates to the complexity of the TPD products, attainable in a framework of a one-semester course. Notably, throughout the decade that the course exists, it has constantly evolved along two axes: the engineering (EE) axis and the design (ID) axis. The two main changes took place in recent years were: 1. Four years ago, in two of the core courses that precede the TPD course, we started to teach (and extensively experiment) the Arduino platform, and later on, the Raspberry pi platform. These changes provided the students with considerably more updated and flexible platforms for building more complex, functional products. 2. Three years ago, an ID co-teacher was joined to the course (previously, he was a freelance counselor, on demand). As a result, students became familiar with some of the ID-related methods of product design (I.e., elements of design thinking). In addition, an ID student was added as an assistant, mostly for helping in tasks that required 3D printing. These changes resulted in stepping up the appearance, and the ergonomics of the prototypes. In recent years, the prototypes tended to look more like real products, rather than a bare breadboard attached to some wires and LEDs (as was case in the earlier years of the course). Altogether, these two changes have upgraded the level of the typical TPD course product.

The fourth aspect is the way students view the TPD course. Over the years, student's feedback was monitored, qualitatively and quantitatively, by conducting teaching surveys. The results normally show a high satisfaction rate, e.g., course grade above 6 out of 7. In the qualitative part, students acknowledge the high effort that the course requires, considerably higher than the accredited academic points “justify”. However, the final goal of a fully working, presentable prototype seems to keep most students highly committed, despite the time-consuming effort required. Also, students are quite satisfied with the "widening horizons" attitude of the course, touching various industry aspects that are not taught in any other curricular course. Notably, the course includes guest lecturers, given by external experts, that deal with various hi-tech industries subjects, such as entrepreneurship, R&D, and accounting.

CONCLUSION

We described, and discussed, a CDIO-oriented course that was developed, and is being taught at Shenkar college (Israel), for about a decade, in the third year of study. The course provides a platform for students to implement core EE knowledge that was accumulated during their first two years, in developing a product. It is taught in collaboration, by EE & ID teachers, and as such incorporates elements of product design into the traditional core engineering knowledge base. It also prepares the students for their 4th year capstone projects, encouraging them to carry out challenging projects. Bottom line is that students are, in general, highly satisfied by this experience, judging by their feedbacks, and the many long hours that they dedicate to the design of the course products.

The following topics for study are: The contribution of this course to the quality of the capstone projects and the impact of the skills acquired during the course on the success of the graduate in achieving key positions in the high-tech industry.

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SYSTEMS THINKING IN A MECHANICAL ENGINEERING PROGRAM

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ABSTRACT

In engineering programs, systems thinking capability has been promoted for a long time. The capability of students to apply various systems thinking approaches is not only supported by educational staff, but also highly required by various employers. The aim of the study is to investigate the inclusion of systems thinking aspects in the Mechanical Engineering program at Linköping University. Two research questions address this aim. According to involved teachers, (1) What aspects of systems thinking are included in the Master Program in Mechanical Engineering?, and (2) What teaching and learning activities concerning systems thinking are included in the Master Program in Mechanical Engineering? Empirical data was gathered through focus group interviews with involved teachers from two Master profiles. The results indicate that systems thinking is present in the respective Master profiles, however not explicitly communicated with the students. Systems thinking is often coupled with disciplinary knowledge, which supports CDIO standard 3. Some examples of how systems thinking is taught relating to disciplinary knowledge (CDIO standard 7) were presented by the teachers. Examples of teaching activities specifically aimed at systems thinking were however missing, alongside examination of systems thinking in particular.

KEYWORDS

Systems thinking, Teaching and learning activities, Master profiles, Applied Mechanics, Mechatronics, Standards: 3, 7

INTRODUCTION

The world is growing more and more complex and fast-changing, which makes it a challenge to prepare today's students for decades of working life. In engineering programs, systems thinking capability has been promoted for a long time. Considering the growing complexity in practically all societal contexts, systems thinking has also recently gained increased attention as a means to bring order to and improve the understanding of a wide variety of contemporary phenomena. The capability of students to apply various systems thinking approaches is therefore not only supported by educational staff, but also highly required by various employers.

Against this background, the board of Mechanical Engineering and Design at Linköping University decided to investigate how the engineering programs under its supervision address systems thinking, and how the modules and the program support the students' development of a systems thinking capability. The engineering programs at Linköping University are all designed and managed in line with the CDIO framework. Hence the connection between the CDIO framework and systems thinking is of interest to the board.

In response to the urge to investigate systems thinking and the relation to CDIO, the aim of the study is to investigate the inclusion of systems thinking aspects in the Mechanical Engineering program. Two research questions address this aim:

RQ1: What aspects of systems thinking are included in the Master Program in Mechanical Engineering (cf. CDIO standard 3)?
RQ2: What teaching and learning activities concerning systems thinking are included in the Master Program in Mechanical Engineering (cf. CDIO standard 7)?

RESEARCH ON SYSTEMS AND SYSTEMS THINKING IN EDUCATION

There are many different definitions of systems and systems thinking, because both concepts have been used in such diverse fields as biology, ecology, health science, environmental and climate science, chemistry, technology and engineering, computer science, geosciences, logistics, complexity science, economy and management, and social science. In this paper, we will adhere to a broad definition of a system taken from Ingelstam (2012): A system fulfils a particular purpose, it consists of components, relations or connections between these components, and has a system boundary. Beyond the system boundary is the surrounding, which may interact with the system but is not part of it. Systems thinking could refer either to a scientific discipline, a methodology or a skill set (Elsawah, Ho, & Ryan, 2022; Oskarsson, 2019). With Ho (2019), in this paper we define systems thinking as "a set of skills for understanding, analyzing, and working with systems consisting of multiple interconnected elements and exhibiting emergent properties" (p. 2764).

Students of varying disciplines and of all ages find it difficult to understand systems, so systems thinking is generally not well developed (Booth Sweeney & Sterman, 2000; 2007). As regards technological and engineering systems, students gain a deeper understanding of systems as they grow older, especially regarding the included components. However, there is no significant difference between younger and older students, or student teachers. In this regard, control mechanisms and flows of information are particularly difficult to grasp, as is the role of humans in and around a technological system. Non-linear systems are also generally more difficult to understand than linear systems (Arbesman, 2017; Hallström & Klasander, 2020). It is apparently effective to study aspects or layers that are common to more than one system, thereby allowing for structured comparisons between systems. This, in turn, is important for students to be able to generalize systems knowledge (Hallström, 2022).

Such generalized knowledge could be called systems thinking, in line with the above definition (Hallström & Klasander, 2020; Ho, 2019). Research about students' systems thinking shows, for example, that regardless of discipline undergraduate students' systems thinking skills can be improved with appropriate teaching interventions (e.g. Elsawahet al 2022; Rosenkränzer, Kramer, Hörsch, Schuler, & Riess, 2016). Rosenkränzer et al (2016) also suggest a model outlining a progression for deepening and improving systems thinking skills, which has been adjusted specifically for technological and engineering systems by Engström & Svensson

(2022). However, as Elsawah et al (2022) conclude in a recent study, “which teaching approaches and methods (e.g., mapping, simulation) are most effective for promoting systems thinking skills has not yet been determined” (p. 89).

RESEARCH DESIGN

At bachelor level the Mechanical Engineering program at LiU consists of compulsory modules. Thereafter, at Master level, the students follow one of ten specializations, so called Master profiles. Each Master profile has a defined set of modules, some of them mandatory, others eligible. Since the different Master profiles cover different content and are given by different teachers, we supposed that systems thinking would be treated differently between these profiles. Therefore, we focused our study on this later part of the program.

In consultation with the Program Director, we selected two Master profiles as our studied cases. These were chosen for the following reasons: focusing different parts of mechanical engineering, together they cover a broad view of the field; there was a preconception that systems thinking is treated differently in these profiles. A brief description of the two profiles is given in the following table.

Table 1. The studied Master profiles

Master profile	# of compulsory modules	# of eligible modules	# of students per year
Mechatronics	7	17	25-35
Applied mechanics	5	18	10-15

For each profile, or case, we studied module curricula to see how and to what extent systems thinking was expressed in the “expected learning outcomes” and “module content” in these documents. We informed the coordinators for each Master profile of the study. In consultation with them, teachers were selected for participation in focus group discussions in order to include a second-order perspective in the RQs. All teachers have long teaching experience and are examiners for one or more modules in the respective profiles.

The planning and conducting of the focus group discussions were informed by e.g., Bryman and Bell (2011), Dahlin Ivanoff and Holmgren (2017), and Wibeck, Dahlgren, and Öberg (2007). We prepared discussion themes with inspiration from Jackson and Hurst (2021) and used information from the reviewed curricula as input for the discussions. Before the sessions, the participants were informed about the purpose and setup of the study, their voluntary participation, and the anonymization and overall management of data (according to GDPR). Subsequently, they all consented to being part of the research study (Swedish Research Council, 2017). One of us acted as moderator, with the intention of letting the participants talk freely, but slightly steering the discussion to cover the prepared themes. The discussions were audio-recorded and thereafter transcribed. Some details about each discussion are provided in Table 2.

Table 2. The focus group discussions

Master profile	Participating interviewers	Participating teachers	Extension (minutes)
Mechatronics	2	6	87
Applied mechanics	3	3	73

A content analysis was performed, where we categorized relevant content from the discussions. As Eisenhardt (1989) and Braun and Clarke (2006) suggest, we started out with tentative categories, in this case inspired by Jackson and Hurst (2021). However, following Finfgeld-Connett (2014), we allowed for modifications of the categories, i.e., the analysis combined deductive and inductive elements. At least two of us made an individual analysis of each discussion, which after comparison were combined to an aggregated one.

RESULTS

The analysis of the focus group data yielded altogether six themes, of which two relates to RQ1 and four to RQ2.

The Nature of Systems Thinking

The interviewed teachers described a great variety of different systems – mostly technological – that were addressed in their teaching in the Mechanical Engineering program. They also reflected upon systems thinking: what it entailed for them and its presence in teaching in general.

Types of Systems

The teachers in the Mechatronics profile mentioned a number of different systems that are dealt with in their teaching, of which most are technological systems such as mechatronic, hydraulic, electronic, electro-hydraulic, mechanical, and automotive vehicles and systems. To a lesser degree they mentioned systems such as bridges, robots, medical technologies, as well as other types of systems like quarks, economic systems, political systems, and the climate system.

They also referred to different types of systems such as dynamic systems versus static systems, although they mostly taught about dynamic ones. There was also mention of open versus closed systems, as well as how different systems can be connected and/or entangled. The informants also claimed to go into detail about certain systems when teaching, in particular different types of control systems (e.g., technological systems or a human riding a bicycle), using concepts such as input – process – output, feedback, disturbance, regulator, servo, state, sensor, and component/s working together. The system boundary was also referred to when talking about what could actually be included in a system, for example: "*to us program code, algorithms and such are kind of part of the system*"; *"it is much about algorithms and such, and the control system. That is also part of [the system]"*.

The teachers in the Applied Mechanics profile discussed systems in a more implicit way, compared to those in the Mechatronics profile. They suggested that kinematics of rigid bodies and associated force analysis could be seen as an application of the systems concept, as it concerns parts that interact and generate movement.

Thermodynamic systems in general were put forward as typical systems, even though they are taught at the bachelor level. A concrete example was the gas turbine, which can be seen as a system in itself but also as part of a system interacting with a compressor and a combustion chamber. Finally, the human body was also suggested as a system. Modules that focus on the human body are offered both in solid and fluid mechanics.

Presence and Characteristics of Systems Thinking

When prompted, the informants in the Mechatronics profile referred to systems thinking as something that is a natural part of both research at the department and teaching within the mechanical engineering program. One teacher put it like this: *"Well I have been here for ages and systems and systems thinking, those are kind of mother's milk".*

Systems thinking was also mentioned as being practiced and trained among students during the program, and also as an outcome after having obtained the mechanical engineering degree. When prompted, the teachers could mention some kind of definition of systems thinking, for example: "*I think about this ability to actually picture something with boxes and arrows. Here is this part, these are interesting. And then there, I integrate with this part over here, which in turn integrates with this. So maybe we have kind of a feedback loop like this. To abstract a situation with boxes and arrows, that is systems thinking to me.".*

Another teacher put it like this: *"we have the system. And we have a kind of standard measurement, we are supposed to reach something. And what is often present in our world, the mechanical world […] there are always conflicts. In engineering problems we must make a trade-off. And there are inherent trade-offs all the time. And the more you make the system fit with reality, the more such conflicts well over you"*.

Yet another teacher focused on the system's boundaries: *"systems view entails different perspectives on the same item".* By putting the item of interest in relation to other items *"that is different models. And it is the same physical item. But that is another system's view. I made a limitation that is context related. And to me it is the context, the limitation that, so to speak, is the systems thinking*".

However, although systems thinking permeates the program and the Mechatronics profile on various levels, it is in practice mostly implicit both to teachers and students. One teacher thus described how he structured a module and included systems to promote students' systems thinking. By starting with one motor component and viewing it from various angles, and then putting it in the wider context of other motor components, he "built" the system for the students and thus in practice introduced the systems thinking.

A salient feature of the implicit promotion of systems thinking in the modules is the teachers' inclusion of aspects of modelling of systems. One of the aims of modelling is for the students to be able to distinguish between a model of a system and the actual, real system.

The informants in the Applied Mechanics profile agreed that the systems view was closely related to the nature of the problem at hand: *"Yes, in the end it depends on what the problem is about"*.

Overall, systems thinking was perceived as concerning how components interact with their context, or with another component or another system. Interacting systems were related to a holistic view and engineering thinking in general. Sometimes the teachers use the term model in parallel with system, where the system model is used for creating a mathematical model: *"Yes, well, the system is then, kind of, we take the reality and then we isolate it. And then we try to interpret it, or transfer it to a mathematical equation system. And that is the model"*.

The teachers also discussed that systems thinking is manifested through a collection of fundamental rules, and that systems thinking was represented by a set of methods for progressing analysis. Furthermore, the system boundaries were discussed among the teachers as important: *"And you have a small component, there is a fluid inside there, and then you draw the little system boundary, and decide what passes over the boundary here and there, energy and work and current. And there you have your system and system's boundary".* But the system boundary also has different significance among the modules on the profile: *"When you [in fluid mechanics] talk of systems it is very natural that something passes the system's boundary. It passes, thus integrates with the system's boundary. And that is not so obvious in [solid] mechanics, where you have a smaller detail like a link or a cogwheel, or something. So, in solid mechanics a system's boundary is seldom something to pay attention to. You complete your force release. And that is the system's boundary.".*

It appears that the term system is not so often used, instead terms such as components are used, but often the meaning is the same. Even though not explicitly discussed between teachers and students, the teachers agree that systems thinking is of essence. How to set up a model with the systems' boundaries, setting boundary conditions, was agreed to permeate the discipline and hence the modules in the master profile.

Teaching and Learning of Systems Thinking

Teaching and Learning Activities

One way of concretizing how the actual system differs from the model, according to teachers in the Mechatronic profile, is by way of simulating and building various systems: *"The model concept, that survives a simulation. And it…so that module is half…focused on knowledge of how to build the system. And the other half is the ability to simulate this, kind of making engineering stuff"*. Another teacher proposed laboratory exercise as an important means to teach systems thinking: *"in control technology the laboratory exercises are on a physical item. Let be it is small, but there is the computer with its software, and there is the item to be controlled. Thus, this becomes visible"*.

One teacher from the Applied Mechanics profile suggested that students' appropriation of systems thinking needs to be supported in a process of trial-and-fail/succeed: *"You might learn more from crashing and burning than if somebody tells you where to go and what to do".*

Examination

The laboratory exercises mentioned by the Mechatronics teachers also represent examination, however no explicit attention is paid to the nature of systems thinking. In the written exam in one of the basic modules (control technology) the students are sometimes asked to model a bicyclist, which reflects their systems thinking – however this task is not necessary to pass the exam as a whole. But the teacher who mentioned this found that the failure of students also reflected on the teacher: "*And, yes, many [students] get to that. But some fail. And then you* *feel totally unsuccessful as a teacher yourself".* Overall, the Mechatronics profile teachers suggested that systems thinking is implicitly examined during projects in the modules.

In the Applied Mechanics profile, the teachers agreed that no particular examination is carried out that concerns students' ability to take a systems approach to problem solving. Instead, systems thinking is considered as needed for the final major project module, and for the master thesis project. Nevertheless, a problem here is that students work in groups or pairs in these modules, and the students are not individually examined.

Progression

In line with the lack of concrete teaching and learning activities, there was also by and large a lack of deliberate and planned progression regarding systems thinking in the Mechatronics profile. However, there can be said to be a very overarching progression line between modules within the Mechanical Engineering program, concerning systems. One teacher thus pointed to the focus on hydraulic systems in the basic modules, control systems and electronics in the intermediate modules, and actual design and building of real technical systems in the advanced modules.

The teachers in the Applied Mechanics profile described in different ways how the systems understanding was built module by module: *"you start from the bottom…but during the program we simply add on to that knowledge base. In the final module, [the student] brings a back-pack with quite a few insights, and in the advanced modules you start to integrate the different things from the backpack. And kind of build the umbrella or roof over it all and thus creating greater understanding"*; and "*expand and build on, increase the complexity, make it applied, and see other applications, or more different applications"*.

The teachers are aware of this progression, but according to the teachers the students may not be. Progression also supports the understanding of present as well as past modules and knowledge: *"There are lots of equations, and they don't really understand how they are connected. And that is not strange, but simply a maturation process….On the other hand after a couple of years here, suddenly the pieces fall into place, it appears. And sometimes…when you talk to them afterwards, they don't even understand what was once so difficult"*.

The last example also connects to the next category, presented in the coming section.

Student challenges

When the teachers in the Mechatronics profile described learning difficulties among students they had mostly to do with deficient mathematics or programming skills, but sometimes also deficient knowledge of control theory or systems thinking such as the need for approximations when modelling a system. It could also be the ability to read block diagrams, or the role of flows of information in a system: *"And I have full respect that it can be difficult to get used to, as a student. But cause, effect, the relation, that is boxes and arrows.".*

The teachers in the Applied Mechanics profile also mentioned the students' propensity to get stuck in details: *"They don't see the forest for all the trees".*

DISCUSSION AND ANALYSIS

The first RQ concerns “What aspects of systems thinking are included in the Master Program in Mechanical Engineering?” This includes both the concrete systems and their elements in the respective profiles, and the more philosophical stance on systems thinking and its visibility in the profile.

For both profiles, the types of systems related closely to the topical areas and to the application areas for each profile. Based on the nature of the profiles, the Mechatronics profile included a wider scope of concrete systems, whereas the Applied Mechanics profile more focused on solid and fluid mechanical systems, with the exception of the human body as an example and also as a focus in some modules. Furthermore, static as well as dynamic systems were present in both profiles, where the Mechatronics profile to a larger extent focused on dynamic systems.

With respect to systems thinking, there was a consensus across the master profiles of the importance of integrating interacting components, and that the definition of system boundaries are all core knowledge elements in systems thinking (in line with Ingelstam, 2012; Klasander, 2010). The term model was also central although it was used somewhat differently between the profiles (cf. Hallström, 2022). In addition, a common feature between the profiles is the implicitness of systems thinking: whereas the teachers - who are also researchers - are comfortable in discussing systems thinking, they agree that this is very seldom explicitly discussed with students.

Systems thinking is often coupled with disciplinary knowledge, which supports CDIO standard 3. Furthermore, systems thinking also resonates with the CDIO emphasis on an integrated curriculum, which, in turn, promotes inter-personal skills and competencies related to the promotion of sustainability conscious engineering.

The second RQ concerns “What teaching and learning activities concerning systems thinking are included in the Master Program in Mechanical Engineering?”. The question was posed openly, and the four categories of responses are a result of the discussions.

Despite prompting the issue during the interviews, only few examples were given of *teaching and learning activities* in the profiles. Laboratory exercises and trial-and-failure/success sequences were suggested to promote systems thinking among students. It appeared difficult for the teachers to define teaching activities that explicitly support the development of systems thinking among students (cf. Elsawah et al., 2022). Likewise, *examination* of systems thinking was basically not present. One example of a written task was given, but this task is not compulsory. Rather, the teachers’ perception was that in advanced project courses and in the Master thesis projects, the students would probably fail without having acquired systems thinking. Hence, systems thinking is conceived to be ‘implicitly examined’ in relation to the overall program goals.

Progression in acquiring systems thinking was more extensively mentioned, and many examples were given. Starting with smaller components and expanding the system through interconnected components in successive modules was a pattern that arose, that would indicate progression in complexity, technical nature and size of systems. This relates to expanding the system boundaries (Hallström & Klasander, 2020), something that is also addressed in the systems thinking section above.

Besides the lack of various technical skills, an important challenge for the students over time was not to get lost in details and instead focus on the system level.

While only few examples were given of how systems thinking was taught, most of the discussions circled around topical examples which served to illustrate systems thinking in teaching, and, by implication in students' learning. Furthermore, in relation to CDIO standard 7, the teachers also function as role models: "it is important that students recognize engineering faculty as role models of professional engineers, instructing them in disciplinary knowledge, personal and interpersonal skills, product, process, and system building skills".

CONCLUSIONS

The research at hand represents the teachers' views on systems thinking in teaching in the master profiles Mechatronics and Applied Mechanics, in the Mechanical Engineering program at Linköping University. Overall, the results indicate that systems thinking is present behind the topics discussed, and also behind the development of teaching. However, more explicit discussions with students are not part of the teaching activities. Still, the teachers perceive that the students examined from the program possess a considerable capability of systems thinking. Further investigations into this topic should include the students' perspective, in order to confirm the insights gained on the basis of teachers' perspectives.

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SIMULATION-BASED MATH IN THE FACULTY OF ENGINEERING AND BUSINESS

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ABSTRACT

The world today needs rapid innovation, product development and consideration of sustainability. Different types of models are efforts used to forecast the future, for climate, economy, and population growth, to name but a few, as the information does not exist otherwise. In general, use of simulations and various computer aided methods play a key role, as they are efficient in developing, evaluating, and comparing different solutions. The "simulation-based math" standard is a corner stone in providing engineering students with the skills and mindset to respond to modern world challenges in their future careers. At Turku University of Applied Sciences (Turku UAS) the implementation of the latest simulation-based mathematics -standard started collectively in the faculty of Engineering and Business in spring 2021. The first step was to examine to what extent computational methods are present in education. This survey was done in four different departments. Each department explored their course selection and based on how much and how systematic the use of computer-aided mathematics in the courses was, defined the initial stage in the rubric. The survey showed that the initial state at different departments varies notably. Some departments clearly have more structure in utilizing the methods whereas others had not yet started any thorough process of implementing the new standard. A common goal is to synchronize the practices and create a learning curve that starts from the basic courses with simple tasks and continues until the later stages of studies with more complex problems. This paper discusses the review process, its' findings, and the ideas how to start improving the implementation of simulation-based math-standard in separate courses and at the programme level through the whole faculty. In addition, challenges and the concrete next steps will be outlined.

KEYWORDS

Math, Simulations, Numerical methods, Standards: Optional standards 2

INTRODUCTION

Whereas the framework and standards for CDIO were established already more than a decade ago (Brodeur and Crawley, 2005), the optional standards are a rather new issue. The idea of optional standards was first introduced in the paper by Malmqvist et al (2017) where the authors discussed the need of educating engineers with new competences, thematically linked with the current societal issues such as sustainable development, internationalization, innovation, and multidisciplinary problem solving. In addition to these competences Kamp (2016) emphasized the need for an attitude for life-long learning, reflecting on the fact that the operating environment and the challenges we are facing are constantly changing, both locally and globally. In addition to preparing engineers with the field-specific competence, but they also need to be able to provide creativity and innovations even outside the engineering discipline, consider the needs of the society and to be able to communicate their achievements to public. The drivers and the need for revision of the CDIO standards were discussed also in Malmqvist et al. (2019) and Malmqvist et al. (2020). Besides these generalized skills, the mindset and internal and external drivers, Enelund et al. (2011) pointed out a concrete trend of increased use of computational and numerical methods in real-world engineering problem solving, and that these skills should also be included in engineering education. In their case, the use of computers and numerical exercises as complementary tools for traditional symbolic mathematics assisted students in learning and understanding math. The use of numerical methods and simulations enables much better possibilities for studying real-world engineering problems than basic pen and paper exercises and via them, more complicated mathematical methods can be used. The suggested new standards act as a complementary set up to serve as a guideline for possible specialization in the curriculum, whereas the original twelve standards form the fundamental basis for CDIO. However, not to only be applicable in a very limited context, the optional standards are suited to be used widely in various fields of engineering and thus, acts as one of the generalized transferrable skills needed in many tasks and careers.

The selection of optional standards serves this need well, considering the four themes selected for the standards. Especially sustainable development is one of the core competences today, being also promoted by the UN, that has set seventeen different goals to be achieved. Globalization has made the world greatly flexible what comes to the place where the work is done and by whom. In addition, considering the manufacturing industry, the supply chains can be rather complex and often require international mobilization of goods and people. From that perspective, it is justified to have had added the fourth optional standard. There has been plenty of discussion nationally and worldwide (e.g., EU, OECD) about how the work and employment will change in the future, so it is important to include entrepreneurship studies in engineering education too. The simulation-based math standard can be neatly used in many of these aspects too. Being often highly independent from place, it can be utilized not only from the mobilization point of view but also from the sustainability aspects, since it enhances resource efficiency and guides for clever product development from the very beginning.

The simulation-based math standard is an excellent addition to the standard since the use of simulations in industry is increasing and the need of innovations require research. In both of those, the knowledge and understanding of the relevant phenomena and processes are essential but it is also equally important to be able to test and verify possible new ideas and assumptions reliably. In the past, the testing phase often included massive prototyping, which was slow and costly. As the simulation and numerical tools and computers keep evolving it makes sense to utilize them more extensively. As they are quite sophisticated and involve complex mathematics, it is good if students can get in touch with these tools during their studies. Especially if one wishes to pursue simulations as their career, the earlier these topics and methods are introduced, the better it is for development of their expertise and understanding. Not only to consider the standard just being promoted in math but it should be utilized in other courses too, such as physics and possible lab projects.

To start better utilizing the possibilities the simulation-based math standard enables, four different departments in the faculty of Engineering and Business at Turku University of Applied

Sciences started mapping their current state of methods and practices as compared with the simulation-based math standard self-assessment rubric. The departments participating in this survey were Chemical Engineering, Information and Communications technology, Mechanical Engineering and Logistics, Services and Industrial Management. Each department selected a group of people working with mathematics and physics courses to evaluate the content and practices in their department. The courses are rather similar and thus, it was good a basis to start internally discussing and sharing the practices and ideas. In addition, the possibilities to collaborate and synchronize the methods were also recognized. In this paper the findings and the future development for increased implementation of the simulation-based standard is introduced as a case study at one faculty and its departments.

CURRENT STATUS

Background

The education at Turku University of Applied Sciences is based on so-called innovation pedagogy where the goal is to prepare students with the skills needed for future engineering work. There are many similarities between Innovation Pedagogy and the CDIO concept such as active learning and teaching methods, working life orientation and flexible curricula (Konst et al., 2014). Because of this novel pedagogical strategy, that neatly complements the CDIO standards, it is reasonable to set goals and synchronize the curriculum with respect to the "simulation-based math" -standard jointly at four different departments educating engineers at Turku University of Applied Sciences.

Findings and discussion of the survey

As a starting point we used the self-assessment rubric presented in Figure 1, to start mapping the level on which each department thinks they are at utilizing methods that are related and can be linked to the simulation-based math standard. It was found that all the departments have activities and tasks that contribute to the standard as indicated in Table 1.

5	The course/module and programme learning outcomes for mathematical programming, modelling and simulation are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders.
4	There is documented evidence that students have achieved the intended learning outcomes for mathematical programming, modelling and simulation.
3	Course and/or programme learning outcomes for mathematical programming, modelling and simulation are validated with key programme stakeholders, including faculty, students, alumni, and industry representatives and levels of proficiency are set for each outcome.
2	A plan to incorporate explicit statements of learning outcomes at course/module level as well as programme outcomes for mathematical programming, modelling and simulation is accepted by programme leaders, engineering faculty, and other stakeholders.
1	The need to create or modify learning outcomes at course/module level and programme outcomes for mathematical programming, modelling and simulation are recognized and such a process has been initiated.
0	There are no explicit programme learning outcomes at course/module level nor programme outcomes that cover mathematical programming, modelling and simulation.

Figure 1. Rubric for self-assessment of Simulation based mathematics- Standard.

Table 1. Simulation-based math standard self-assessment rubric levels in the different departments.

Department	Current level	Goal level (near future)
Chemical Engineering	1	2–3
Information and Communications Technology	1–5	2–5
Logistics, Services and industrial Management	1	2–3
Mechanical Engineering	1	2–3

However, the practices and methods used vary notably between the departments. One common element in many of the courses are Matlab and Simulink and the learning material provided with the software supplier (e.g., Matlab and Simulink online courses). In addition to Matlab, Excel is often being used. For both software, there are campus-wide packages that are also available for students, so it makes sense to utilize them heavily. In addition to these common solutions, each department has its own specialized tools, including machine learning, different gaming applications, CFD and FEM for simulating 3D physics-based problems, for example. Besides these more field-specific tools, common programming languages such as Python, and some online tools like WolframAlpha, are utilized. Some of these tools are introduced in the first courses and some of them are used in the later stage studies and courses. In most of the departments a complete learning path from the beginning of the studies to the graduation stage doesn't yet exist. On the other hand, since the study programme and curriculum in each department is different, it does not surprise that the practices are not convergent. The tools and methods that are most useful and should be included in the studies also depends on the career the students will pursue after graduation. It may not be reasonable to make all the students go through the same learning curve in terms of using computer aided-methods.

Based on the review of discussion in each department, it was rather straightforward to recognize the main challenges and problems regarding applying and utilizing the simulation-based math standard. The first and biggest challenge is that students' math skills are very heterogenous. Some students know and can use more advanced mathematics, but a relatively large number has problems with basic algebra. The reason for this is the variety in the students' background. Some of them have been already in working life concentrating on practical work and are now, at a more mature age, re-educating themselves. For many of them, the earlier qualification is from vocational education, where mathematics is not being taught at a very advanced level. Many of the younger students also have their initial qualification from vocational school and their competence in mathematics is not very good. In addition to these students, there are some students who come from general upper secondary school, where it is possible to choose the advance syllabus in mathematics. Thus, some of these students are quite skilled and able to deal with more difficult topics. This makes the realization of all the math courses cumbersome, because some students find it hard to learn even the very basic issues and need lots of support to do so, whereas more skilled students may find it frustrating to use plenty of time on a very basic level when they would have the competence to go further and learn more difficult subjects. This fact brings us the question about how to implement simulation methods as complementary tools in math courses when the math needed to understand and perform the simulations is not on solid and advanced enough level? This discrepancy suggests that there should be many different learning paths for mathematics itself. Learning skills related to simulations and using computer aided tools should reinforce the learning of basic mathematics. Division should be made in a way that all the students should be provided with basic skills and more difficult practice should be introduced only for more advanced students so that the simulation-based math approach would give the additional value in its full potential. Even when the same pedagogical strategy is used throughout Turku UAS, there are many different methods and practices used at the four departments on which this analysis was performed. When working towards common goals it might be problematic to have plenty of versatile practices and methods in use.

OUTCOME AND FUTURE DEVELOPMENT

In all the departments the need for deeper application and integration of simulation-based math was identified. It was agreed, since campus licenses for Matlab exist, that it should be used through the studies, starting already from the first year. Efforts to increase the use of Matlab were already made during the spring of 2021. Turku UAS is using an online learning environment called itslearning (itslearning) where a self-paced Matlab -course was created. It's based on the Matlab Onramp -course (Mathworks) and in addition to its content, extra exercises were created on the course platform. The course was created in a way that it is possible to do it independently or it can be included as a part of some other relevant course. This course was already included as a part of a basic math and IT course in mechanical engineering in fall 2021, for example. In these courses there were altogether about 150 students. Based on the feedback collected, there was variation in how students experienced the course and learned the software. Some of the students found the course and software interesting and learned it well, whereas some of them reported that it was very difficult and that they are not interested in learning any software in general. One might speculate that the background of the students plays a role in this, but the feedback survey did not ask about the students' background, so this cannot be concluded. If the information were available, it would be worthwhile to compare the answers with the earlier education of the students. Further development of this action is to collect more feedback and create more examples and assignments that can be used to deepen learning and give opportunities to apply these methods for more complex real-world problems.

In general, it was discussed that the departments should collaborate closely in these development efforts to create a database for different types and levels of assignments and exercises that can be used in different courses. However, due to the issues regarding the students' variable math skills, it is complicated to create anything that could emphasize the learning for all students. Thus, it was agreed that as a starting point, the focus should be on basic simulation skills and that the good, existing practices should be shared and synchronized throughout the departments. This means also that these learning outcomes and aims should be clearly indicated and be written in course and programme descriptions. To be able to induce more advanced learning and provide students with versatile simulation skills, the very basics should be at strong enough level so that students would benefit from these actions. Thus, it may not be reasonable to heavily implement simulation-based math in all the courses and study programmes but to educate the very basic methods and then create alternative or optional courses or program for the students who are interested in learning these skills and have the necessary competence to adopt and understand them. This seems plausible, since not all the students will need these skills in their working life. In addition, universities of applied sciences tend to be more practical compared with universities, so the curriculum for these skills could justifiably be more pragmatic but still it should give the basis, that would enable the adaption of more progressive learning and knowledge.

CONCLUSIONS

This review reveals the very heterogeneous practices at different departments and the challenge in comprehensive implementation of simulation-based math standard in one faculty. Due to the differences in study programmes, it may be difficult to create very intensely synchronized, common practices that would fit everyone and all programmes. It is also worth noticing that all members of the teaching personnel are not familiar with the principles that are needed in educating ideas of simulations, either, and thus to incorporate these methods in all the courses might be too ambitious. Instead, efforts should be put in sharing the best practices and in creating manners that would be suitable for as many as possible to take advantage of additional value that the simulation-based math standard offers. For those who wish to pursue extensive knowledge of simulations there should be optional courses or exercises which would reinforce learning and give the ability to apply these methods in practice. As a conclusion it can be also stated that none of the departments will set any specific level where to aim but will concentrate more on the methods and best practices that can enhance the learning of these skills.

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CHALLENGES AND OPPORTUNITIES WHEN INTEGRATING VIDEOS IN COURSE DESIGN

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ABSTRACT

Due to the pandemic, universities were challenged to switch into distance mode, causing teachers to make pedagogical adjustments. One adjustment was the use of pre-recorded videos applied as complement in the education. However, a pedagogical miss-match arises, as course designs often are based on face-to-face (F2F) teaching, while videos are designed for self-education. Consequently, there is a need to understand what challenges, but also what opportunities appear as videos are integrated into course design. The purpose of this paper is hence to *describe challenges and opportunities when integrating pre-recorded videos in course design in traditional campus teaching.* An interview study with teachers and a survey to capture the student perspective have been carried out. The results of the teacher perspective highlight opportunities and challenges when it comes to the technical and content as designing videos as well as design of the lectures concerned. Learned from the students´ opinion videos need to be purposeful designed, and the information included need to be well thought through. When videos are used, the design of lectures becomes more important since the F2F interactions are reduced. This challenge teachers in their design of activities and for students to adequately prepare for F2F activities. At the same time, with videos available, students can pause and rewind if needed, and the potential to learn more basic facts from the videos. If F2F activities are purposefully designed, there is the potential for students to deepen their understanding, achieve greater learning outcomes and to increase progression. Videos also increase flexibility for students by possibility to shape their own learning opportunity and how it suits them and their everyday life. The findings from the study are related to several of the CDIO standards, mainly Standard 8, 6, and 10 by Active Learning, Engineering Workspaces, and Enhancement of Faculty Teaching Competence.

KEYWORDS

Educational videos, Course design, Learning outcomes, Challenges, Opportunities, Standards: 6, 8, 10

INTRODUCTION

Educational videos have for some time been an important pedagogical tool and a part of higher education (Brame, 2016). With the Covid-19 pandemic, universities were challenged to switch into distance mode, causing teachers to make pedagogical adjustments. One adjustment made by many was the use of videos, applied as a complement in the education. The pandemic thus fuelled an increase in the use of videos in higher education.

Videos can come in different forms and for different reasons, such as pre-recordings of lectures or recorded instructions (i.e. tutorials) (see e.g. Noetel et al. 2021). They can for example be a part of traditional courses on campus or the primary educational tool for online courses, and they can be used for lectures as well as tutorials (Noetel et al., 2021; Brame, 2016). This paper focusses on pre-recorded videos used in teaching, as opposed to videos that are a recording of lectures that are first held live (see e.g. Gorissen et al, 2013). As for these pre-recorded videos (henceforth videos), they can be of different types, such as skills demonstration or pre-recorded lecture (Noetel et al., 2021). This paper addresses a variety of types of videos, as long as they are of the pre-recorded.

Benefits of using videos in teaching include enhanced learning and test scores (Noetel et al., 2021; Kay et al., 2012), and appreciation from students (Kay et al., 2021). With the digitalisation as a result of the pandemic, there is now a greater longing for videos to be a larger and a natural part of the traditional campus teaching. Teachers of traditional campus courses can, however, face challenges in the adoption of videos such as course designs are often based on face-to-face (F2F) teaching, while videos are designed for self-education. Consequently, there is a need for redesign of course materials and teaching activities correlating to the video material, which can have larger consequences for the design of courses. To gain a wider perspective of the opportunities and challenges related to the integration of videos, the purpose of the paper is to *describe challenges and opportunities when integrating pre-recorded videos in course design in traditional campus teaching.*

This paper relates to several of the twelve CDIO standards, of which number 8, 10 and 6 are the most relevant. Standard 8 includes active learning methods, and enabling such learning is one of the challenges with incorporating videos in traditional campus courses.

THEORETICAL CONSIDERATIONS

Educational videos

Educational videos can be divided into different categories, for example, Noetel et al. (2021) distinguish between learning context (e.g. lectures, tutorials, homework), interventions (description, duration, level of active learning, type of video, where the latter relates to e.g. skills demonstration or recorded lectures).

There are several potential reasons why videos have become an important part of higher education. For example, based on a systematic literature review, Noetel et al. (2021) find that student learning is enhanced by adding videos to the educational tools in courses. This was found to be true for a wide variety of settings and results even pointed to that teaching by videos was superior to F2F classes. There are, however, also challenges identified in previous research. For example, Kay et al. (2021) divides such challenges into reasons not to use (e.g. technical problems, lack of time), attitudes (videos seen as add-ons at best), behaviors (lower attendance at lectures, self-discipline issues) and learning performance (no improvement in test scores).

Regarding if, and how, students use videos for learning, there are some insights from previous research. Gorissen et al. (2013) focused on lectures that were available online after first being live lectures. They found a span of student behavior, from some that only watched the beginning of the recorded lecture, others looked at parts of the lectures, while some watched almost the complete recorded lecture. This diversity poses a challenge for teachers when they design their courses. Gorissen et al. (2012) also noted thirteen reasons for viewing recorded lectures, and of these making up for a missed lecture, preparing for the exam and improving test scores were three of the highest ranked reasons.

Brame (2016) argue that teachers should consider three elements when using videos as an educational tool: cognitive load (i.e. memory-related), elements that impact student engagement, and elements that promote active learning (as opposed to passive learning). Keeping these three elements in mind, Brame (2016) arrives at some general recommendations for using videos in teaching:

- Videos should preferably be kept brief and relate to learning goals.
- Audio and visual elements should preferably be combined to explain targeted issues.
- Signaling, i.e. text or symbols, can be used to highlight important ideas or concepts.
- Engagement can be enhanced through a conversational, enthusiastic style in the videos.
- Facilitate active learning by combining videos with guiding questions, interactive elements, or associated homework assignments.

Marketing literature and teaching

A concept coined in the marketing literature by e.g. Grönroos (2011) is creation of value by combining the provider (of a product or service) sphere with the customer sphere. In service logic, providers offer value proposition in terms of service, and they can be viewed as a value facilitator to the value created in the customer spere (Vargo & Lusch, 2008). Furthermore, there is also interaction where the two spheres overlap, i.e. joint value creation process. Providers participate together with the customers in this interaction and providers can therefore be viewed as a co-producer of value (Grönroos, 2011).

With inspiration from the spheres presented in Grönroos (2011), similar logic can be applied to education. The provider sphere (creation of the offer) can be translated to teachers that design courses and course materials (e.g. recording videos). The customer sphere is the students who use the course materials at their own time (e.g. watching the videos). The overlap between the spheres is when teachers and students interact, for example at F2F activities.

METHOD

This paper is part of a one-year long pedagogical development project that targeted the use of videos in teaching and how they can be used for preparation before F2F activities. Two separate methods were used, semi-structured interviews with teachers who were also course coordinators (i.e. responsible for the course design) and a survey capturing the student perspective. All data were collected from courses in logistics management or quality management and the courses are mainly for engineering students at master level.

Interviews were selected since it made it possible to adapt questions, something that is highlighted as a benefit with interviews by Bryman and Bell (2015). This was important as there was a need for adaptation based on how videos had been used in the courses. To secure a high dependability, the same interview guide was used for all interviews (see e.g. Halldorsson & Aastrup, 2003). The questions in the interviews targeted for example how videos had been used, what effects videos had on course design, and teachers´ perceptions of effects on learning outcomes for the students. In total, eleven teachers were interviewed, which encompasses 20 courses. Two researchers were present for all interviews, with one in charge of questions and one responsible for taking notes. The length of the interviews was about 45 minutes. To increase credibility, the notes were later summarized and discussed between the researchers to ensure that no information was missed or misunderstood.

A survey has the benefits of reaching a high number of respondents and creating a broad view of a subject (Visser *et al.*, 2000), something that was of relevance in this case since the aim was to create a view on e.g. how students use videos when they study. A total of 15 questions were formulated in the survey and they were a mix of questions with a five-point Likert scale, given alternatives, and open-ended questions. The questions in the survey were tested and reviewed by two teachers and two students to ensure that the survey was comprehensible. The survey was sent out to all students that had taken any of the courses that were included in the interview study (in total 751 students in year 3, 4 or 5 in engineering education). The survey was provided in both Swedish and English, which enabled the respondents to choose preferred language. A total of 166 out of 751 students, i.e. 22%, answered the survey and a large number of comments were submitted which provided a more multifaceted view of the results of the survey. The question with the most comments got 77 unique comments (i.e. 46% of the students that answered the question left a comment)

EMPIRICAL RESULTS - INTEGRATING AND INTEGRATED VIDEOS IN COURSE DESIGN

Results from the interviews

Interesting insights were found about how teachers integrated videos in course design based on the 20 courses included in the study. For example, videos had been used as self-education material or as preparation material for different types of F2F teaching (question time, seminar, lecture developing the video content, interactive lecture adding new content, tutorials or labs).

Redesigning of course structure when using videos

When redesigning courses, the teachers' considerations foremost concerned the links between the content of the course, course objectives and examination. Additional considerations were about the rhythm of the course (when learning activities are to be performed and when to release videos), and about the fact that it is time-consuming to create and distribute videos. Four different methods of redesigning courses to fit the new course material of video were identified:

- *Straight transformation*: former F2F lectures turned into a video with only minor adjustments.
- *Selected transformation:* basic knowledge cut out from F2F lectures and turned into video; remaining content highlighted in F2F occasions as prior to change.
- *Total redesign:* redesigned content and course design, thorough reworking of the course structure where some parts are video (e.g. literature areas or lab instructions), other course elements are updated or redesigned
- *Instructions:* instructions formerly in text or oral (e.g., labs, tools, formulas, instructions for a specific task or specific element such as Excel tutorials) turned into videos.

Designed support for processing the content of videos

Another theme found from the interviews shows how teachers designed support for processing the content of videos by adding new activities into the courses. Four different supporting activities were identified:

• *Simpler processing of the content:* reconciliation by quizzes or polls
• *Slot for questions:* more or less structured question time concerning the content of the video
• *Seminars:* planned opportunity for discussion and further analysis of the video content, possible preparation by varied level of threshold
• *Specific tasks:* specific individual or group assignment

There were also examples of no designed support for processing the content, thereby leading to one-way communication as the students process the videos themselves without feedback on their learning.

Added interaction activities

Several teachers added F2F interaction activities (nonmandatory) by discussion and analysis beyond consolidate the video content rather develop and add further dimensioned to the content as well as challenging the students' mindsets were also discovered through the interviews. The common question seemed to be what the students should be told in the video and not how to nudge them to reflect about a certain content to properly be prepared for the F2F teaching. There was also a consensus regarding the importance of a clear and limited task with a reasonable scope for the students to prepare based on a video to achieve good interaction at F2F activities. It thus turned out that teachers often struggled to get students to participate in the interactive activities. To attract students the teachers designed the videos to breed curiosity so that the students must attend the lecture to hear what the others have to say about a certain question or tried to attract the students by pointing at the exam where there would be reasoning and analyzing questions. The interactive activities were carried out in particular by *controlled discussions* and *prepared questions,* for example by:

• news articles linked to some theme from videos
• extended theory review
• repeat certain parts of the video and question the content
• open broad discussion, but through preparation from the teacher, the discussion narrows down to manageable
• specific questions to start a discussion prepared by teachers
• prepared questions by students, specified topic
• prepared answer matrix with pros and cons for students to try to fill in boxes
• simple questions as: what was the most challenging from the movies? What do you want more detail described?
• polls with basic knowledge or concepts

Results from the survey

How videos have been used by students

When it comes to how students are using videos, 75% of the students answered that they watch videos more than one time, and the reason was foremost to repeat specific parts of videos throughout the course (85%) or repeat in close connection to exams (36%). From the comments, multiple respondents noted that they had the opportunity to repeat specific parts that were more difficult to understand. To be able to listen to the lecturer’s explanation was viewed as a great complement to the slides and other course materials. Furthermore, it was also noted that being able to pause and rewind the videos reduced the stress for the students.

Regarding when students watch videos, 54% answered that they watch the videos continuously during the course, 42% only watch when recommended by the teachers, and 56% answered that they watch them in relation to assignments or exams. Based on the comments from the respondents, two types of groups exist in relation to the question. One group that appreciates the flexibility with videos and that they can watch it anytime and do not see the need to have watching videos scheduled. While the other group requested planned times in the schedule to watch videos since the students are usually fully booked.

Preferred type of videos

If traditional lectures/activities (typically 90 minutes) are replaced or complemented with videos, there is a need to understand how the students view alternatives. Table 1 below shows the distribution of the answer, and as can be seen the most popular answer was that the lecture was to be broken down into several shorter videos that focus on specific topics. When it comes to teaching activities that were preferred to be transformed into videos, 82% of the respondents answered that they preferred instructions for e.g., a computer program to be recorded.

Table 1. Distribution of preferred alternatives

Preferred alternative if a traditional lecture is transformed into videos	
Several shorter videos	82
Two videos, 45 minutes each	41
A 90-minute video	37
Other	4
Do not know	2

Based on the comments, it was highlighted that a video takes longer time to watch, compared to live lectures, since students often pause and rewind. Teachers often did not take it into account and students ended up spending more time than was planned.

Students' view of F2F activities

On the question how students viewed interactive activities (an example of F2F activity) as part of their education, 3,91 out of 5 (Likert-scale) noted that they desired interactive activities with both other students and teachers. However, students preferred, to a larger degree, to not go to the campus if the most important course materials were available on videos (2,97 out of 5 points). Furthermore, 103 out of 166 (62%) noted that interactive activities are important to gain new insights and 72 (43%) noted that interactive activities are important to achieve learning outcomes. Lastly, 26 (16%) students answered that they do not like interactive activities and want to learn by themselves. The comments indicate that interactive activities can look vastly different, and this also affects the students' view of them. Examples of interactive activities brought up were discussions in smaller groups during lectures, scheduled QnA, and seminars focusing on specific parts.

DISCUSSION - CHALLENGES AND OPPORTUNITIES

Pre-recorded videos as course material provide opportunities, while at the same time there are several challenges in dealing with an additional form of teaching. This study observed challenges for both teachers and students from their perspective.

For teachers

Video design

Both challenges and opportunities arise when you separate the teaching from the meeting between student and teacher. The aspect of eternity is markedly present when designing and recording a video for teaching in contrast to traditional live lecture where the teacher's words are deleted at the same time as they were uttered. It seems to be a “forced” course development as the material is more processed and the video content maybe thereby also is more concentrated and maybe more adequate for the content of the course, course objectives and examination. The students also seem to take everything in the videos as equally important thereby forcing teachers to deliver more concentrated content and to make it explicit. Videos are used as "fact boxes", jeopardizing the discourse, how things are connected and the total picture. Is the video a new kind of compendium instead of reading? Another concern is the pedagogical ability to create teaching via video for different types of learning.

A technical aspects of video construction have also been recognized. The students describe that video takes longer time to watch in contrast to a live lecture since they use the opportunity to re-watch and pause when needed in addition to the difficulties of maintaining concentration when watching videos. However, like Gorissen et al. (2013) found there is a span of watching behaviors and Gorissen et al. (2012) thirteen reasons for viewing videos also were detected in the included student survey. This diversity poses a challenge for teachers and a need to adapt the video design to this knowledge about students´ watching behavior. In line with Brame (2016), students in this study preferred shorter videos with content divided into segments.

Creating purposeful videos always takes time and focus and challenges the educator (Brame, 2016). A video can potentially be reused over and over, thus creating economies of scale. However, questions arise about the actual efficiency in reusing since the recurring distribution also must be included as well as questions about how self-critical you can be, how time independent the content is, and if it is acceptable to use videos made by former colleagues.

Lecture design

The F2F activities have a more important role when videos are used, since some of the interaction that happens naturally during regular lectures is removed. This points to the need for thought-through F2F activities. Depending on the content and the role of the videos, different challenges arise when integrating videos in the F2F teaching. When the video is used for instructions to an assignment or a tool (e.g., calculation in Excel) or laboratory work, it seems to be quite unproblematic with designing the F2F. Although, when the purpose is interaction, to consolidate the knowledge or to improve the students´ ability to analyze or increase the insights, it seems to become more problematic.

One challenge concerns the separation between basic facts presented in videos, and the discussions, and reasoning (higher learning taxonomy) taking place at lectures. Videos are more available for students but risk fewer coming to F2F, while at the same time creating opportunities for higher qualitative discussions and analyses when students are prepared at lectures via videos. Do we risk isolation of basic facts in monologue for self-studies and only interaction for ambitious students? Though, it can lead to increased progression since the course materials are treated in different stages and at different levels. In accordance with Grönroos (2011), the teacher can actively affect the students and hence the potential for learning. An additional challenge is the lack of possibility to get feedback from the students to develop content, structure, or technical aspects in producing teaching videos as teachers are not present when students consume videos.

The former standard time for a lecture, e.g., 2x45 minutes, can now be questioned as some teaching takes place via videos. Is watching videos self-study or is it to be compared to a scheduled lecture? Depending on the answer, it affects the scheduled time for F2F teaching. The restructuring of learning activities by isolating the teaching monologue to videos leads to new demands on the lecture design. Is it for example still acceptable to have a teacher monolog when lecturing? How to attract students to participate at the interactive moment was a challenge raised by the teachers, and Kay et al. (2021) also reported such behavioral challenges (e.g. lower attendance on lectures and self-discipline issues). Time, focus, and creativity are invested in attracting students to interact and to attend lectures. Perhaps the teacher's identity is challenged when students can consume lectures by videos. The joint value creation process described by Grönroos (2011) in this interaction the teacher can participate together with the students and be a co-producer of learning. But teach without meeting, who am I as a teacher then?

Further opportunities and challenges are due to the issue of responsibility and commitment. At the same time as teachers are to produce pedagogical, informative, and content-relevant videos, teachers can teach but not learn for the students since they are the ones who learn by them self. A balancing act where teachers cannot take the necessary commitment in learning from the students by making it unrealistically easy for them nor transfer the pedagogy responsibility to the students by abandon them with videos. Gorissen et al. (2012) found that students´ perception of courses´ importance for their studies could impact the way in which students engage in watching videos. The video can thus be seen as a trigger for learning and the interaction in F2F depending on how well videos are integrated in the course design.

For Students

Capture the advantages of videos

One of the main advantages of videos is the possibility to pause and rewind the videos, something that can make the content more understandable and easier to digest. With the videos available during courses, there is also the potential to repeat the content as preparation for exams or to rewatch something during the course. The survey showed that this was highly desired by the students and is in line with the results from Gorissen et al. (2012). When it comes to the type of course materials that students preferred to be recorded on videos, a large majority wanted instructions or tutorials. This is not surprising, especially if this includes tutorials for some type of computer application. Having the opportunity to rewatch certain segments and at your own pace go through the same steps as the teacher can be very beneficial. By eliminating or simplifying certain thresholds connected to applications, students can instead focus on deepening their understanding in relation to courses' learning objectives.

Basic knowledge of videos

As the results from the interviews with teachers show, videos can be incorporated in different ways in the course design, and this affects the type of impact it has on the students' learning outcomes. Examples from the empirical data show that videos can be used to present more basic knowledge or information that is needed to understand the next step. By doing this, there is the possibility to evoke students' interest, making them more involved, and the possibility for them to reflect on the course material. Basic knowledge is the first step, the next step is to deepen students' understanding, for example, during F2F activities with both students and teachers. By having watched videos and hopefully created a basic knowledge of the subject, the F2F activities can be designed in a different way and not focus on more basic knowledge.

Flexibility when to watch

The nature of videos implies that they can be watched anytime, which also means that there is great flexibility. In line with Gorissen et al. (2012), the results from the survey showed that students appreciate this flexibility. As many as 75% of the students in the survey noted that they watched the videos more than once, and often at different times during a course. However, flexibility also has its downsides, for example, when there is the opportunity to watch videos anytime, there is also the risk of postponing, especially if there is no follow-up or teaching activity that requires students to have watched the videos. When there are lectures live in classes, students know that this is the sole opportunity to receive the course material orally, a vast difference compared to videos. Furthermore, even if videos can lead to more flexibility and some of the learning is moved from lecture halls to students' homes, there is a risk that students will not travel to campuses to the same degree. Kay et al. (2021) describes such challenges as behavior problems with lower attendance at lectures and self-discipline issues among students. This can possibly also negatively affect students' social connections, reduce crosstalk between students, and their motivation.

CONCLUSIONS

There are lots of challenges and opportunities associated with integrating pre-recorded videos in course design in traditional campus teaching. This paper describes three thematic areas concerning these topics for both teachers redesigning courses and implementation as well as students who experience it attending the courses: technical issues, increased flexibility, and digital paradigm shift.

Technical issues concern designing and recording videos. It takes time and focus to do that, and this study provides insight into students' viewing behavior and wishes about how videos are structured in terms of both content and form. However, to achieve economies of scale or at least not increase the need for resources, videos should be able to be reused or used in more than one course. When videos become a part of the course material it affects the remaining learning activities, requiring a need for redesign and probably changed pedagogy. The potential for tutorials and similar interventions seems higher and less problematic than separating course material within current lectures. Moreover, from a student's perspective it is also time consuming to watch videos duo to the possibility of rewind and review, like reading a text over again. Hence, an updated study techniques to highlight the most important things and not to fall into the time devastating everything-is-important-trap seems to be a necessary development.

As for increased flexibility, videos give the students an opportunity to shape their own learning opportunity and thus learn individually according to what suits them. Flexibility in everyday life and the student themselves customize learning. Students have an increased opportunity to plan their own time for group work, laboratory work, lectures, etc., and can consume the videos in a way they prefer on an individual level. In a larger sense, collection of videos can be combined into modules and the modules can be used in a larger context than just one course. This has the potential to increase flexibility even more, where students can pick relevant modules and individualize their learning experience. Additionally, the former standard time and concept of lectures can now be questioned and provide more flexibility for the teachers as well.

The third area is digital paradigm shift. The digital transformation in society affects both teachers, students, and the meeting between them. This journey has just begun, and it is an exciting paradigm shift we are all in. It is similar, in fact, as when the art of printing made books available to the public. However, all available information and knowledge, such as lessons on YouTube, are available to the public. A free knowledge society, but is that free? New abilities in navigating and valuing knowledge then become more important. We teachers also contribute to the abundance of information and videos can help us in condensing the messages and knowledge we want to convey. Nevertheless, one of the downsides of using videos is the risk of students relying too much on them and not, to the same extent, using other course materials. This can negatively affect students' learning outcomes since textbooks and articles usually go more in-depth of the subjects than what is possible on videos. Furthermore, by tying information into videos, there is a risk that this affects students' ability to find information themselves in either textbooks or other media. There is also a risk of students' skills of independently questioning and critically reviewing material being affected. This further points to the need for teachers to not just record videos, but also have a well thought out plan on how the videos are integrated into the course.

The paper relates to the CDIO standards in primarily three ways. Standard 8 includes active learning methods, and enabling such learning is one of the challenges with integrating videos in traditional campus courses. The findings correlate to CDIO standard 10, as they can have a direct impact on teachers' competence and ability to develop courses that include the benefits of videos, without jeopardizing the learning of the students. As for CDIO standard 6, which relates to engineering workspaces, the paper contributes by identifying how students gain knowledge, and also where (through videos or other teaching activities) such learning occurs.

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CDIO-BASED SYLLABUS DESIGN IN THE CONTEXT OF TEACHER EDUCATION

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ABSTRACT

Although the CDIO framework was originally developed to serve the purpose of producing the next generation of engineers, it has been implemented for non-engineering programs such as development practice (Martins, Ferreira & Quadrado, 2017), informative media (Thollar & Rian, 2020), food science and technology, music and audio technology, library information services, chemistry, and business (Malmqvist et al., 2016). Yet not much literature has focused on how the framework can be adopted for teacher education programs. This paper starts with arguments for the feasibility of CDIO application in the context of teacher education at a university in Vietnam. It argues that a teacher also goes through the cycle of conceive, design, implement and operate, and that the CDIO standards fit the requirements of quality assurance and accreditation conventionally set for teacher educational programs. In the paper, a CDIO-based syllabus for English language teacher education programs is proposed. The syllabus contains four pillars (disciplinary knowledge and reasoning, personal and professional skills and attributes, interpersonal skills, and conceive, design, implement and operate English programs in the school context), each of which consists of knowledge, skills, and attitudes necessary for the teaching profession. While more evidence may be needed to prove its effectiveness, the syllabus has successfully described the most essential requirements for a high school teacher, serving as a guide for the lecturers as they redesign courses for the program.

KEYWORDS

CDIO syllabus design, CDIO standards, teacher education, non-engineering programs, Standards 1, 2, 3

INTRODUCTION

Over the past decade, the CDIO approach has gained its popularity among educators of both engineering and non-engineering programs. The flexibility of this framework allows curriculum designers to apply it to quite a few other fields than engineering. Previous studies have reported that the CDIO implementation in non-engineering disciplines can produce better quality assurance and strengthen the connection to the professional context (Crawley et al., 2014; Malmqvist et al., 2016; Thollar & Rian, 2020). Along similar lines, a group of colleagues at Vinh University, Vietnam have attempted to formulate a CDIO-based syllabus for teacher education, based on which a set of learning outcomes (LOs) for the English language teacher education program was established. In this paper, we will explain why the CDIO framework might be a good fit for teacher education, and then describe how the CDIO teacher education syllabus was constructed. In addition, the paper will present the process of converting this general syllabus into a bank of LOs for a specific program, in this case, the English language teacher education.

LITERATURE REVIEW

CDIO Implementation in Non-Engineering Disciplines

The benefits of CDIO implementation in non-engineering disciplines have been reported in several previous studies. Malmqvist et al. (2016), for example, assert that the CDIO framework can be applied in science, business, performing arts and other areas. The study examined six cases of CDIO implementation, including Food Science and Technology, Music and Audio Technology at Singapore Polytechnic, Singapore; Business and Library and information Services at Turku University of Applied Science, Finland; and Chemistry and International Business at Vietnam National University-Ho Chi Minh City, Vietnam. The results indicate that the CDIO approach is applicable in non-engineering disciplines as long as a professional context of the education is identified and the CDIO standards are translated to the said context. The adaptation of the CDIO framework allowed those programs to be reformed systematically and encouraged the faculty to improve pedagogical competence. It also led to better program management and multi-disciplinary collaboration amongst staff and students. In addition, the CDIO syllabus promoted integration of critical and creative thinking as well as ethics and responsibilities.

Past research has also explored cases in which the CDIO syllabus was adapted for non-engineering programs. For instance, Fahlgren et al. (2018) described why and how the CDIO framework was implemented to a BSc program in biomedicine at Linköping University. The rationale for the adaptation was that new employment categories were being created for alumni while the main focus of the program had always been to provide graduates with academic skills, which had resulted in substantial decrease in enrolment rate. The educators, therefore, initiated the adaptation of the CDIO framework to include a clearer educational profile and assist learners to develop skills that were necessary for their work outside academia. The redesigned program contained project-integrated courses that facilitated learners' professional skill development. These projects run parallel with courses that focused on disciplinary subjects. The outcome of a CDIO syllabus survey, which was distributed to the students and professionals, showed that the CDIO framework is beneficial for programs within the biomedicine field (Fahlgren at al., 2019).

Along similar lines, Thollar and Rian (2020) surveyed the application of CDIO to a non-engineering educational environment with four adaptations of CDIO standards: Clinical Engineering Education, Business Systems in Education Network for Practical Information Technologies, Short-term ICT-based International Workshop, and Teaching Business Concept of Creating Shared Value. It was found that during this adaptation process, the curriculum was designed with closer attention to stakeholders' needs and requirements. It, therefore, included cross-departmental subjects and offered more integrated learning experiences and design-implement experiences.

Another case of CDIO adaptation in non-engineering disciplines was reported by Martins, Ferreira and Quadrado (2017). In this paper, the authors explained how CDIO was used in the process of designing a master-in-development-practice program. The scholars applied the full stack of CDIO standards in the spirit of problem solving and project development process. The curriculum was constructed to enhance learners' development of competences that are necessary for sustainable development goals. It was reported that the faculty members found the framework useful. Based on this evidence, the authors contend that it is possible to adapt the CDIO approach to support the design of a non-engineering program.

CDIO Implementation in Teacher Education

Although CDIO adaptation for non-engineering programs have been reported by other educators too (Petrova et al., 2017; Tangkijviwat et al., 2017), the literature in CDIO application to teacher education is still in its infancy. Among the very few publications related to this topic is the paper by Dunbar, Seery and Gordon (2006). The authors presented the process of integrating the CDIO philosophy into the newly revised modules of an undergraduate teacher education program. The adaptation framework they deployed shows a cyclical process, as shown in Figure 1.

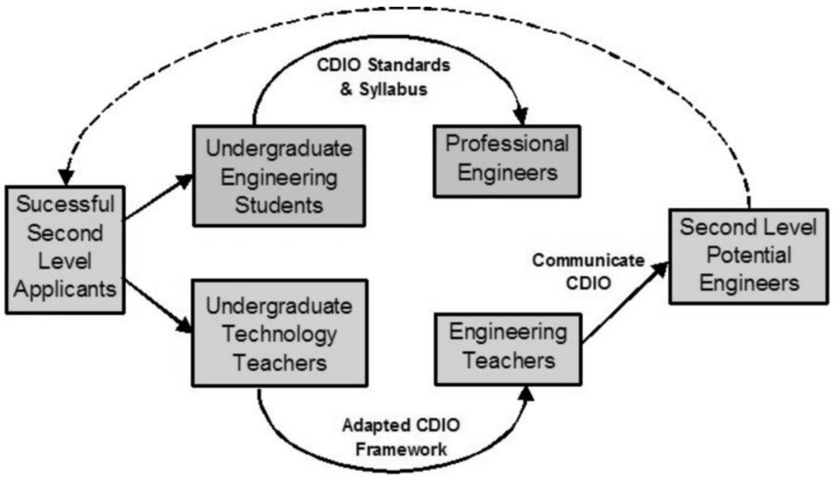

Figure 1 Adapting CDIO for Teacher Training (Dunbar, Seery & Gordon, 2006)

One of the procedures carried out in the reported process is to determine the students' learning styles. An analysis of the students' learning experienced when faced with an alternative educational paradigm was carried out, too. In addition, inter-group variations of student attitudes and preferences were examined. The research methods and instruments included questionnaire surveys, focus group interviews and evaluation mechanism. The results suggested that the students were highly motivated, holding positive attitudes towards the more collaborative learning environment. These findings have highlighted the advantages of the CDIO framework for teacher education programs.

CONTEXT OF THE WORK

Vinh University has adapted the CDIO framework for its educational programs since 2016 (Tran, Tran & Nguyen, 2020). As it is a multi-disciplinary university providing both engineering and non-engineering programs, the implementation of the CDIO approach was a tenuous process at first. Most of the faculty had very little experience with curriculum development and the CDIO philosophy. However, as more and more staff members were given opportunities to attend workshops and conferences on syllabus design and CDIO, we managed to perform a comprehensive review of all 43 then-running programs. A CDIO expert group was formed to provide faculty members involved in the curriculum design with consultation and guides. Within two years, the then-existing programs were redesigned, showing that our efforts were paid off. The new curricula were launched in September 2018. In 2020, another curriculum review was carried out. Changes and modification have been made to the program LOs and specifications. In September 2021, the revised versions started to go into effect. In short, this five years experience of CDIO adaptation can be described as a struggling, laborious but very rewarding process.

Among the 43 programs that the University offers, the teacher education programs account for around 30%. These include programs such as Bachelor of Chemistry Education, Bachelor of Mathematics Education, Bachelor of Physics Education, Bachelor of Geography Education, Bachelor of English Education, Bachelor of History Education, Bachelor of Biology Education, Bachelor of Physical Education and so forth. During the first four years of curriculum renovation, equal attention was paid to the application of the CDIO philosophy in teacher education as to other disciplines. There was no collaboration among the faculty members of different programs. However, since 2021, the University administrators started to put immense emphasis on developing teacher education programs. By that time the faculty had realized that no matter which subject a teacher student would teach in the future, they should possess certain skills and attitudes that are necessary for the teaching profession. For these reasons, a group of experienced curriculum designers and educators were assigned to execute a project to design a CDIO teacher education syllabus. This general syllabus would be used as a guide for the 14 teacher education programs to establish their own set of LOs. This would allow the programs to provide stakeholders with a general picture of a teacher student graduating from Vinh University and at the same time show them the competencies that are specific to each program.

APPROACH AND PRODUCT

In order to construct the CDIO teacher education syllabus, the expert group held a few meetings in which they discussed approaches they would use. After a lot of discussion, they reached a consensus that the syllabus would be built on the basis of:

- The Vietnamese Qualifications Framework for Higher Education (See Table 1)
- K12 teacher standards (Vietnam Ministry of Education and Training, 2018)
- The CDIO syllabus and philosophy
- The University's mission, vision, goals, and educational philosophy
- The characteristics of the teaching profession
- The needs of stakeholders (yielded from the stakeholder survey previously done in another project)

Table 1 Vietnamese Qualifications Framework

Knowledge	*Skill*	*Level of Autonomy and Responsibility*
A. Solid practical knowledge and advanced theoretical knowledge of the discipline B. Fundamental knowledge of social sciences, politics and law C. Knowledge of technology to meet job requirements D. Knowledge of planning, execution and supervision of plans E. Fundamental knowledge of management and administration of professional activities	A. Necessary skills of solving complex problems B. Leadership skills C. Entrepreneurship skills D. Skills of creating work for self and others E. Critical thinking F. Skills of using alternative solutions in changing environment G Skills of evaluating the work after completing it and assess the results by team members H. Skills of explaining a problem and solution to other people I. Skills of transferring knowledge and skills in performing specific or complex tasks J. Proficiency at Level 3 in a foreign language	A. Work independently or in teams in a working environment that is subject to change B. Take responsibility for self and for the team C. Instruct and supervise others' performance of a specific task D. Self-direct, make professional conclusions and defense personal opinions E. Make plans, manage resources, evaluate and improve practice

Table 2 The Teacher Education Syllabus

Code	LOs
1	*Disciplinary Knowledge and Reasoning*
1.1	*Apply knowledge of basic sciences in teaching, education and research*
1.1.1	Explain fundamental issues in social sciences, politics and law
1.1.2	Apply fundamental disciplinary knowledge
1.1.3	Apply specialized disciplinary knowledge
1.2	*Apply knowledge of educational science in teaching, education and applied educational research*
1.2.1	Explain the rules of psychological, mental, intellectual, physical and social development that affect learners' learning
1.2.2	Analyze the nature and process of planning for teaching, testing and assessment, and curriculum development
1.2.3	Analyze the nature and process of executing and organizing educational, vocational, cultural and experiential learning activities
1.3	*Apply advanced knowledge to meet the requirements of the society*
1.3.1	Apply advanced knowledge of basic and applied sciences
1.3.2	Apply advanced knowledge of educational science
2	*Personal and professional skills and attributes*
2.1	*Deploy personal and professional skills to solve problems in education*
2.1.1	Apply critical thinking, system thinking, problem-solving and creative thinking
2.1.2	Apply self-study skills for proactive professional development and change adaptation
2.1.3	Apply technologies to design and operate teaching activities and school management
2.1.4	Apply teaching methods for the subject to meet the demand of educational innovation
2.1.5	Apply teacher professional skills to educate learners and build an educational environment
2.1.6	Apply basic practicing and experimenting skills for teaching and research
2.2	*Demonstrate personal and professional attributes of a teacher*
2.2.1	Demonstrate the spirit of continuous learning and self-developing to improve teacher dignity
2.2.2	Demonstrate work ethics and conducts that are suitable to the teaching profession
3	*Interpersonal skills and communication*
3.1	*Apply collaboration and teamwork skills in teaching, education and research*
3.1.1	Apply collaboration skills to share with stakeholders about learning and professional practice
3.1.2	Apply teamwork skills to effectively perform assigned tasks in learning and professional practice
3.2	*Apply communication skills in teaching, education and research*
3.2.1	Use modes of communication suitable to the professional context
3.2.2	Use a foreign language at Level 3 in the Vietnamese National Framework of Reference for Foreign Languages in communication and professional practice
4	*Conceive, design, implement and operate teaching and educational plans*
4.1	*Analyze the social and school context*
4.1.1	Analyze the social context in relation to the K12 or kindergarten educational context
4.1.2	Analyze the school context of teaching and educational plans
4.2	*Conceive, design, implement and operate teaching and educational plans in the social and school context*
4.2.1	Formulate ideas for teaching and educational plans
4.2.2	Design teaching and educational plans
4.2.3	Implement teaching and educational plans
4.2.4	Operate teaching and educational plans

After the first draft of the CDIO teacher education syllabus was made, it was sent out for feedback collection, hence modification. It was a rather strenuous and time-consuming process, during which we continuously argued, debated, reviewed, and revised the product.

Table 2 shows the final version of the syllabus. Constructed from the CDIO syllabus, it is comprised of many items found in the CDIO syllabus. We believe that whether people work as teachers or engineers, they need a group of skills and attributes that are desirable in any profession. Some examples of these skills and attributes are creative thinking, critical thinking, system thinking, life-long learning, teamwork skills, communication skills, communication in a foreign language, ethics, and social responsibility. As it can be seen from Table 2, the CDIO teacher education syllabus contains four pillars: disciplinary knowledge and reasoning, personal and professional skills and attributes, interpersonal skills, and conceive, design, implement and operate teaching and educational programs in the school context. We are convinced that if the central of an engineer's work is a product, process, or system, the central of a teacher's work is teaching and educational activities. Teachers should be able to formulate ideas (conceive); transfer them into a teaching and educational plan (design); carry out the planned activities in class/at school (implement); and finally evaluate, develop, and communicate it to other stakeholders such as administrators, parents and the society (operate). Therefore, instead of using the term *'product, process and system*' for Pillar 4, we used the term *'teaching and educational plans*'

The teacher education syllabus also integrates all the competencies presented in the Vietnamese Qualifications Framework. For instance, items Knowledge A and B in the Vietnamese Qualifications Framework are reflected in LOs 1.1.1, 1.1.2 and 1.1.3; item Knowledge C is reflected in LO 2.1.3; items Knowledge D and E are reflected in LOs 1.2.2 and 1.2.3. Similarly, items Skill A, E, F, and H are reflected in LO 2.1.1, 2.1.3, and 2.1.5; item Skill J is reflected in LO 3.2.2. Furthermore, it meets the standards set by the Ministry of Education and Training (Vietnam Ministry of Education and Training, 2018).

Besides those above features, the common syllabus reflects the University's mission, vision, goals, and educational philosophy. Additionally, it captures the characteristics of teaching and is very likely to meet the needs of stakeholders. Note that each topic/heading is expressed using a Bloom verb that indicates the minimum level of competence students are expected to achieve. This is to make sure no programs would set up too low LOs, which may prevent the program to meet the minimum requirements of the government (shown in the Vietnamese Qualifications Framework). When it comes to designing LOs for specific programs, designers can consider changing the level, hence using a different Bloom verb.

As the CDIO teacher education syllabus was approved, it was distributed to the departments that offer teacher education programs, including the foreign languages department, which manages the English teacher education program. Based on the CDIO teacher education syllabus, specific program LOs were constructed by faculty members of the departments.

As it can be seen in Table 2, the common syllabus only provides general descriptions of competencies that a teacher student will have obtained by the time they graduate, with no specific reference to the subject a teacher student specializes in. Therefore, for the set of LOs for the English teacher education program, we made specific reference to the subject (English) in different ways.

First, it is clearly stated in the LOs of the English education program (See Table 3) that by the time of graduation, students will have reached Level 5 of English in the Vietnamese National Framework of Reference for Foreign Languages, which is similar to C1 in Common European Framework of Reference for Languages (Council of Europe, 2021). Second, in a few items of the common syllabus (e.g., 1.1, 1.2, 3.1, 3.2, 4.2), the context is mentioned by the generic term *'teaching, education and research*'. However, in the English teacher education program, we converted the terms into *'teaching English, education and research*'. Besides, while item 2.1.6 (*Apply basic practicing and experimenting skills for teaching and research*) is included in the common syllabus, it is not present in the English teacher education program. This is because the item refers to skills that are not relevant to English language teachers' work. Finally, whenever possible, we have constructed LOs that are specifically relevant to English language teaching. For instance, item 1.1.3 in the general syllabus (*apply advanced disciplinary knowledge*) has been converted into program LO 1.1.3 (*Apply knowledge of the culture, politics, and society of Vietnam and English-speaking countries and translation skills in teaching English, education, and research*). Likewise, item 1.3.1 in the general syllabus (*Apply advanced knowledge of basic and applied sciences*) has been converted into LO 1.3.1 (*Apply advanced English skills and linguistics in teaching English, research and professional development*).

Table 3 The English teacher education program LOs

Code	**LOs**
1	*Apply fundamental knowledge of educational sciences, English skills, linguistics and English language teaching methodology in teaching English, education and research*
1.1	*Apply fundamental knowledge of educational sciences and English skills at Level 5 (Vietnamese National Framework of Reference for Foreign Languages)*
1.1.1	Apply fundamental knowledge of social sciences, politics and law in teaching English, education and research
1.1.2	Apply English skills at Level 5 (Vietnamese National Framework of Reference for Foreign Languages) in teaching English, education and research
1.1.3	Apply knowledge of the culture, society and politics of Vietnam and English-speaking countries and translation skills in teaching English, education and research
1.2	*Apply knowledge of educational sciences and English language teaching methodology in teaching English, testing and research*
1.2.1	Apply knowledge of learners' psychological, mental, physical and social development to provide effective English teaching and education.
1.2.2	Apply knowledge of planning, teaching methods, testing and assessment in English teaching and professional development
1.2.3	Apply knowledge of methods to organize educational, vocational, cultural and experiential learning activities
1.3	*Apply advanced knowledge of linguistics, English teaching methodology and curriculum development in teaching English, research and professional development*
1.3.1	Apply advanced English skills and linguistics in teaching English, research and professional development
1.3.2	Apply advanced knowledge of academic writing, English teaching methodology, curriculum and material development in teaching English, research and professional development
2	*Apply personal and professional skills and attributes in teaching English, education and research*
2.1	*Apply personal and professional skills in teaching English, education and research*
2.1.1	Apply critical thinking, system thinking, problem-solving skills and creative thinking to organize English teaching and educational activities and conduct research in social sciences and educational sciences
2.1.2	Apply self-study skills for professional development
2.1.3	Use technologies and digital materials in English teaching, education and research
2.1.4	Apply English teaching methods for competency-based education to meet the demand of education innovation
2.1.5	Use teacher professional skills to educate learners and build a civilized, friendly, safe and democratic educational environment
2.2	*Demonstrate personal and professional attributes of a teacher*
2.2.1	Demonstrate teacher dignity while carrying out English teaching and educational activities

Code	LOs
2.2.2	Demonstrate work ethics and conducts that are suitable to the teaching profession
3	*Apply collaboration and teamwork skills in English teaching, education and research to meet the demand of adaption to changes in the professional context*
3.1	*Apply collaboration and teamwork skills in English teaching, education and research*
3.1.1	Apply collaboration skills while working with stakeholders and learners to reach shared goals of teaching, education and research
3.1.2	Apply teamwork skills to facilitate cooperation among team members to complete assigned tasks and maintain a constructive working environment
3.2	*Apply multi-modal communication skills and skills in a second foreign language in English teaching, education and research in multi-cultural environments*
3.2.1	Use suitable modes of communication in teaching English, education and research
3.2.2	Use a second foreign language at Level 3 in the Vietnamese National Framework of Reference for Foreign Languages in communication and professional development in multi-cultural environments
4	*Conceive, design, implement and operate English teaching activities and educational activities*
4.1	*Analyze the social and school context*
4.1.1	Analyze the social context in relation to school context and teachers' roles and responsibilities to develop relationships between school, parents and society
4.1.2	Analyze the school context for teaching and educational activities to build an educational culture, promote democracy in school and maintain a safe learning environment
4.2	*Conceive, design, implement and operate English teaching and educational programs*
4.2.1	Formulate ideas for English teaching and educational activities
4.2.2	Design English teaching and educational plans
4.2.3	Implement English teaching and educational plans
4.2.4	Operate English teaching and educational plans

CONCLUSION

The CDIO teacher education syllabus was developed in order to meet the demand of improving and systematizing teacher education at Vinh University. Given that different departments at the University concurrently provide teacher education programs, it was necessary that a common syllabus be established. In the first place, this was to make sure the learning outcomes designed by these departments share common features of the teaching profession. Furthermore, having different department develop learning outcomes based on a common syllabus will guarantee that each program's learning outcomes reflect the University's vision, mission, goals and educational philosophy.

The syllabus was constructed on the basis of the Vietnamese Qualifications Framework, the CDIO syllabus and philosophy, the University's mission, vision, goals, and educational philosophy, the characteristics of the teaching profession and the needs of stakeholders. It consists of many topics in the CDIO syllabus, for the belief that some skills and attributes are universal. In this era of fast changing workforce, it is crucial to equip our students with competencies that most professions require, such as teamwork skills, communication skills, work ethics, life-long learning, critical and creative thinking, system thinking, and problem-solving.

The CDIO teacher education syllabus has been converted into specific banks of learning outcomes for various teacher education programs, including English teacher education. While the profession is generally stated as *teaching* in the common syllabus, in the specific program learning outcomes, the name of the subject is added to differentiate the programs. If not applicable, an item in the general syllabus may not be present in a specific program. In addition, the cognitive level of complexity, and thus the Bloom verb used in the general syllabus, can be changed depending on the characteristics of the program, the needs of stakeholders of the program, and the requirements of the society.

Having a common syllabus brought about tremendous benefits for the program directors and faculty members of the departments that offer teacher education programs. First, it was much more advantageous to have a group of educators and curriculum designers to sit down together and establish a set of common features of all programs. Second, the consensus on universal skills and attributes to be included in the syllabus helped the designers of different programs to easily formulate their program outcomes. Finally, the general syllabus promotes uniformity and consistency among teacher education programs, and hence transparent communication of learning outcomes to their stakeholders.

The usefulness of the CDIO teacher education syllabus may not be limited to its conversion to specific program learning outcomes. It also provides a general description of a teacher's qualifications so that employers can have a clear understanding of their employees' profiles. The syllabus might be used as a reference for policy makers and educational administrators of teacher education in Vietnam. It may be an inspiration for the leaders to put forward regulations and rules that reinforce uniformity and consistency among universities that offer teacher education programs.

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JUST-IN-TIME LEARNING PRODUCT DESIGN AND DEVELOPMENT THROUGH GAMIFICATION

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ABSTRACT

Solving design problems is a core activity in the engineering field. Design teaching is often project based and follows a cycle from idea to implementation, which perfectly fits the Conceive Design Implement Operate (CDIO) approach. However, it is challenging to design teaching using problems that resemble those found in real engineering practice in a single course. Real problems are typically complex and multidisciplinary, requiring the course to cover both the general design content and the content from each specific discipline. Indeed, to support their work during the design process, the diverse engineering disciplines use different tools and techniques, which must be effectively combined. This multidisciplinary content must also be meaningfully linked and delivered in a way that prevents students from losing their interest when dealing with content from a different discipline. This paper proposes an approach to solve this challenge, which combines gamification and just-in-time learning in a flipped-classroom and project-based learning setting. The gamified project creates a scenario (set of specific tasks/problems) for the just-in-time pulling of learning content, which is made available online. The students learn as needed to play the game in class and are assessed according to their reflections on their game choices and results, rather than whether they win or lose the game. This paper explains the proposed approach's background, describes its gamification elements and dynamics, shows its use in a mechanical engineering master's course intervention, and reflects on the results from the intervention implementation. The students' feedback shows that the approach was able to bring awareness on how the different engineering disciplines contribute to the design problem solution while keeping the students motivated and engaged in the course's activities.

KEYWORDS

Design Teaching, Active learning, Blended Learning, Gamification, CDIO_Standard 4, CDIO Standard 8

INTRODUCTION

Engineering education must help learners develop analytical, communication and teamwork skills, alongside independent learning, while meeting ever-increasing content demands for solving engineering practice problems (Jonassen, 2015; Johri et al., 2011). In this context, design is widely considered to be a core and distinguishing activity of engineering and is probably the most common kind of problem in engineering practice (Simon, 1996; Mills &

Treagust, 2003). Design problems are typically complex and require an interdisciplinary approach, thus integrating multiple content domains.

Due to the amount of content involved, teaching product design and development (PDD) in a setting that resembles reality is a challenge (Dym et al., 2005). It requires covering the general design and development process theory and the content from each involved discipline (i.e. design tools and techniques typically used by the discipline). It also must provide a meaningful relationship between these areas while making sure that students do not lose interest when dealing with the content from disciplines that are not their own. In addition, not only do the diverse engineering disciplines use different tools and techniques (T&T) that can be combined in different ways, but new T&T also become available every day. Therefore, learning how to choose and combine promising T&T during each PDD phase and defining an appropriate PDD processes to specific PDD scenarios is an important learning goal.

The underlying research question behind this work is, 'How can design T&T choosing be taught so that an adequate development process is defined according to a realistically complex and multidisciplinary PDD scenario?' To contribute to answering this question, this paper aims to propose, explain and discuss the results from the implementation of an intervention in a mechanical engineering master's course, which served as a preliminary validation of an approach that uses gamification to pull just-in-time learning in a flipped-classroom and project-based learning setting. The choice of a gamified scenario instead of a real development is motivated by the complexity of including an actual multidisciplinary product development and its common possible issues (what-if analysis) in the context of a single course. The proposed approach embeds the Conceive-Design-Implement-Operate (CDIO) framework in a game in which the 'product' is the PDD process that each team has to define, serving as a competition for how to best solve the proposed challenge.

This paper is a follow-up from Pereira Pessoa, Oude Alink, et al. (2021) and Pereira Pessoa, Wachter, et al. (2021), which proposed but did not implement need-based learning (NBL) and gamification in the Ingenious game. The following sections present the background behind the gamified approach development, detail the developed game and gamification approach elements and mechanics, describe a design course intervention by using the approach, discuss the intervention implementation and the achieved results and reflect on the achieved results and on the students' feedback.

BACKGROUND

The developed gamified approach relied mainly on the NBL pedagogical model (Pereira Pessoa, Oude Alink, et al., 2021) and gamification theory, particularly through the Octalysis Framework (Chou, 2016) and the Ingenious game (Pereira Pessoa, Wachter, et al., 2021). Note that 'need' in the context of NBL is about the students' need of knowledge to perform a task or to overcome a challenge and not about identifying the users' needs during a design process. Therefore, in NBL, the students learn when and what is needed.

Need-Based Learning

The NBL model is composed of six activities (Pereira Pessoa, Oude Alink, et al., 2021) that require combining different pedagogical approaches: project-based learning (PBL), just-in-time learning (JIT learning), the flipped classroom and gamification. JIT learning is an individual or organisational learning approach that promotes need-related training be readily available exactly when and how it is needed by the learner (Riel, 2000), thus avoiding pre-scheduled education sessions that occur regardless of the immediacy or scope of need (Brandenburg & Ellinger, 2003). Although blended learning approaches, such as flipped classrooms, have been used to change the classroom focus to a more practical approach and let students reach the theoretical content online (Bergmann & Sams, 2014), they are limited in terms of adaptiveness and just-in-time content delivery. The challenge in using JIT learning is anticipating the various learners' needs and creating focused and accessible content (Govindasamy, 2001), which is why it is normally used in more predictable contexts like job trainings. In NBL, the game creates such a context by scoping the learning content to be pulled.

In Figure 1, the activities with grey backgrounds are led by the lecturer, while the activities with white backgrounds are mainly student driven. The NBL's student-driven activities embed the CDIO approach, which is in line with Crawley et al. (2014), who stated the capacity for PBL to incorporate CDIO. The activities 'select', 'create' and 'reflect' relate to CDIO's 'conceive and design', 'design and implement' and 'implement and operate', respectively.

Course design under NBL requires first setting the project challenge characteristics and creating a game that represents the project execution. The supporting theory is made available online using methods such as videos, articles and wiki pages. This theory is necessary for playing the game (executing the project) and can be accessed as needed. Before coming to class, the students use the theory to define their gameplay strategy (flipped classroom). The gameplay and the playing reflection take place during class time. The lecturer gives feedback, further explains the theory and ends the cycle by performing a summative evaluation of the students' performance. Technology support is only necessary for hosting the theoretical material, and the game does not need to be based on software.

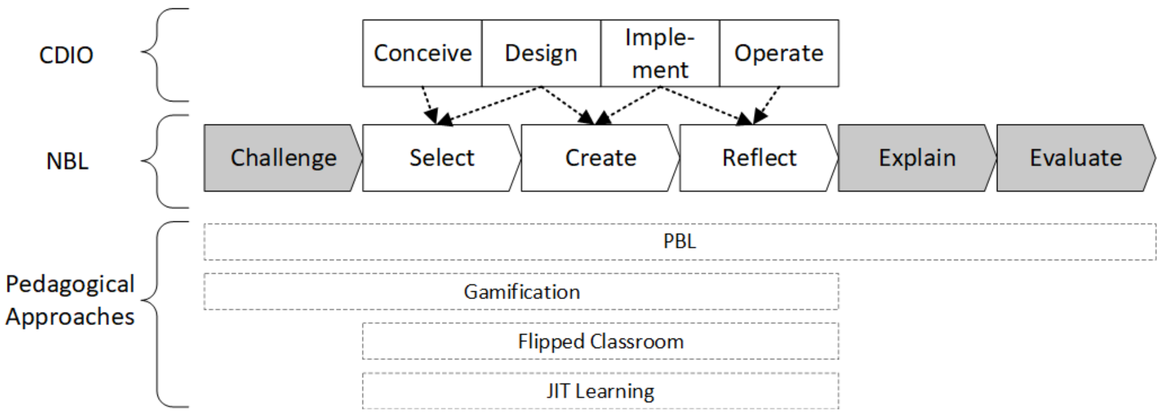

Figure 1. NBL-specific elements.

Games & Gamification

While games are normally self-contained, played individually or in groups, and can include collaborative and/or competitive elements, gamification is the use of game elements and game-design techniques in non-game contexts, thoughtfully applying typical game-like elements to real-world or productive activities (Chou, 2016; Deterding et al., 2011; Werbach & Hunter, 2012). Gamification can be integrated with other class activities, potentially as a part of individual or group activities (Díaz-Ramírez, 2020). Gamification, therefore, does not require a self-contained 'game' (but it can use one), and its success relies on creating the motivation necessary to induce desired actions.

Chou (2016) proposed a practical gamification design framework called Octalysis, which includes eight core drives that function as prerequisites for fostering motivation and triggering the planned behaviour: (1) **Epic Meaning and Calling** refers to when people believe they are doing something greater than themselves; (2) **Development and Accomplishment** drives one to perform better, develop skills and achieve mastery; (3) **Empowerment of Creativity and Feedback** engages players in a creative process; (4) **Ownership and Possession** motivates players through the feeling that they own or control something; (5) **Social Influence and Relatedness** incorporates the social elements that motivate people; (6) **Scarcity and Impatience** drives wanting something simply because it is difficult to reach; (7) **Unpredictability and Curiosity** creates engagement because of the uncertainty of what comes next; and (8) **Loss and Avoidance** is the motivation to avoid negative consequences.

The potential pedagogical importance of active learning games was already highlighted by Weck et al. (2005) in the 1st CDIO International Conference. They argued that playing carefully planned and executed active learning games allows students to reinforce their understanding of key concepts while representing a welcome break from the passive learning mode and helps to lengthen attention span and engagement. In addition to this early CDIO paper, 23 more papers were identified in the proceedings from the 1st to the 17th CDIO Conferences (years 2005 to 2021) that had the keywords ‘game’ or ‘gamification’. And out of those, only three discussed to some extent the use of games to support product design and/or development teaching. McManus et al. (2007) taught lean design principles through a hands-on gamified simulation where groups of students competed while using building blocks to model a product; Appleton & Short (2008) used a standard deck of playing cards to create metaphors of PDD that could be played by the students; Ha et al. (2019) used gamification in which soft skills and creative design were used to solve specific ‘game problems’. None of this work, though, dealt with the challenge of choosing and integrating design T&T.

THE INGENIOUS GAME AND THE PROPOSED GAMIFICATION APPROACH

In this implementation, the learning game, which is the core learning method of NBL, has the objective of teaching the students to select the adequate design T&T in a multidisciplinary PDD scenario. The students conceive, design, implement and operate a PDD process in a fictitious yet realistic game scenario. The learning game used in this implementation is an adaptation of the Ingenious game initially proposed by Pereira Pessoa, Wachter, et al. (2021)

The Ingenious game is a collaborative and competitive card game in which groups of students compete against each other to develop a PDD process that effectively solves the issues that arise during gameplay. The game elements were specifically designed to fulfil the implementation’s purpose and to bring modularity and flexibility features. Therefore, the game can be played standalone or as a part of a course gamification. The game is also expandable, thus allowing the inclusion of new engineering disciplines, techniques and background scenarios. The game elements (in bold) and their link to the Octalysis drivers (underlined) are presented in sequence. In this version of the game, the <u>empowerment</u> driver was not included since the game was envisioned to be played only once during a course, and it was not possible to represent the teams gaining experience.

- The **game scenario** describes the development challenge and gives <u>meaning</u> to the game.
- The **risk level** contributes to the sense of loss during the game, so <u>loss avoidance</u> is about keeping the risk level low. Succeeding in solving all the issues reduces the risk level, while carrying unsolved issues to the next rounds increases it.

- The **risk dice** adds an element of unpredictability. They are rolled for each issue card to check if its related risk is triggered.
- The **budget** is the amount of money available for the team to acquire and play the techniques. The budget adds elements of loss avoidance, scarcity and accomplishment to the game.
- The **engineer cards** represent the engineering disciplines playing the game (e.g. mechanical, electrical, software) and needed to solve the game scenario. These cards provide meaning and a sense of ownership. Each player in the team has a card, and some techniques are more effective if acquired and played by specific engineers.
- The **tool and technique cards** represent 63 design and development T&T and show their capability for solving development issues according to their traits. The T&T contribute to the sense of ownership, as they are not the team's property but the property of each engineer that acquired (learned) them.
- The **issue cards** represent typical issues from each design and development phase. A certain number of cards is randomly drawn in each round, which contributes to the game's unpredictability. To solve an issue card, the players need to play a set of techniques in which the traits' values are equal or higher than the ones required by the issue. Each issue card also includes a risk, which may be triggered depending on the risk dice results.

Besides the game itself, the gamification setting includes online material, online quizzes and a results board (Figure 2). The online material and quizzes cover the general design process theory and information about the design T&T included in the game. The results board displays the teams' results (actual budget, risk level and number of performed iterations), thereby increasing the social pressure and sense of accomplishment.

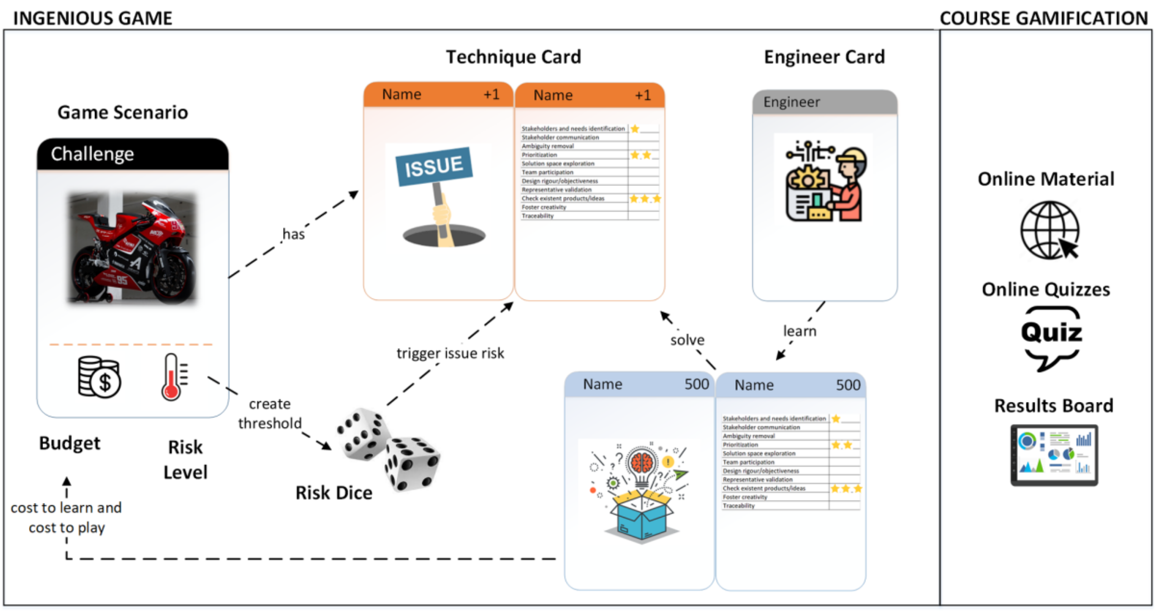

Figure 2. Ingenious game and gamification elements.

The game is played in four rounds based on a typical design and development process (Ulrich & Eppinger, 2012). The rounds represent the conceptual design, system design, detail design, and integration and validation phases. Each member from a group of six players impersonates an engineer from a different discipline (mechanical, electrical, software, system, production and industrial design engineering). While going through the gamified project's phases, the students must select the knowledge to learn 'just in time' by making use of online material. This knowledge supports the teams strategy in selecting the T&T, which will compose the PDD process they will play in the phase. Issues cards are drawn and risks are triggered, which represent typical phase issues that could have been prevented by having selected the right design techniques. By successfully solving the issues, the team of players can go to the next round; if the result is negative, they rework until they get acceptable results.

At the end of each phase, the students reflect on the rationale behind the strategy they chose, the effectiveness of their choices, what they could have done differently and why. The lecturer then gives feedback (explain) based on the reflection. The final activity is to evaluate the students' work; summative assessment is based on the quality of the reflections and not on the game results. Figure 3 shows the game and the gamification mechanics using a simplified sequence diagram (Omg & Object Management Group, 2019), which includes the gamified course activities sequence and the game activities sequence.

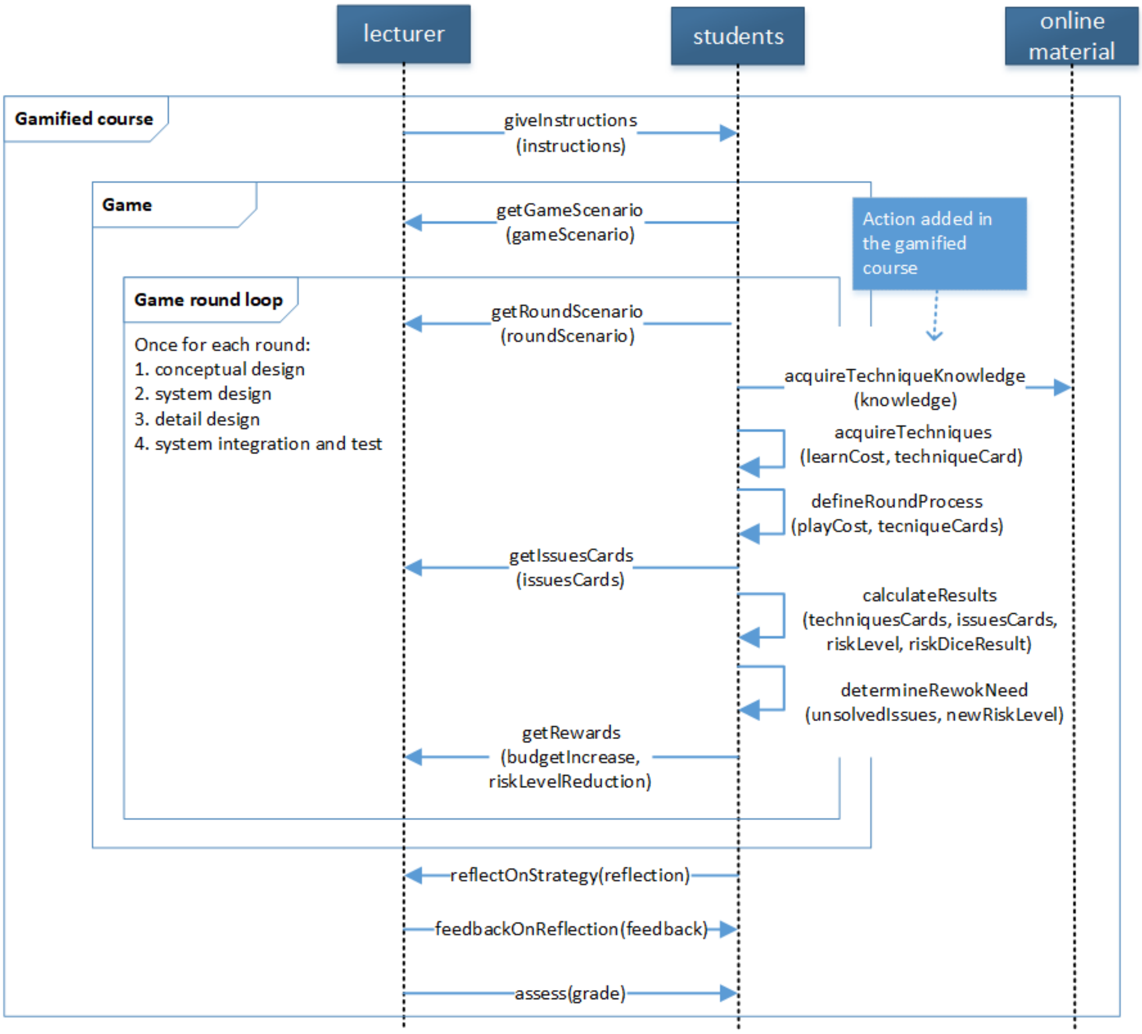

Figure 3. Ingenious game and gamification mechanics.

USING THE APPROACH IN A COURSE INTERVENTION

The Ingenious game and the gamification approach were used to intervene in the Modelling of Technical Design Processes (MTDP) course from the University of Twente's mechanical engineering master's program. The course's six learning objectives (LO) were not changed from the previous year. The intervention aimed to increase the number of covered T&T from 21 to 63 and to use the game to both motivate and create a more dynamic discussion on how to and when (which development phase) to integrate the T&T (LO3, 4, and 5). It also strived to foster more in-depth reflections on the impact of the T&T integration decisions and the likelihood of PDD success (LO1 and 6). The MTDP course relates to CDIO Standards 4 and 8, as it provides the framework for engineering practice in process building and implements active learning. In sequence, I list the LO and describe what took place during each course week.

LO1. Summarise the main challenges for a successful PDD.
LO2. Determine the appropriate PDD model (waterfall, iterative, spiral or agile[1]), considering the product's technical and requirement uncertainty.
LO3. Determine the appropriate design and development T&T for each PDD phase, considering the disciplines needed during the process (i.e. mechanical, electronic, software).
LO4. Integrate into the PDD the best practices for organisational process definition, engineering, and engineering support according to the CMMI-Dev 1.3.
LO5. Integrate creative design techniques into the PDD.
LO6. Reflect on how to use the learnings from LO1 to 5 in a tailored PDD definition.

The MTDP is a nine-week, 5EC (European Credits) course, with two 2-hour classes per week:

- Week 1 – Introduction to the course and the gamified activities.
- Weeks 2 to 5 – In each week, a phase of the game is played by competing groups of six students. The game implementation followed the method presented in the previous section. The students define the T&T to play before coming to the week's first class and playing a game phase. After the first class, they reflect on the results, and the conclusions from their reflection are presented and discussed in the week's second class.
- Week 6 – The student groups reflect on the impact of their game choices in the whole product lifecycle, particularly when the product is used, serviced and decommissioned.
- Week 7 and 8 – Guest lectures with industry practitioners.
- Week 9 – Exam.

During weeks 2 to 6, no content is to be given beforehand, and the game's challenge requires the JIT learning of the content necessary to play each of its rounds. The necessary knowledge is available online, and the students can access it at their own discretion. The gameplay, the teams' results reflection and the lecturer's feedback took place face to face.

THE INTERVENTION IMPLEMENTATION AND RESULTS

The intervention was implemented in the period from September to November 2021. Twenty-nine (29) students took part of this pilot, and there were no restrictions to face-to-face meetings. Quantitative and qualitative feedback was gathered from all attendees. Quantitative feedback

[1] This is not a complete list of possible PDD models, but those that are tough during the MTDP course.

(Table 1) focused on understanding to which extent the intervention kept the course at a master’s level, demanded the expected effort from a 5EC course, the students’ perception that the LO were achieved and to which extent they considered the gamified approach capable of motivating and keeping them engaged during the course. From the results, while the students recognised the motivation benefits (Questions 4 to 7), the approach fell short on the achievement of the LO, particularly the number of hours spent in the assignments and their difficulty.

Table 1. Quantitative feedback results.

Question	Mean	Std. Dev.	Rating explanation
1. Hours spent working on the assignments	1.76	0.77	mean < 2: less than 5EC 2 < mean < 3: around 5EC mean > 3: more than 5 EC
2. Assignments' degree of difficulty	2.55	0.5	mean <2.5: below master level mean >2.5: above master level
3. The course learning objectives were achieved	3.97	0.56	1: completely disagree 2: disagree 3: neither agree nor disagree 4: agree 5: completely agree
4. The approach turned the lectures more interesting	4.17	0.70	
5. The approach made students more motivated and active through all the course	3.93	1.05	
6. The approach gave more motivation to attend the lectures	4.07	1.01	
7. When choosing a future course, I will consider it a positive if this course also uses a similar approach	3.90	0.55	

Further qualitative feedback was gathered to understand the intervention implementation’s strong and weak points. In summary, the students positively highlighted that the intervention was successful in motivating them to come to class (‘more fun’) and to keep up with their studies. It was also helpful in keeping them engaged in group discussions (particularly the more competitive students) in a way they considered ‘closer to real life’. They mentioned that the gamified course made the student groups more interested and interactive, thus encouraging critical thinking about the design steps and about different approaches towards the design process. They considered that it made it easier to learn several new T&T in a short period of time, particularly due to each round’s select->create->reflect cycle, which led to more in-depth analysis and understanding. Finally, they pointed out that the gamification facilitated their recollection of the theory due to it being contextualised in the game.

In terms of weak aspects, the students pointed to the need to both improve the game scenario and to revise the traits in the technique cards. Some techniques have acquiring and playing costs that are not realistic compared to those of the other techniques in the game. The values from the technique cards’ traits do not always fit the round or the issues they are capable of solving. Finally, the game scenario and the issues are not 100% related, which made the scenarios less realistic. The students also made further suggestions for improvement:

- A test round would facilitate the understanding of the game rules.
- Having all the groups present their reflection every week became repetitive once the played techniques and explanations from the different groups became very similar. The suggestion was to add more in-depth and specific assignments directed to the reflections.
- Having a set of technique cards per phase, thus avoiding checking techniques that do not apply to the phase.

- One of the significant downsides of the game is that one can play it without paying much attention to what the techniques do and how they can be applied in a realistic scenario. A description of the issues could be found beforehand, and the team would then decide which techniques to play. Only after the techniques were chosen would the teams allot the technical traits required for solving the issues; so, the selections were not solely based on numbers.

REFLECTION ON THE RESULTS FROM THE INTERVENTION IMPLEMENTATION

Four intervention implementation success factors (SF) were identified to fulfil the stated objective and support answering the research question. They relate to the students recognising that the approach is capable of:

SF1. Having a game scenario that is realistic and requires multiple engineering disciplines to solving.
SF2. Representing the challenge of choosing and integrating design T&T during PDD.
SF3. Keeping the motivation and engagement during the course activities, which includes preparation before coming to class and the execution of the class activities.
SF4. Delivering the MTDP course learning objectives while keeping the course at the master's level and the course attending effort compatible to 5EC.

The feedback gathered during the intervention implementation stated that all key success factors, although satisfactorily achieved, have further opportunities for improvement.

- Although helping to keep the students motivated, both the game scenario and the techniques cards would benefit from further improvements to make the game more immersive and realistic (SF1).
- The Ingenious game mechanics helped the student groups to learn about new design techniques (in total 63) and how to integrate them to solve typical PDD problems. A suggestion was to make visible which T&T are applicable to each phase and thus saving time spent on going through them (SF2).
- The flipped-classroom format, the online material and the gamified approach were highly appreciated and considered to be important factors for keeping the students motivated and engaged (SF3). More in-depth techniques descriptions and practical use examples could be added to the online material and/or presented during the class discussions.
- Although the learning objectives were mostly delivered, the assignments difficulty and the required hours for elaborating the assignments were below expected for a 5EC master course. As suggested by the students, specific and more in-depth questions could be included as part of the game rounds' reflections (SF4).

Finally, the NBL cycle that included select->create->reflect during each round was appreciated by the students and was an important mechanism for learning. When selecting the techniques, the student groups conceived their strategy and started the design of their PDD, During the create stage, they finished their design and implemented it into the game play. They then reflected on their operationalisation. Therefore, the intervention implementation embedded a complete CDIO where the 'product' was the PDD process the student groups created for playing each game round.

FINAL REMARKS

After reflecting on the results from the intervention implementation, it can be said that this paper's objective was achieved. The proposed gamified approach, which integrates gamification and just-in-time learning in a flipped-classroom and project-based learning setting, contributed to answering the question, 'How to teach design T&T choosing so that an adequate development process is defined according to a realistically complex and multidisciplinary PDD scenario?'

The results show that the students considered the gamified approach motivating, both in executing their activities and in coming to class. Other positive aspects were fostering critical thinking and showing the connection among topics and techniques, which are often presented as standalone topics. Valuable feedback was also given in how to improve the Ingenious game and the gamification setting to increase the learning outcome.

The MTDP intervention implementation results give preliminary evidence that the proposed approach can support CDIO, particularly in the context of CDIO standards 4 and 8 and is a good practice for exploring design problem scenarios where the students reflect on their strategies and their decision-making process rather than on the details of the engineering issues.

The main limitation of this work is that the intervention was implemented in just one course, and all 29 students were from the mechanical engineering master's programme. Further research is needed, particularly in a multidisciplinary setting in a class that includes students from different engineering disciplines so that the feedback capture their different PDD perspectives.

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CURRICULUM FRAMEWORK FOR PROJECT MANAGEMENT COMPETENCES – CASE TUAS

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ABSTRACT

The universities of applied sciences educate practically oriented experts for working life. The skills and competences needed in the future can be categorized for example as information and communication skills, thinking and problem-solving skills, and interpersonal and self-directional skills. The learning environments and the curricula should be designed to support the development of these skills. In this paper we present the curriculum framework developed and implemented for project-based learning in Turku University of Applied Sciences (TUAS) faculty of Engineering and Business. By integrating project management skills into the academic curriculum, we support our students' success in the modern working life. The project learning environments used in the implementation are introduced as well. The professional project management competences have been identified and the curriculum has been developed to ensure that students are provided with the necessary skills. By describing the learning process and the learning objectives, we enable a logic and coherent learning path starting from the first year of bachelor studies and continuing to the master studies. The CDIO standards have strongly influenced on the development of the curriculum framework together with the IPMA (International Project Management Association) project management competences. IPMA's Individual Competence Baseline® is utilized in the curriculum development. The students of TUAS have a possibility to take a certification test. Achieving the certification is an international recognition of project management competence described in the Individual Competence Baseline®. For the institution students achieving the certificate is evidence that the learning outcomes are valid, and the students obtain high enough proficiency level. The presented framework has given a backbone for overall curriculum development to our faculty. The project activities (Project Hatchery, Innovation Project Capstone) have strengthened university-industry relationship and have created positive visibility to faculty. The framework has created natural multidisciplinary learning environments and offers an excellent platform for the pedagogical research and development work.

KEYWORDS

Curriculum development, project competence, IPMA, Standards: 4, 5, 6

INTRODUCTION

The students of today face turbulent and ever-changing world with the known and unknown challenges. The OECD (The Organisation for Economic Co-operation and Development Learning) Framework 2030 offers a vision for the future and sets educational goals. In addition to disciplinary skills students need a broad range of other skills such as cognitive and metacognitive skills (critical thinking, creative thinking, learning-to-learn and self-regulation), social and emotional skills (empathy, self-efficacy, responsibility, and collaboration) and practical and physical skills (using new information and communication technology devices). (OECD 2018.) The learning environments and the curricula should be designed to support the development of these skills. The CDIO standards offer fundamental principles for building curricula and learning environments. In case of project management competences, the IPMA's (International Project Management Association) Individual Competence Baseline® supports and complements the CDIO standards.

This paper describes the development and implementation of the curriculum framework for project management in the Faculty of Engineering and Business in Turku University of Applied Sciences. The Faculty of Engineering and Business has seven schools providing bachelor and master degrees to over 7000 students. The education covers basically all fields of engineering and business. The list of engineering programs is following:

- Mechanical Engineering
- Chemical Engineering
- Automotive and Transportation Engineering
- Civil and Community Engineering
- Construction Management
- Environmental and Energy Engineering
- Industrial Management and Engineering
- Information and Communications Technology
- Electrical and Automation engineering.

The presented curriculum framework is aimed at our bachelor programs. In addition to the general framework, the conceptual frameworks, and practical tools, such as applicable CDIO standards, Innovation Competencies and IPMA Competence Baseline® are presented. The background of the curriculum development and design elements for project learning environment are described as well.

CURRICULUM DEVELOPMENT

In the Faculty of Engineering and Business, Turku University of Applied Sciences (TUAS) the CDIO approach has been used as an educational framework since 2006. However, the organization of TUAS has changed remarkably since then. The engineering faculties have had two mergers where three separate faculties covering engineering and business programs have merged to new Faculty of Engineering and Business in 2018. The latest merger put together a faculty that had implemented CDIO several years and a faculty that haven't used CDIO in their pedagogical development, but which had largely involved in development of the university's common pedagogical model (Innovation Pedagogy). At the beginning common elements and structures for the curricula were defined. The CDIO approach was defined as a general guiding principle in the development together with the Innovation Pedagogy. These two approaches support each other and are not in conflict rather they share similar goals and objectives as described in (Penttilä, Kontio, Kairisto-Mertanen, & Mertanen, 2013; Penttilä &

Kontio, 2014; Penttilä & Kontio, 2016). The CDIO approach focuses mainly on engineering education providing concrete support for teaching and learning while Innovation Pedagogy has broader viewpoint of the entire economy and valid competences for future society (Penttilä, Kontio, Kairisto-Mertanen, & Mertanen, 2013). During the years the curricula has been in constant review and development focus as we have tried to improve our performance in teaching and learning (Kontio, 2014).

The key principles and guidelines defined in 2018 were following:

- All bachelor programs have an Introductory course for their degree in the beginning of the studies (CDIO Standard 4)
- All bachelor programs join to faculty wide multidisciplinary Project Hatchery course
- Studies are organized around modules (typically 15 ECTS)
- RDI projects are embedded in degree programs (CDIO standard 5)
- All bachelor programs join faculty wide multidisciplinary industry driven Innovation Project Capstone - course in third year of studies
- Project competences are supported and developed throughout studies.

In addition to these, we have actively implemented the ideas and guidelines of CDIO and Innovation Pedagogy to our teaching and learning activities throughout the years. For example, our degree programs have clear learning outcomes, learning outcomes are aligned with teaching and assessment, active and experimental learning methods are widely used, learning environments and workspaces are modern, sophisticated and in active use.

Curriculum framework for project management

The curricula in the Schools at the Faculty of Engineering and Business are designed to include project courses throughout the studies (Fig. 1). There is a combination of field specific and multidisciplinary courses, and they all are linked to working life through research, development, and innovation (RDI) projects or company assignments. The learning objectives and contents of common project courses are planned and agreed in faculty level to ensure that the project management cornerstones form a logical and coherent path throughout the studies leading to high quality and up-to-date education and relevant competencies for the students. The program specific project courses and activities fulfill and support these faculty wide project competences.

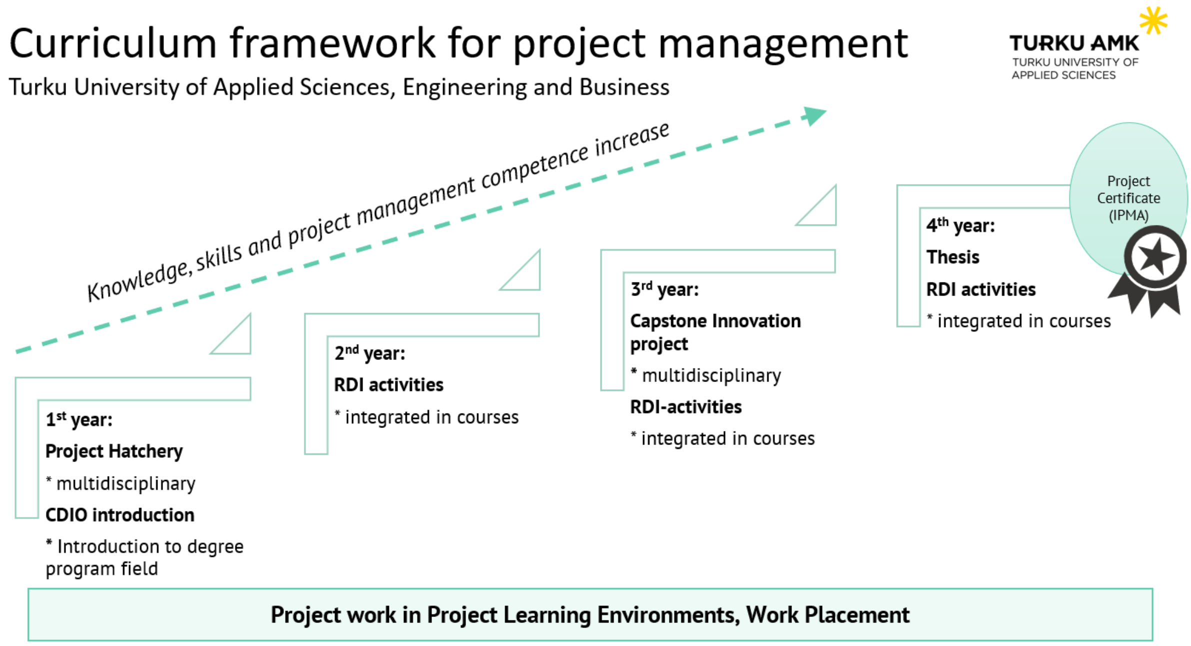

Figure 1. Curriculum framework for project management

Project Hatchery –course (5 ECTS) is scheduled in the beginning of the studies. First year students form multidisciplinary teams, and they work with real-life project assignments. The course aims at getting familiar with studying at the Turku University of Applied Sciences as well as acquiring the basic skills and knowledge in project management. The project assignments are quite general and suitable for very multidisciplinary teams. The CDIO Introduction course taking place during the first study year as well is the first study field specific design-implement experience.

The CDIO standard 4 defines Introduction to Engineering as an introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills. The idea of an introductory course is to provide a framework and broad idea of the profession students are starting to study. Usually this is a one of the first courses and places students in real engineering activities through problem solving and simple design exercises, individually and in teams. The introductory courses planned in our university in Faculty of Engineering and Business were supposed to start in all Bachelor programs in autumn 2019. As the faculty covers business programs too, the Introduction to Engineering was named in the guiding documents as Introduction to degree program field. The schools of the faculty designed different Introduction to modules such as Pump design in Mechanical Engineering, Introduction to Chemical Engineering by making soap, Product development in ICT and Basics in Business Administration.

Both courses (Project Hatchery and Introduction to degree field) are run as projects where learning project principles and activities are one part of the learning outcomes. The difference is that Project Hatchery is operated in multidisciplinary teams and Introduction to course is run within a specific degree program. Approximately 1400 students attend to these project courses yearly. There are over 100 projects during one Project Hatchery round.

During the next years students work with more and more demanding project assignments as the RDI-projects are integrated in the courses. Again, in the third year of studies, students are gathered in multidisciplinary project groups in Capstone Innovation Project (10 ECTS). The course is executed in co-operation with company partners and the project assignments are genuine projects in the companies. The projects' goals are set high by the companies. Students have a possibility to create networks, and there are several examples of the Capstone Innovation Project being the gateway to employment after graduation. Capstone Innovation Project course runs both in the Autumn and in the Spring and the total number of projects is around 90 projects.

The thesis is the biggest personal project for a student. The experience of project work and design-implement experiences support the students in succeeding. The students of TUAS have a possibility to achieve recognition of their project management competence by taking an IPMA's (International Project Management Association) certification test.

PROJECT MANAGEMENT COMPETENCES

In the TUAS Faculty of Engineering and Business the CDIO approach is the fundamental educational framework. Innovation Pedagogy is TUAS's learning approach based on experimenting, sharing of knowledge and expertise, and combining different viewpoints leading to enhancing innovation competences of individuals and groups. Working life orientation, flexible curricula and multidisciplinary learning environments are the corner stones of Innovation Pedagogy. Together with the principles of the CDIO approach, Integrated Curricula (standard 3), Introduction to Engineering (standard 4), Design-Implement Experience (standard 5) and Engineering Learning Workspaces (standard 6) students gain generic skills in addition to disciplinary skills.

Project management competences have been identified to be in central role in modern working life and project-based learning as well as developing project management competences support the development of generic skills.

IPMA Competence Baseline and Certificate

The International Project Management Association (IPMA) has created Individual Competence Baseline® (ICB) for project management competences. IPMA ICB defines the competences that are needed in project work, project management and project portfolio management (IPMA 2015). IPMA defines competence as the application of knowledge, skills, and abilities to achieve desired results (IPMA 2015). The IPMA Individual Competence Baseline® includes three competence areas: people, practice, and perspective competencies (Fig. 2). People competencies consist of personal and interpersonal competencies that are needed to successfully work or lead a project. Practice competencies are the specific tools and methods used in a successful project. Perspective competencies include methods, tools, and techniques to interact with the environment. (IPMA 2015.)

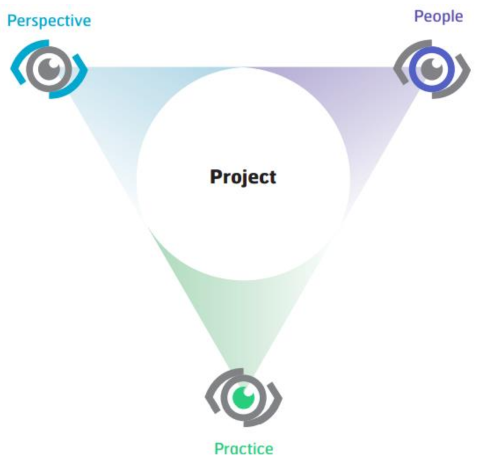

Figure 2. IPMA ICB Competence areas (IPMA 2015).

The IPMA ICB competence areas and their competence elements have been studied and analyzed. The contents of the multidisciplinary project courses, Project Hatchery and Innovation Project Capstone, have been examined to identify the competence elements that are covered in the tasks and learning outcomes of the course. Based on this information a content matrix was formed.

People competences are emphasized in Project Hatchery. The competence elements cover self-reflection and self-management, personal integrity, and reliability as well as personal communication, teamwork, and results orientation. All these competence areas are further developed in Innovation Project Capstone and in addition leadership, and managing conflicts and crisis are taken in account. Practice competences become part of Project Hatchery by using project management tools, such as project plan and gantt-chart as scheduling method. Resourcing and quality are part of the project plan. At the end of the project reflection and lessons learned are utilized. Again, Innovation Project Capstone gets deeper in these competence areas. For example, Kanban charts are used along with gantt, phasing and milestones become familiar. Perspective competences are handled by defining the basic concepts and in Innovation Project stakeholders are defined and considered more carefully than in Project Hatchery.

The content matrix of Projects Hatchery and Innovation Project Capstone is available to be utilized in other courses. The content matrix makes visible the learning outcomes in each competence area that are covered in the mentioned courses. In the other courses, learning objectives and course content can be built on this basis. It can be used as tool to identify possible gaps or redundancies in the students' learning path. It's worth noticing that quite often same competence areas are developed further as an individual gains more experience in project work and project management.

The students of TUAS have a possibility to take a certification test to achieve a certification to verify their skills in project work. The International Project Management Association (IPMA) has a competence-based certification level. The certification is uniform with IPMA Level D® certificate. The Level D® certificate is aimed for starting professionals. (IPMA 2022). For the institution students achieving the certificate is evidence that the learning outcomes are valid, and the students obtain high enough proficiency level.

CDIO Syllabus and Innovation Competencies

The CDIO Syllabus is recognized and utilized is the engineering education in TUAS. There are similarities between CDIO Syllabus and IPMA Individual Competence Baseline®, interpersonal skills for example. The IPMA ICB is applied to complement the CDIO Syllabus with skills specific to project management. In CDIO Syllabus the project management competences are widely involved in 4.3.4 called Development Project Management and in the extended CDIO Syllabus in section 4.7. Leading Engineering Endeavors.

Innovation competencies are categorized into individual, interpersonal and networking competencies. By developing skills in these competence areas, we will have professionals that are creative and initiative, critical thinkers who are able to co-operate and network. Innovation competencies, and especially students' ability to recognize and self-evaluate the development of these competencies, lead to competent and innovative professionals in working life (Keinänen 2019).

As educators we have the tools, such as CDIO Syllabus, IPMA Individual Competence Baseline® and Innovation Competences. Our job is to use these tools to enable our students to evolve into innovative and skilled professionals, capable to creative work in team- and project-based working environments.

DESIGN ELEMENTS FOR PROJECT LEARNING ENVIRONMENT

The CDIO Syllabus statement: "Graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment" (Crawley 2011) is supported in project learning environments. In TUAS the learning environments are designed to enable learning by doing and experimenting in a problem-based manner in working life context (Hänti et al. 2021).

An essential element in projects is learning workspaces (Standard 6). The learning workspaces and laboratories support learning as they emphasize hands-on learning and engage students in their own learning. TUAS has followed a coherent and pragmatic plan to update and remodel our physical and digital workspaces. Autumn 2020 all engineering education moved to one integrated campus with renewed research teaching and research laboratories as well as other learning resources.

As an example of a learning environment Project Hatchery has been analyzed and developed based on epistemic, spatial, and instrumental, social, and temporal design elements (Table 1).

Table 1. Design Elements of a Learning Environment (Hänti et al. 2021).

Design Element	Description of the Element
Epistemic	The task characteristics and task arrangement
Spatial and Instrumental	Physical features, e.g. location, spaces, and tools
Social	Actors and their roles
Temporal	Timespan, intensity, schedule

In Project Hatchery social and epistemic elements are emphasized. Social elements include for example heterogenic and multidisciplinary groups, changes in group members and new roles in a group. Epistemic elements become visible in course assignments where both, the subject, and the working process, are new to a student. The expected outcomes are not always defined by the educators and there is not only one way to do the work. Students must evaluate their work and the results themselves. Spatial and instrumental elements include e.g. the use of several communication channels and platforms. Project Hatchery groups work mainly on campus at certain time and place but working online is occasionally used. Temporal elements include planning and scheduling the project work. There is a general schedule based on the CDIO-model. But each group creates their own schedule based on their project assignment and the general outline. The groups are instructed to plan and document their work on weekly basis. (Hänti et al. 2021.) As a learning environment, Project Hatchery supports the students' personal development in several competence areas mentioned in IPMA competence elements and in CDIO Syllabus.

CONCLUSIONS AND FUTURE DEVELOPMENT WORK

The Curriculum framework for project management competences was introduced and implemented in 2019. The first group of students that have gone through this path are to graduate in 2021-2022. There is a long history of collecting survey data of the student experience in the Project Hatchery. Since the curriculum framework introduction, the survey data has been collected from the same students after completing Project Hatchery as well as after completing Innovation Project Capstone. In addition, project clients and educators have evaluated the success of each implementation. The comprehensive data analysis is to be done and the effectiveness of the curriculum framework will be studied.

The framework for project management enables students to certificate their competences with standardized IPMA test. Every year part of the students utilize this opportunity, but still, it is less than 5 % of the engineering and business graduates.

From faculty perspective the common framework has worked well. It has given a backbone for overall curriculum development, and it has still given freedom for the degree programs to create degree specific solutions. The project activities (Project Hatchery, Innovation Project Capstone) have strengthened university-industry relationship and they have created a lot of positive visibility to the Faculty of Engineering and Business as well as to our university. In addition, they have provided us platforms where both our personnel and students work naturally in multidisciplinary environment with people representing various fields in engineering and business. These learning environments also offer an excellent platform for the pedagogical research and development work.

Turku University of Applied Sciences offers a Master's degree program in Project Management. Our Bachelor's and Master's degree programs are working closely together, and the curriculum framework has a continuity to the Master's thesis level. In the upcoming years, the effectiveness of the curriculum framework may be seen in the competence level of the new Master's students. Originally the Master's degree program in Project Management started based on the need to provide even more deeper project management competences for the industry around us as well as to our alumnis. Nowadays it is connected to the framework and the path from the first year Bachelor's studies to Master degree are better aligned regarding the project management competences.

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Improvement of Facilitation and Management Skills by Whole Systems Approach

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ABSTRACT

The whole systems approach (WSA) is a generic term for varieties of methods such as Open Space Technology, Appreciative Inquiry, World Café and so on, which are commonly based on dialogue and attach great importance to communication among all stakeholders. It is widely introduced in the business scene for the purpose of organization reform, making innovative team and so on. The WSA has been introduced to reconsider the role of teacher and to introduce the rational educational policy intended to the PBL classes in NIT, Tsuruoka college. For this purpose, we held a workshop for the teachers in charge of the PBL classes. Through the workshop, the teachers could learn the essence of the WSA, focusing on "Being" aspect of facilitators and teachers. In the next step, they try to introduce its know-how in the classes. This activity apparently improves the teacher's approach to the classes and quality of communications among teachers and students.

KEYWORDS

Whole systems approach, Dialogue, Faculty Development, Standards: 9, 10

INTRODUCTION

One of central topics in the C-D-I-O implementation in the higher education would be a change of roles expected to teachers and students (Kontio, 2015) (Penttila & Kontio, 2016), which is closely related to CDIO standards 9 and 10. To realize the education with the keywords such as independence, innovation and active learning, only the system reform is insufficient, and the role of teachers should also be reformed well. Especially, what is important for "Being" a teacher in the class would be a critical problem rather than "How To" teach in the class. Since Japan is one of countries which put emphasis on hierarchical relationship in the society, surely including school, the shift from the teaching-based lecture is not so straightforward. Even if the PBL-typed class is introduced, there is no practical improvement in the learning culture if the teachers don't understand the problematic points of their attitude and the way of communication or instruction. This is not the problem only in the PBL class, but also the problem in ordinary lectures. The teachers' attitude with the full of themselves implicitly restrict the diversity of thinking of the students and limit the chance of important feedback from the students.

In National Institute of Technology, Tsuruoka College (NITTC), to reconsider the role of teacher and to introduce the rational educational policy (intended to PBL-typed class), the whole systems approach (Adams & Bill Adams, 2000) (Holman, Devane & Cady, 2007) has been introduced. The whole systems approach (WSA) is a generic term for varieties of methods such as Open Space Technology, Appreciative Inquiry, World Café and so on, which are commonly based on dialogue and attaches great importance to communication among all stakeholders. This approach is closely related to ideas of the Theory U (Scharmer, 2016) and the Learning Organization (Senge, 1990).

WHY DO WE INTRODUCE THE WHOLE SYSTEMS APPROACH?

"What the student does is actually more important in determining what is learned than what the teacher does. " (Shuell, 1986) (Murphy & Kontio, 2018) This sentence plainly speaks what is important to foster the active learners, and implicitly describes importance of what is in demand to "be" a teacher, while not a few teachers focus on only "how to" introduce the active learning. Thus, one of important things for the learning culture improvement from teacher sides are become aware of above "be" aspect. Also, since the modern engineering scene shows faster progress than ever before and the required skills for product/service development become mutually connected and complex, there could be more than one solution for a problem in many cases, and we need to seek an appropriate solution depending on the situation, and continuous feedback and refinement action are important. The WSA can give a strategy to these problems, by focusing on the collaborative leadership, the collaborative and sustainable improvement of learning cultures and programs, sharing the commitment and outcomes. Especially, the problems in the modern society are not a jigsaw puzzle type in many cases, but the Rubik's cube type, which means one solution for an aspect can cause a problem in different aspect. Then, the mutual and collaborative communications among students is important than the teacher's teaching-based guidance.

As mentioned before, the WSA based on dialogue and attaches great importance to communication among all stakeholders. Then, in the activities based on the WSA, all the attendees work under an equal relationship, which is important to realize the more stimulating and effective interaction between teachers and students, being expected to lead the refinement of the class contents and flexible operating of the class.

STRATEGY FOR THE SPREAD OF THE WHOLE SYSTEMS APPROACH

To effectively introduce the WSA, at first, we concentrated to make a core team in our college. For this purpose, we had a workshop for the core teachers to take charge in the PBL classes and also for management level staffs such as (vice-)president. Our expectation in the workshop was to understand the importance of the WSA to improve our classes, and to become aware of the potential of the WSA, which can apply for the system reform. In the workshop, plenty of experimental activities were introduced, limiting the learning of the theory minimum. The workshop was organized by the present author and the main facilitator was played by Mr. M. Baba, who is working for the regional vitalization by using the WSA. He could attend the workshop from truly objective viewpoint since he does not belong to NITTC. As a result, his facilitation was a key point for active dialogue, being apart from each position. The attendees could find out the effectiveness of dialogue-based communication, and its advantage against the discussion-based communication. While the purpose of the discussion or debates is to appeal how one's own opinion is better than the others' opinion, the purpose of the dialogue is to get a common understanding among attendees. Also, the relationship between the attendees has been apparently becomes better, sharing the positive and hopeful atmosphere with great smiling. Also, attendees could share the vision for the improvement of the classes.

In the second stage, the attendees of the workshop familiarize the WSA through their activities. For this purpose, the attendees have started to introduce the essence of WSA to their classes and recommend the other teachers to visit the classes freely. Also, they introduce the know-how of the WSA in meeting for personnel, taking care of dialogue-based communication. As a result, the communication besides meeting has also become active, leading the better relationship among teachers.

WORKSHOP FOR TEACHERS

The workshop mentioned before was programmed as sequential two days sections, being followed by one day reflection section after one month, with attendance of 10 teachers. The program of the workshop is given in Figure. 1.

Day 1	Day 2	Reflection
✓ Opening & Check-in ✓ Paired Interview & Re-story ✓ Inquiry for future I want ✓ Check-out	✓ Check-in ✓ Theory lecture (WSA, Growth mind set, future thinking) ✓ Meeting by Open Space Technology (OST) ✓ Future Newspaper (Quick Prototyping) ✓ Check-out	✓ Check-in ✓ Reflection of activity ✓ Theory lecture(AI, OST, etc.) ✓ Meeting by World Café ✓ Check-out

Figure 1. Program of the Workshop

In the workshop, the lecture of the theory behinds each method was kept to a minimum, and the active and experimental activities was introduced abundantly. This is mainly from two reasons. One is to experience the activity based on the WSA without prejudice since the teachers tends to think too logically to action. The other is to feel the importance of "Being" aspect in the facilitation and management than "How to" one from the reason mentioned before. Then, detailed program was kept in secret until the workshop.

Check-in & Check-out

In each day, Check-in and Check-out session were set up to share each motivation, impression and expectation. In the first day, each attendee commented about "What do you want to feel after the workshop?" to activate thinking from the growth mind set and the future thinking. Also, to enhance the readiness, the pre-survey was done.

Paired Interview & Re-story

Attendees work in pairs. In a pair, both persons play an interviewer and an interviewee by turns, and the interviewer asks the questions along the list given. In the interview, to get deep insight, the questions are designed to answer as a story from interviewee's experience, thinking deal of imaging and feeling. After the interview, the results are presented to all attendees from the interviewer. By this, the interviewee could reconsider its own opinion objectively and sometimes could notice a gap between "what he/she talks" and "what he/she listens to". In this time, the audience writes the phrases in the presentation, which feel positive and important, down to a post-it. This post-it, we call it as “Positive-it”, is presented to the interviewee. The positive-it could improve a feeling of self-approval and makes the interviewee happy.

Inquiry for the future I want

In this section, the attendees imagine what they want to realize in the future, this time we set the future as 5 years later and share their image with the others. This session is aimed to think a problem by future thinking, in which one consider what they should do now by the back-casting from the future one wants to.

Meeting by Open Space Technology

A specific point of Open Space Technology would be that the progress of dialogue is not controlled by the facilitator and respect the independence of the attendees (Owen, 2008). In the workshop, the theme was “Things you want to talk with the present attendees”. The topics was offered from the attendees and each attendee could join any topics they want.

Future Newspaper

The attendees make a newspaper very quickly (typically less than one hours), to experience quick and dirty prototyping. The theme was “NITTC is featured its activity __years later”. In the beginning, each attendee gives interesting topics and share them with everyone. Next, the attendees make groups to write the article according to their interests. This process enhances consensus-building among members and independence. In this activity, the attendees can also learn the importance of visualization of ideas for deeper understandings and quick feedback.

Reflection of activity

Reflection session was set up one month later from the initial two days’ workshop. In the end of Day 2, each attendee made an activity plan for the next one month to achieve each goal in future. Until reflection session, the attendees periodically communicate for the peer-coaching. In the reflection session, each attendee commented about their activity, including what they can, what they feel (difficulty, happiness and so on), and the positive-it was given again.

Meeting by World Café

The session by World Café method (Brown & Issacs, 2005) was set up with three rounds. In the first round, the attendees separate into small groups and have a conversation. In the second round, remaining one person as the table host, attendees move to different tables and share what happened in the first round at each group. In the third round, attendees work in the same group with the first round and conversation again. Finally, individual insights and results from the conversation are shared. Interestingly, we can find things in common and visualize the flow of thinking in total (collective intelligence). The theme for inquiry in first and second round was “how does quality of relationship change in the workshop?” and “what do you learn and how do you apply it for future activity?”. In third round, the inquiry was “what is necessary for both teachers and students to work independently and actively?”.

Figure 2. Scenes in the workshop

Results from comments and survey

After the workshop, we did not take the survey with numerical evaluation of topics. Instead of it, we took interview and survey by writing down of comments, to see the feeling and emotional aspect. The most impressive point in these comments is that almost comments are hopeful and positive toward the future. In the pre-survey before the workshop, almost of teachers commented about the practical problems they are facing and how to seek the solution for it, being forecasting viewpoint.

The other perception was that almost of teachers have a gap between what they want to achieve and what they actually do now since teachers are basically busy and there is no enough time for refinement of their activity. This gap with the busy environment makes them negative and bothersome feeling. After the workshop, however, everyone noticed that it is important to be positive for the better work and education, and such positive thing always exists nearby.

In some comments, the attendees could develop mutual trust and relationship through the dialogue-based communication. In the workshop, varieties of teachers, who are from different expertise, worked together, while the teachers communicate only with some fixed teachers generally. On this point, the workshop became a chance to expand their companion to talk with and to get a fresh insight.

DISCUSSIONS

In the workshop, we focused on the “Being” aspect of facilitators and teachers, putting emphasis on communication through dialogue. Also, we did not treat the practical problems, which the teachers are facing directly, so much. As a result, the teachers could concentrate on importance of dialogue and future-thinking.

In the classes, the essence of the WSA has been introduced on many aspects. For example, now we have spent more time for team building in the PBL classes than before. By introducing the group-interview and re-story, the communication among group members becomes apparently better. Also, by introducing the essence of the Open Space Technology, the students can choose the group members in the project, which have a similar opinion about the working theme with them. This enhances the motivation for the work. On the other hand, this method is sometimes problematic for the students, who cannot indicate his/her intention explicitly. In these case, the teacher's support with deep understanding about him/her becomes important.

In the PBL classes, the quality of communication among teachers becomes better and frequent discussions and continuous improvement of contents become usual. Also, the positive and lively activity of teachers simulates the students so much, resulting in active communication with group members and also with teachers.

In Japan, students generally call a teacher as "(Name) - sensei", where "sensei" means teacher, while teachers call a student only by name. This system is originally coming from the hierarchical problem according to position and age. Recently, however, some teachers are recommending to call their name as "(Name) - san", where "san" means Mr. or Ms., regardless of teachers and students. This is a very small thing, but would be an important step for the improvement of quality of communications between teachers and students.

CONCLUSION

In NITTC, the WSA has been introduced to reconsider the role of teacher and to introduce the rational educational policy intended to the PBL classes. Through the workshop, the core teachers could learn the essence of the WSA and try to introduce its know-how in the classes. This activity apparently improves the teacher's approach to the classes and quality of communications among teachers and students. This activity has just started and continuous activity to expand the ideas of the WSA to the whole is necessary. As one of such activities, the workshop, working students with teachers and engineers together, has been started (Ohnishi, et al, 2020). We will report our further activities elsewhere.

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ADDRESSING CHALLENGES OF HYBRID CAPSTONE PROJECTS IN A PANDEMIC ENVIRONMENT

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ABSTRACT

Capstone courses are a common way to bring together earlier learnings into a practical demonstration of the skills acquired. At Åbo Akademi University, our Capstone course, or Project Course, has been running as a very practical, hands-on course, emphasizing the physical presence and interaction among students. The Covid-19 pandemic made it impossible to run the course in the standard way affecting the main course objectives. This article discusses the challenges and solutions of running the course in both hybrid and online format, and what learning can be drawn from this. The different tools and methods used for forming the teams and formulating the projects are analysed and evaluated, both through a student survey and using the lecturer's qualitative hindsight. We show that by using proper tools and methods we can compensate for the drawbacks and limitations of a Pandemic environment.

KEYWORDS

Hybrid and online teaching, capstone course, standards: 5,6,7

INTRODUCTION

The IT department at Åbo Akademi University has since the start of engineering education in IT had a project course on the curriculum. The course is designed to map on the CDIO stages (Crawley et al., 2011) as follows:

- Conceive - the student team negotiates with the customer the project proposal and the initial requirements
- Design - the student team designs the architecture, subsystems/components, UI
- Implement - The student team implement and validated the system
- Operate - decide internally how the interaction with the customer takes place, how feedback is collected, how different versions of the product are demoed and delivered.

One of the main goals of the Project Course is to teach students the so-called *soft skills*. Soft skills is an umbrella term that describes a list of non-technical skills such as social aptitudes, language and communication capabilities, friendliness, and ability to work in a team (Cimatti, 2016). Recent research has shown that soft skills are becoming increasingly popular and in-demand term in the industry, many times companies give a higher weight to the soft skills compared to the technical (hard) skills when hiring (Cimatti, 2016). Research studies have also shown that there is a discrepancy between the soft skills taught in academic environments and those needed in the industry (Börner et al., 2018).

Our capstone Project Course attempts to close this gap by creating an environment in which students can experience and learn soft skills while completing an IT project. Teaching soft skills is hard (Idrus, Abdullah, et al., 2009) and in our course we approach it as a *problem-based learning* (PBL) teaching situation Barrows, Tamblyn, et al., 1980; Hung et al., 2008. In PBL, students are supposed to identify solutions to real-world problems. Differently, from traditional teaching, PBL challenges students to think deeper and learn to defend their decision, work in complementary teams towards a common goal, utilize previous knowledge to critically analyze complex issues, and be motivated by understanding from the beginning the goals of the course (Nilson and Nilson, 2010). Furthermore, previous studies have shown that PBL and CDIO can be regarded as complementary approaches (Edström and Kolmos, 2014).

In our version of the capstone course, the teams and the projects are self-organized. That means, that the students are required to find a suitable team and a suitable project to perform during the next 6 months of their studies. This was traditionally done using physical meetings and mini-workshops, where the students had time to meet face-to-face and discuss possible topics and roles in the team. The Covid-19 pandemic changed how the course startup could be made and there was an abrupt change in how the course was started. In order to mitigate this issue, we had to adapt and resort to online tools and increased supervision.

After two course startups in a pandemic environment using the new set of tools and methods, we have analyzed the impact of our measures. The main objective of the analysis was to investigate to which extent the deployed methods and tools were able to compensate for the lack of physical presence. The research questions addressed in this analysis are the following:

- RQ1: How did the remote setting affect the course?
- RQ2: How did the newly adopted tools affect setting up the course?
- RQ3: How suitable is it to continue using the adopted online tools in the future?

Since the teaching of soft skills in this course was directly affected by the pandemic, the analysis is focused mainly on the tools and methods used to assist with collaboration, communication and general project management practices.

The basis for this analysis is both the opinion of the teaching personal involved in the course and a survey that was answered by the students of the two courses. The survey is analyzed and supported by the lecturer's perspective and compared to similar studies.

THE TRADITIONAL PROJECT COURSE

The project course has been running in quite similar format for the last 5-6 years. For the current version, the following learning goals are given:

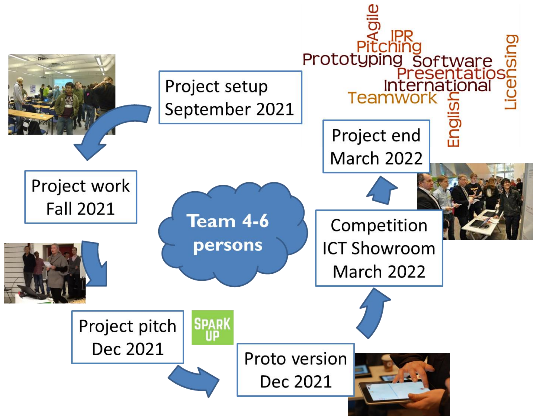

Figure 1. The flow of the project course for academic year 2021-2022

- **Interact with a customer** and learn how to communicate requirements and design decisions.
- **Plan and follow up** a software development project. Review the plan during the execution of the project and reflect over your initial expectations and estimations.
- **Work in a team** via team coordination, meetings, planning and internal communication. Use basic collaboration tools in software development such as an issue tracking system and a software repository and version control system.
- Carry out **a development project** from beginning to end: Create and document a design. Implement the design. Test the implementation.
- **Define** the business goals for the software project
- **Presentations** of the project, product, work plans and documents to colleagues, stakeholders and the general public.
- **Produce documentation**, both technical and for end-users, that is usable and understandable.
- **Personal skills**: project management tools, project planning, project evaluation, business evaluation

The course starts with a one-month introduction part (**Phase 1**) with weekly meetings. In these meetings, there are lectures on topics related to running the course, but the main focus is to get teams formed from collected project ideas. Project ideas are provided by companies and researchers at the university, but the student teams can also implement their own ideas. **Phase 2**, running until the Christmas break, is a core project development phase, where the students work on their product, ending at a Business pitch and a prototype demo event. **Phase 3** consists of further development and finalization, ending in a student project competition called ICT Showroom, common for all IT students from three different universities in the city of Turku. The overall flow of the project course is shown in Figure 1.

This paper focuses on the analysis of Phase 1, where the student are forming the teams and selecting/creating a project idea to work on. Most of the challenges due to pandemic restrictions imply that the normal ways of getting to know each others and doing brainstorming is not available.

HOW COVID-19 RESTRICTION AFFECTED THE COURSE SETTINGS/ LEARNING GOALS

With the entry into effect of the Covid-19 related restrictions, on-campus teaching has to be suspended throughout the Project Course. This had a negative impact on the course settings and on the learning environment as follows.

- **team forming** - previously students from different study lines and degree programmes would meet in class, get to know each other via different social games such as the *Marshmallow Challenge*[1], and form teams based on their interests and complementary skills.
- **execution of the project** - previously students would meet and work in groups for different deliverables of the the project (source code, status reports, technical documentation).
- **communication with customers and project demonstrations** - before the pandemic, these interactions with the customers will take place face to face and sometimes complemented with teleconferences. However, all the demonstrations of the product at different phases of maturity would take place face-to-face with all the teams present.

PREVIOUS RESEARCH ON HYBRID / DISTANCE LEARNING

University teaching and learning have increasingly become what some authors call post-digital; a combination of elements that is neither completely online nor entirely physical (Green et al., 2020). The transfer to distance education that was forced by the Covid-19 pandemic meant a sudden necessity for educators to eliminate physical elements and build a heightened reliance on online elements. Previous research discusses the designable elements in a course design to be of four types: epistemic design (learning tasks), physical or set design (tools, artefacts, learning spaces), social design (groups, roles) and learning outcomes (Goodyear et al., 2021). When transferring the project course online, the epistemic design and learning outcomes remained largely the same, but the physical and social design required thinking anew. Liukkunen et al., 2010 describe challenges related to online communication falling into five categories: loss of communication richness, coordination breakdown, geographical dispersion, loss of 'teamness' (diminished effectiveness of collaboration due to issues with trust and problems with knowledge management), and cultural differences. To successfully complete a complex group task in a distance setting, individual students need to be given possibilities to build interpersonal relationships and community (MacMahon et al., 2020). In addition, Gama et al., 2021 observed that online socialization and synchronous (rather than asynchronous) work played a key role in engagement and achieving better results in a group project. In the distance setting, also teachers' possibilities to observe non-verbal cues and provide support in student interactions change, which should be taken into account when planning the physical design of the course. In summary, when choosing tools for the physical design of a course, providing possibilities for groups to socialize and build community is important. Any tools or artefacts should ideally help in overcoming the above mentioned challenges of online communication.

[1] https://www.marshmallowchallenge.com

Yuan and Kim, 2014 present some guidelines for achieving 'communities of learning' in online course settings. They propose a mix of both synchronous and asynchronous tools, to ensure that both students and teachers are visible and active in online environments, to employ diverse formats for discussion, to promote both social and task-oriented discussions, and - if possible - to arrange a face-to-face orientation meeting. The students' background and digital competence should also be taken into account. Toti and Alipour, 2021 highlight that university students on lower-level courses have a more difficult time transitioning to online teaching, most likely because of the heightened self-efficacy and independence required in online learning. It seems intuitive that students with a high level of digital competence, such as computer science students, would more easily make the switch to online learning. Toti and Alipour, 2021 find, however, that even though computer science students have an advantage due to their digital competence, they do find many aspects of online teaching challenging; some issues related to technology are mentioned, but most prevalent were challenges related to social interaction - asking questions and interacting with peers, teachers and teaching assistants. Some previous research has evaluated the effectiveness of specific tools or artefacts in remote teaching. For instance, Gama et al., 2021 identified Discord as a helpful tool for groups to socialize and engage with group tasks. Ironsi, 2021 evaluated online resources such as Padlet, Mentimeter and Zoom breakout rooms and found student opinions to be varied, as students experienced not only confusion about the goal of using the tools but also found them helpful in aiding interactions. Emenike et al., 2020 focused on the role of learning assistants in remote instruction, concluding that the role of the learning assistants was in many cases quite central to the success of student learning.

In light of previous research, communication and interaction appear to be among the most salient issues that need to be supported when transitioning online. Most of our course participants are masters level students and digitally competent, which gives them an advantage but does not eliminate social issues. Thus, the tools we introduced in the course were chosen mainly with the purpose to improve online communication and interaction.

CHANGES PERFORMED TO SUPPORT HYBRID TEACHING OF THE COURSE

Covid-19 pandemic started in March 2020. The project course 2019-2020 ended the day lockdowns started in Finland, but it was likely that the next version of the course needed some changes. Fall 2020 started in hybrid mode, with a restricted number of students in class, and the rest in Zoom. The objective was to use the format of the normal project course as much as possible and provide tools to deal with the issues of not meeting physically in class using digital tools and alternative activities. These were the changes that were done to facilitate starting up the project course in a hybrid format:

- **Extensive use of the Zoom and Zoom breakout rooms**. Lectures were performed both in class and over zoom. To facilitate getting to know each other we performed different kinds of exercises over Zoom breakout rooms so that students were forced to interact. Typically we assigned them to rooms by random, to perform "get to know each other"-tasks similar to those you can do on-site.
- **Miro board for idea development and forming teams**. The Miro online collaborative Whiteboard was used to visualize the current situation of the idea and team formation

status. The idea was to try to provide a visual picture of the team forming situation, corresponding to the situation one can see in the classroom: What project ideas are available, what is the current team forming situation, which students are still looking for partners, etc.

- **Teaching assistant / social officer**. We also started with a new position of a teaching assistant with the special role of what we called "social officer", with the task of communicating with people and making sure that everyone finds their teams. The main task of the social officer was to online connect students with each other, which normally happens during the physical meetings especially in the beginning of the course.
- **Special networking session**. For the year 2021-2022 we also introduced a special networking session. For 2021-2022, we had Covid-19 restrictions for indoor activities, but we organized an event in an old barn "Kurala" that allowed enough distance between persons to facilitate the event. This was to drive the student out of the normal work environment and to inspire them to think openly.

EVALUATION OF THE APPROACH

The data for this study was collected through a self-completed online survey available for three weeks in November-December 2021. An invitation to participate in the study was sent out to all students participating in the course during the 2020-21 and 2021-22 academic years, 47 students in the first group and 42 in the second. The first cohort completed the course in March 2021; the second set of students have just ended phase 1. The questionnaire comprised of three main sections: (a) background information on respondents, (b) a set of questions gauging the respondents' experience with different aspects and tools used in the project course, measured as attitude scale questions, and (c) a set of open-ended questions giving the respondent the possibility to provide more information on the tools used in the course. The main focus of the questions was on phase 1 of the course, where team formation, team building, and choosing a project take place. Answering the survey was anonymous. As an incentive for answering, respondents were offered the option to participate in a lottery of a small prize; contact information for the lottery was collected separately from the questionnaire answers.

Results from the survey

Thirty students participated in the data collection. Eight took the course in 2020-21, and 22 are attending the ongoing course 2021-22. Thirteen of the respondents identified themselves as international exchange students or participants in an international master's program.

From the responses, it was found out that the most difficult parts are to get to know the other students, form a team, and become a team (Figure 2). With becoming a team we meant the process of achieving a well-operating team, not only a formal team on paper. This very much reflects the assumptions of the lecturers of the course, that getting the teams formed is the main challenge.

When it comes to the different tools that support the different activities, the results of the survey are collected in Figure 3. Looking at which tools or activities best helped with solving the challenges of the course, weekly hybrid course meetings would best solve the challenges of

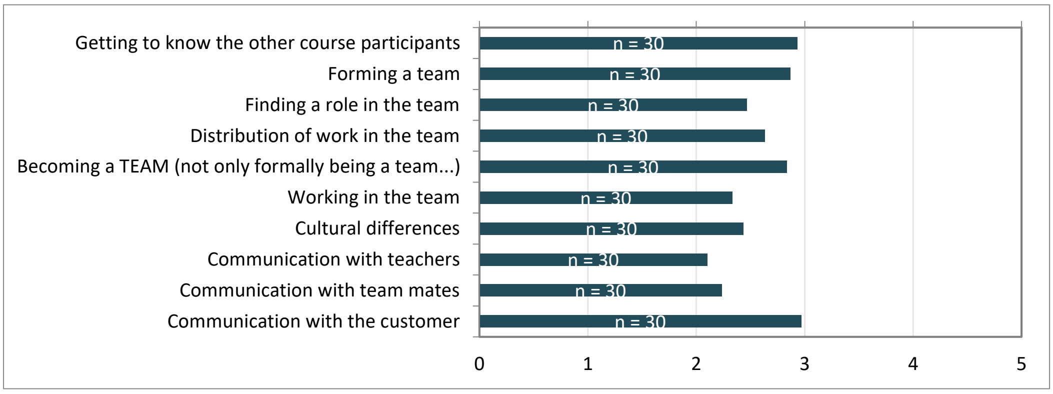

Figure 2. How would you rate the following aspects of the Project Course (1=easy, 5=difficult)

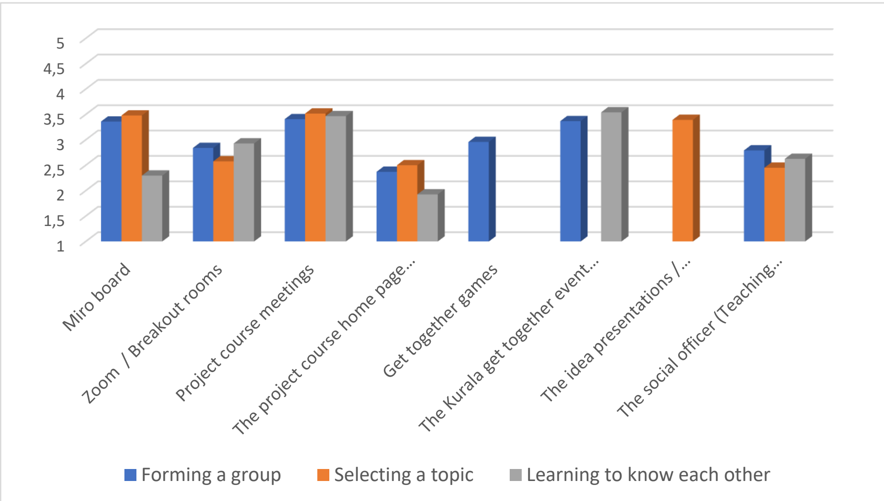

Figure 3. How did different tools contributes to the different aspects of the course (1=did not help, 5=helped a lot)

the course. For selecting a topic and forming a group, the Miro online board tool was clearly on the top, whereas the Zoom breakout rooms were the second most helpful. We also see that the teaching assistant, new for helping form teams during Covid-19 restriction, also was of help.

We also collected information of which tools the students were using for group work, this is shown in Figure 4. Git was clearly the most used tool, as the teams are supposed to create and version software. Next are tools for online-meeting and sharing documents, which also is very logical. The tools WhatsApp and Discord are commonly used by students. In this list of tools, there was not really anything that was very surprising, it reflects the common tools being used for project work.

Students, in general, were happy with the tools used for handling the hybrid situation (figure 5). To note, however, that the physical meetings and company idea presentations were the most liked methods. This is a clear indication that the students still think that the normal ways of working are still more efficient.

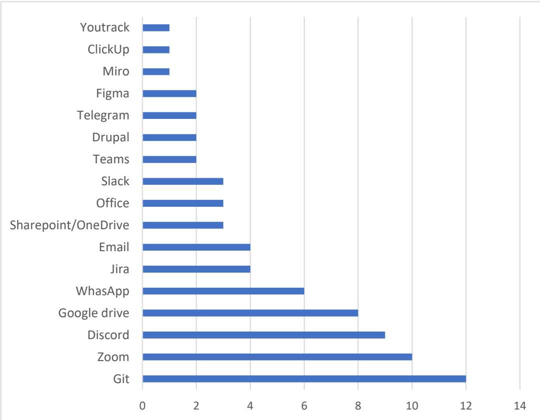

Figure 4. Tools used by different teams, reported by the students

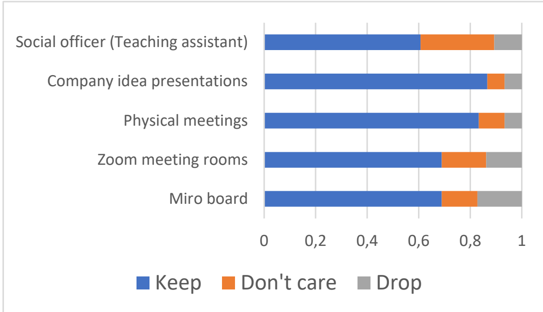

Figure 5. Student opinions on tools/methods retention

We asked the students for open comments on tools, we got the following:

- "It was challenging to participate in Zoom activities while being physically in the classroom - it could be good to be notified before the lesson that we should for example take headphones with."
- "Our team had some on-site meetings in the beginning which I felt were vital in getting to know one another and finding a common vision for the project. Later on in the fall once we got going and during the spring our weekly meetings were using Zoom."
- "The tools used in the project course are very suitable for the current situation."
- "Obviously, Covid-19 is a problem for physical meetings, but these are very important imo."
- "A great course, allows you to explore new roles and learn new things about project work while on the same time offering repetition."

The results from the survey quite clearly show that the traditional ways of getting the teamwork going using physical meetings were the most popular. However, in the hybrid setting, the tools that have been used are considered useful and functioning. There were no direct new ideas received from the students.

CONCLUSIONS

With respect to RQ1, Covid-19 restrictions changed significantly how the Project Course at Åbo Akademi University could be implemented. We had to move from a very physically oriented course to an online version. Using a student survey, we analyzed how tools can be used to compensate for the lack of physical meetings. The survey showed that the traditional ways of physical meetings are the most popular, but by effectively using online tools, the drawbacks of Pandemic lockdown and isolation can be handled. The tools in our course, Miro and Zoom, seem to have achieved enough interaction to still facilitate the forming of groups.

We can also make use of the adopted tools and methods used at the point where we get back to normal on-site education. The Miro tool taken into use was very powerful for documenting project ideas and monitoring student activity, and will most likely be used also in the future.

Regarding RQ2, the adoption of online tools was rather smooth, as our students are IT students, and are used to dealing with online tools. However, from a teacher's point of view, the main drawback of a hybrid format is the very limited direct feedback from students.

Some of the adopted tools and approaches (e.g., the social officer) will be applied also when we return to normal on-site teaching. Miro is useful also in a physical setting for having a written record of project ideas and participants, which makes it possible to access them in between meetings.

The answer for RQ3, as shown in feedback from students the online tools deployed, were useful in both the hybrid version of the course as well as in the future on-site version. This conclusion is based both on the results of the survey and on the opinions of the teachers involved in the course.

The results of this study show that addressing the Covid-19 restriction challenges in capstone courses can be done via a proper selection of online tools. Such tools compensate for an on-site presence and based on the student and teacher feedback some of them will be used in the future also in on-site settings.

What remained unsolved was how the handle the lack of insight in the project work from the teachers point of view, due to only virtual presence. This made it difficult to spot internal team problems in time and give relevant feedback during the course.

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VISUALIZING THE EFFECTIVENESS OF CROSS-COURSE-TYPED PBL ON GENERIC SKILLS

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ABSTRACT

National Institute of Technology, Sendai College, Hirose Campus has been conducting a general skills (GSs) survey using external standardized tests in Japan since 2014. The results showed that our students' skills related to teamwork, planning, and practice were inferior to the average of university students and needed to be strengthened. Therefore, in the academic year 2020, we arranged a cross-course-typed (integrated) PBL as one of the experimental subjects in the 4th grade, in which students with different specialties were grouped together to solve practical problems and try to improve their skills in team activities, planning, and practice. Through this cross-course-typed (integrated) PBL class, the results of the GSs standardized test that they took improved. By comparing the test results, it was found that there was a significant improvement in the skills of team management, planning solutions, and self-control after the cross-course-typed PBL. In addition, the students conducted self-assessment before and after the integrated PBL class in 2020 and 2021, and improvement in all the targeted skills was observed. The peer assessment and teacher assessment were generally close to the self-assessment, and it was found that the integrated PBL class led to the improvement of students' skills.

KEYWORDS

Project/Problem-Based-Learning, Visualization of Educational Effectiveness, Generic Skills
Standards: 5, 7, 8, 11, 12

INTRODUCTION

In engineering education, it is important not only to help students acquire specialized knowledge and skills but also to develop general skills (GSs) to apply the acquired knowledge and skills in the real world. Hence, many educational institutions, regardless of their types or classifications, focus on developing their students' GSs. National Institute of Technology, Sendai College, Hirose Campus has been working on students' GSs development since 2014 by extensively reorganizing its curriculum to incorporate many techniques of active learning (AL) and problem- / project-based learning (PBL). To assess the impact of curriculum improvements on GSs, self-assessments by students, peer assessments among students, and direct assessments by faculty using the curriculum are used for short-term school events and courses. In addition, to track changes over time, we have used a standardized GSs test as an objective assessment method and have measured students' skills once a year. In 2018, the five-year survey from enrollment through graduation was completed and it revealed the growth characteristics of students' skills in our curriculum. The results of the survey of Hirose Campus students indicate that they were able to develop abilities in many of the literacy and competency assessment items. This result can be attributed to educational improvements such as the introduction of AL and PBL on our campus. On the other hand, however, it also became clear that they were not able to develop some skills (Team management, Planning solutions, and Implementing solutions) enough. In order to effectively develop these three skills, we began implementing cross-course PBL for the fourth-year students in 2020. This was because we believed that by creating groups of students unrelated to their course affiliation to work on the project, we could selectively and effectively develop the three targeted skills. The effectiveness of PBL based on students' self-assessment and assessment by faculty was reported at the 17th CDIO Conference (Yajima et al., 2021). The results of the self-assessment revealed that the students felt growth through the experience, and furthermore, the self-assessment, peer assessment, and teacher assessment after the PBL showed improvement in the target skills. This paper reports the results of an assessment of the effectiveness of cross-course PBL using the annual objective GSs assessment method.

In addition, we will also report the results regarding the implementation of the cross-course-typed PBL for the new 2021 fourth-year students to confirm the continuous score growth, and the self- and peer assessment of each student's skills based on the rubric conducted before and after the PBL, as well as the assessment conducted by teachers.

CHARACTERISTICS OF GSS GROWTH OF STUDENTS AT NATIONAL INSTITUTE OF TECHNOLOGY, SENDAI COLLEGE HIROSE CAMPUS AND POSITION OF CROSS-COURSE-TYPED PBL

As reported in CDIO 2021, our school uses an external standardized test, Progress Report on Generic Skills (PROG) (Kawaijuku Group 2020), to evaluate students' GSs. In the academic year 2018, the continuous survey on students' GSs from the year of entrance to the year of graduation was completed. The GSs growth characteristics of our campus students were evaluated and reported at the 16th CDIO International Conference (Kawasaki et al., 2020). The report revealed that the literacy and competency of our students had been growing steadily as their grades progressed. Further detailed analysis and comparison with university students revealed the skills that need strengthening and could be further developed. While all of their literacy skills grew enough, some of the competency items needed to be strengthened, and others could be strengthened. Figure 1 shows the first-year scores (blue) and fifth-year scores (red) for students enrolled in 2014 in the major and medium categories of competency assessment items. The difference (red minus blue) is the growth score at our school. As reference data, the average value for college students in 2018 is shown in black. It is clear from Figure 1 that, in the large category, (3) Problem solving skills did not grow, and even the 5th-grade score is lower than the average score of college students. In addition, (1) teamwork skills also showed some growth, but the score of 5th graders was lower than the average score of college students. In the middle category, (3-2) Planning solutions and (3-3) Implementing solutions showed no growth or little growth, and their scores were lower than the average for college students, indicating that these skills need to be strengthened in the future. For (1-1) Relating with others, (1-2) Cooperating with others, (1-3) Team management, and (2-3)

Behavior control, growth was observed, but it was equal to or lower than the average value for college students. These results suggested that team activities and behavior control were skills to be improved. They indicated that the skills related to team activities, planning, and practice were inferior to the average for college students and needed to be strengthened.

In order to improve these skills, the school started a cross-course-typed PBL (CI-PBL) for the fourth-year students in 2020. In that class, the students were divided into groups regardless of their specialized course in order to conduct more practical team activities and to master project management on a large-scale PBL. As reported in the 2020 paper (Yajima et al, 2021), the students' self-assessment using a unique rubric as a criterion was found to help improve their skills. David Boud (1995), on the other hand, points out areas of concern for evaluation using self-assessment and examines each of these. Therefore, we report the results of GSs before and after the course for the students who took the cross-course-typed PBL in 2020 using a standardized external GSs test, which is an objective evaluation method. The PROG results (objective evaluation) also revealed that the target skills were sufficiently developed.

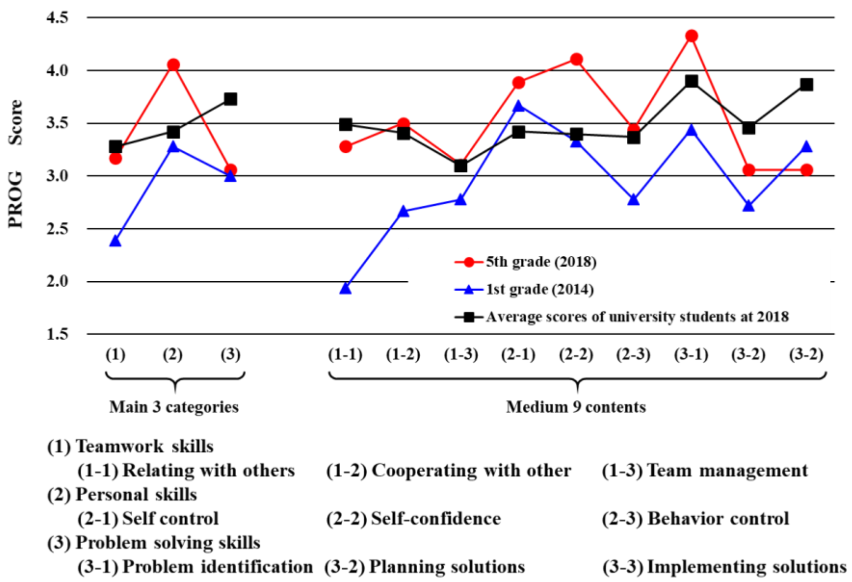
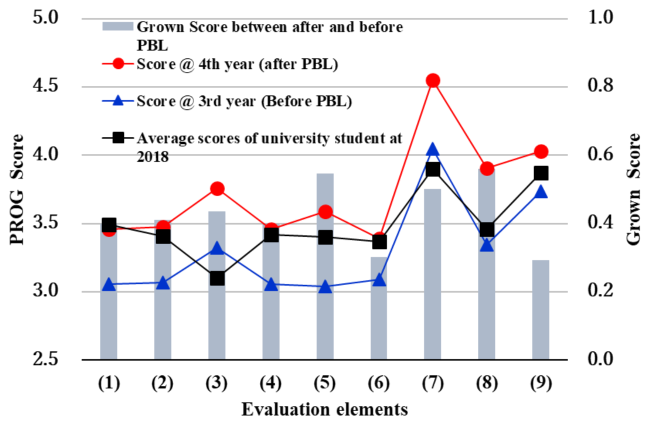


Figure 1. PROG scores of the detailed elements of Competency part.

COMPARISON OF SCORES ON THE STANDARDIZED GSS TEST BEFORE AND AFTER THE CROSS-COURSE-TYPED PBL

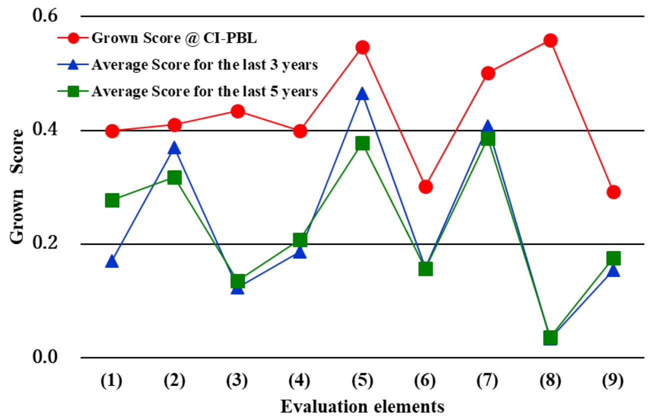
We examined what changes occurred in GSs as a result of the cross-course-typed PBL implemented in 2020. Figure 2 shows the standardized test scores and extended scores for the same students in their third- and fourth-years. Figure 3 shows the growth in scores of last year's fourth-year students who took the cross-course-typed PBL class, and the average growth scores of students who did not take the cross-course-typed PBL class for the past three years and the average growth scores for the past five years. For the major category (3) Problem solving skills, which was the issue (weakness) of the students on this campus, we evaluated (7) Problem identification, (8) Planning solutions, and (9) Implementing solutions in the middle category in Figure 2. As a result of the assessment, it was found that the 4th grade students improved their scores by about 0.3-0.6 points compared to when they were in the third year. . In addition, from Figure 3, when we compared the skills of the students who took the cross-course-typed PBL with the average of the skills of the students who did not take the cross-course-typed PBL for 3 and 5 years, the skills of the former were higher than those of the latter.

Specifically, the students who took PBL showed greater growth in (3) Team management and (8) Planning solutions showed greater growth. This suggests that the acquisition of project management knowledge and its application in practice led to the improvement of skills. In addition, there was also a significant improvement in (4) Self-control skills. It is thought that self-assessment led to the improvement of self-control because it allowed the participants to evaluate themselves objectively and learn about themselves. In addition, the results of Figure 1 show that the students' performance in (1) Relating with others was about the same as the university students' average, but they exceeded in all other skills, especially in (3) Team management, (7) Problem identification, and (8) Planning solutions. These results indicate that the PBL was effective in improving the students' team management, problem identification, and planning skills. In the case of (9) Implementing solutions, it is necessary to improve the education on how to transfer the solution plan to practice.



(1) Relating with others (2) Cooperating with other (3) Team management
(4) Self control (5) Self-confidence (6) Behavior control
(7) Problem identification (8) Planning solutions (9) Implementing solutions

Figure 2. Relationship between PROG scores and extension scores before and after taking an integrated PBL class.



(1) Relating with others (2) Cooperating with other (3) Team management
(4) Self control (5) Self-confidence (6) Behavior control
(7) Problem identification (8) Planning solutions (9) Implementing solutions

Figure 3. Relationship between PROG Score Growth with and without Integrative PBL Courses.

CROSS-COURSE-TYPED PBL IN 2021

The cross-course-typed PBL is one of the experimental subjects in Hirose Campus. Hirose Campus consists of three courses as follows: The Information Systems Course, which focuses on software; the Information and Telecommunication Course, which focuses on communication; and the Intelligent and Electronics Course, which focuses on hardware. The PBL is a compulsory subject for all courses and is taken by all of about 120 fourth-year students at Hirose Campus and is a 2-credit course that is offered every week for 180 minutes a week (90 minutes x 2, 2 sessions) for 15 weeks. Students are divided into 24 groups (about 5 students per group) regardless of their course affiliation. Each group has a set budget to spend and is free to purchase items within the budget and will have one support teacher. The purpose of this course is to improve students' skills in team activities, planning, and practice by forming groups with students of different specialties and conducting large-scale PBL projects.

In the academic year 2021, the theme was the same as last year: "solving a problem or creating something interesting in the community or at the school," and when setting up the project, we also imposed conditions such as "making someone other than the group members happy" and "the project must include some kind of challenge for the group. Compared to last year's PBL, the 2021 PBL was held in a way that each student was given more responsibility by clearly assigned roles (project leader, general manager, treasurer, etc.) in addition to the division of tasks. To make it more effective, workshops on entrepreneurship by outside experts were also conducted before the start of project activities.

In the first and second weeks, guidance was given to the students, explaining the purpose of the course, achievement goals, assessment methods, and schedule. In the third week, we had group work on entrepreneurship education and know-how about starting a business based on actual ideas. In the fourth week, students learned how to use the Work Breakdown Structure (WBS) and Gantt chart, which are essential for project management. In the fifth and sixth weeks, students decided on the topics to be covered in the group work. In the seventh week, students presented their work on the theme, roles, and WBS/Gantt chart in a midterm debriefing session. The weeks 8-13 was spent implementing and summarizing the project. In the 15th week, individual interviews were conducted by teachers. Table 2 shows the list of project themes for each group. We found that many of the themes were business-based, as the students were expected to start their own businesses using their ideas for solutions.

Table1. Schedule of Course-Integrated PBL

Week	Contents	Method, etc	Submissions
1	Guidance (explanation of purpose, achievement goal, evaluation method, schedule, etc.) and design thinking workshop by experts	Face-to-face	
2	Workshop on how to determine the theme of team activities (projects)	Face-to-face	
3	A workshop to simulate the experience of starting a business	Face-to-face	
4	Project management training, determination of project theme, creation of WBS and Gantt chart	Face-to-face, Team activities	Personal daily report, Team activity report, Self-assessment sheet
5	Review project plans (themes, plans, etc.) as a team	Face-to-face, Team activities	Personal daily report,Team activity report
6	Create WBS and Gantt chart and prepare for the interim report meeting	Face-to-face, Team activities	Personal daily report,Team activity report
7	Interim report meeting	Face-to-face,, Team activities	Personal daily report,Team activity report
8-12	Execution of the project	Face-to-face, Team activities	Personal daily report,Team activity report
13	Prepare for the achievements report meeting	Face-to-face, Team activities	Personal daily report,Team activity report
14	Achievements report meeting and Contest	Online, report video	Personal daily report, Team activity report, Voting card for a good project
15	Personal interviews by teachers	Face-to-face, interviews	Personal daily report, Team activity report, Project report, Self-assessment sheet, Mutual-assessment sheet

Table 2. List of themes of each group.

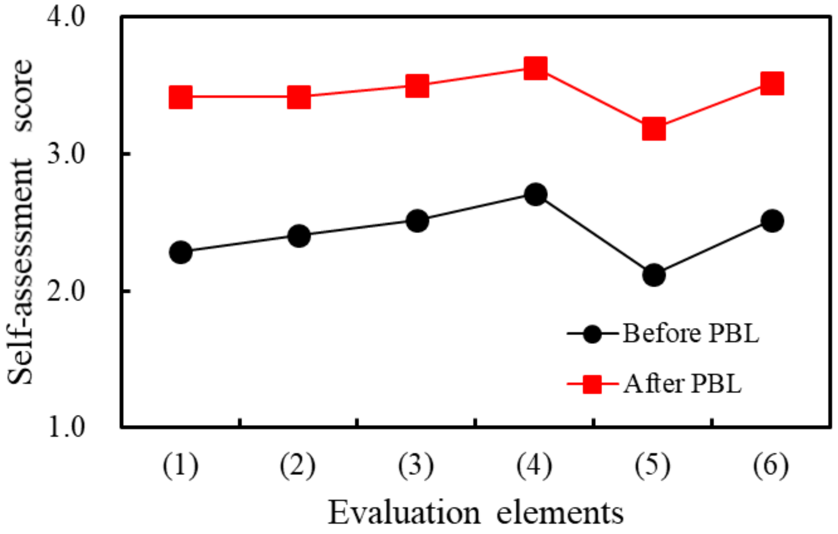
Group No.	Theme of PBL
1	PC Classroom Usage Management Application
2	OMATASE, a service that eliminates the anxiety of the other party during appointments
3	Development of "Yomitoru-kun" attendance confirmation system
4	Sai-Say, an application to reduce mishearing by people with auditory information processing disabilities
5	NCT Bullet, a recruiting business that connects technical college students with companies
6	MAKER, an app that provides cooking recipes to improve health through better eating habits
7	Ayashi Online Agent, an app that allows you to complete procedures outside of government office and bank hours.
8	Development of Umbrella, an umbrella that is easy to disassemble and assemble
9	A service that provides opportunities for people who live alone to cook
10	Development of mud splash prevention curtain for rainy days
11	Development of a system to reduce congestion in cafeterias
12	Content development for quick and easy access to detailed school information
13	Development of a PC controller for sound game players
14	Development of Home Delivery Box with GPS to Prevent Theft
15	Development of a community-based restaurant map to find restaurants in the neighborhood
16	A company that provides support to people in poverty and those who have trouble disposing of things they no longer need
17	Online try-on application "MY FITTING ROOM"
18	Used teaching materials trading service "Saiteki"
19	Consideration of ways to make residents feel more comfortable by observing good manners on their way to school
20	Development of an umbrella with a drone attached
21	Development of a learning support application "Kachi-gumi"
22	Development of an automatic waste separation bin
23	Development of "Easy Communication," a calling application for easy communication
24	Developing an optimized task management application

SELF-ASSESSMENT BEFORE AND AFTER THE CROSS-COURSE-TYPED PBL CLASS

For self-assessment, the rubric for the individual assessment in Table 3 continued to be used, and the students' own self-assessment, mutual assessment among students, and assessment by teachers. Figure 4 shows the results of self-assessment before and after PBL, and Figure 5 shows the results of self-assessment, peer assessment, and teacher assessment after PBL. Figure 5 shows the results of self-assessment, peer assessment, and teacher assessment after PBL. This is similar to the results of the 2020 survey, indicating that the effects of the class were being obtained even when different students took the cross-course-typed PBL course. Figure 5 also shows that the results of self-assessment, peer assessment, and teacher assessment were generally similar. However, for (5) Transmission power, there was a large difference between the students' self-assessment and other assessment, with the self-assessment being lower than the other assessment. This was probably due to the modest self-assertiveness of Japanese people in self-assessment. In the future, we plan to carefully explain the rubric-based assessment criteria to the students and encourage them to actively input their assessments.

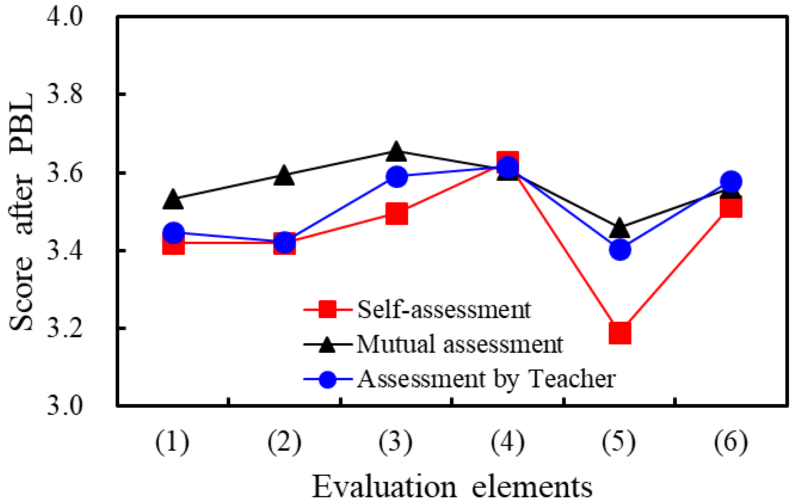
Table 3. Rubric for personal assessment

Levels	**Skills to make a team project successful**					
	Independence			Cooperativeness		
	(1) Reflection on myself	(2) Time management	(3) Responsibility	(4) Ability to Listen closely	(5) Transmission power	(6) Skills of Reporting, Communication and Consultation
4 (Exceeding Standard)	Student can make specific reflections on the personal goals they set each time.	Student can perform their tasks as planned or better.	Student can take positive action to play a role in a group.	In addition to Level 3, student can listen while confirming that they understand the content.	Student can devise ways to convey their opinions in an easy-to-understand manner, such as by drawing diagrams.	Student can report, communicate and consult in an appropriate manner.
3 (Proficient)	Student can set personal goals and reflect on them, but concrete reflections are sometimes inadequate.	Student are able to perform his/her tasks almost as planned, but sometimes he/she do it in a hurry just to meet the deadline.	Student can take actions to play a role in a group.	Student can listen to others while reacting to make it easier for the speaker to speak, such as "nodding."	Student can express their opinions, and most of what he/she say is correctly communicated to others.	Student can report, communicate and consult in an almost appropriate manner.
2 (Progressing)	Student can set personal goals, but they cannot look back enough.	Student can do his/her tasks, but sometimes is late for the deadline.	Student take actions to play a role in a group, but they are sometimes inadequate.	Student listen quietly to others, but often do not understand the content.	Student expresses their opinions, but often the content is not correctly communicated to others.	Student can report, communicate, and consult, but the content is often inadequate.
1 (Unsatisfactory)	Student cannot set personal goals or look back on his/her own.	Student misses the deadline for his/her tasks.	Students cannot take actions to play a role in a group.	Student is looking away, talking wastefully and doing irrelevant things when others are talking.	Student cannot express his/her opinions.	Student cannot report, communicate or consult.
Main evaluation sources	"Reflections on the goal" in personal daily reports, etc.	"Progress of implementation contents" of personal daily report, progress of Gantt chart, etc.	Project initiatives, meeting behavior, etc.	Attitudes when others are speaking at the meeting, etc.	Remarks at meetings and team activities, etc.	Reporting, Communication and Consultation at meetings and team activities, etc.



(1) Reflection on myself **(2) Time management**
(3) Responsibility **(4) Ability to Listen closely**
(5) Transmission power **(6) Skills of Reporting, Communication and Consultation**

Figure 4. A self-assessment results before and after the PBL.



(1) Reflection on myself **(2) Time management**
(3) Responsibility **(4) Ability to Listen closely**
(5) Transmission power **(6) Skills of Reporting, Communication and Consultation**

Figure 5. Self and Mutual assessment and assessment by teacher after PBL.

CONCLUSION

National Institute of Technology, Sendai College Hirose Campus has been conducting a General Skills (GSs) survey using external standardized tests since 2014. The results showed that our students' skills related to teamwork, planning, and practice were inferior to the average of university students and needed to be strengthened. Therefore, from 2020, as one of the experimental subjects for the forth-year students, we arranged a cross-course PBL program in which students with different specialties are grouped together to solve practical problems and try to improve their skills in team activities, planning, and practice. While it was clear that students were improving their self-assessment skills through the cross-course-typed PBL classes in 2020, the results of taking the GSs standardized tests were also evident and will be reported. The results of the GSs standardized tests were also revealed, although it was clear that the students had improved their skills in self-assessment through the cross-course-typed PBL classes. The results of the standardized test comparison also showed significant improvement in the skills of team management, planning solutions and self-control after the cross-course-typed PBL.

In addition, self-assessment before and after the cross-course-typed PBL class were conducted again in 2021, and as in the previous year, improvements in all the targeted skills were observed, and peer assessment and teacher assessment were generally similar to the self-assessment. In the future, we will continue to conduct standardized tests and self-assessments while we correlate and analyze the data to improve students' skills, and utilize the results to improve the cross-course-typed PBL classes.

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In the cross-course-typed PBL, we asked for the cooperation of faculty members from various fields to implement PBL. We would like to express our sincere gratitude to them for their guidance to the team in the form of a laboratory and for their guidance after hours.
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WORK-BASED LEARNING IN COMPUTER SCIENCE EDUCATION – OPPORTUNITIES AND LIMITATIONS

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ABSTRACT

Collaboration with the surrounding society is increasingly identified as high priority in the governance of Swedish universities. The contribution in the universities' immediate areas, as well as more globally, should in such contexts influence the purpose and implementation of the education. Here, work-based learning has a special role where students are active in a real workplace that may correspond to their future employment, with clear win-win situations as a result. While work-based learning can be seen as relatively well-defined for, for example, teacher or nurse training, it can be more difficult to carry out corresponding training towards a highly specialized technology industry. Students do not have the skills needed in such contexts, and representatives from the technology industry do not have the resources required to train students so that they become sufficiently independent. In addition, a change is taking place in certain parts of the technology industry, where more and more work is located at a distance, and where it is therefore no longer as relevant with training elements located in a real workplace. In such circumstances, therefore, ambitions for work-based learning need to be reviewed to consider both opportunities and limitations, in order to provide good benefits, and not interfere with constrained situations that are hard to overcome. This contribution problematizes the concept of work-based learning and looks at opportunities to reach as far as possible regarding its benefits with existing limitations. The profiling regarding work-based learning at the home university for the authors of this paper, will be addressed. A survey regarding the topic is presented based on attitudes from companies in the IT area concerning opportunities and desires, as well as student attitudes, and approaches at other selected universities. Examples of implementation in courses where the authors are involved based on student activity-oriented learning, will be presented.

KEYWORDS

WBL, WIL, System Engineering, Software Engineering, IT-industry, CDIO Standards 5-10.

INTRODUCTION

Work-based learning (WBL) is a learning method that prepares students for a future profession through real-world work activities. The method thereby increases the students' employability, at the same time as employers can be given confidence that future employees have experience in real work. Here, Kristianstad University (HKR, home university of the authors of this paper) profiles itself as unique amongst Swedish universities by offering WBL for students at all undergraduate programs. WBL (or rather Work-Based Education. We will, however, in the continuation use the term WBL), is here seen as significantly rewarding for both students and potential future employers. It should be noted that students can choose freely regarding their degree project and thereby also do their work for a company. However, this paper relates to a compulsory WBL for students in a course that is not the course for the degree project.

At the core of the concept of WBL lies that the student performs tasks at an actual workplace for a period of time. This is of great importance in profession-preparatory educations for, for example, nurses, and teachers, which are also large educational programs at HKR. Here, the tasks are often fairly well defined, and can be performed for a few weeks during the training, to the benefit of both the student and the workplace representatives. The concept of WBL at HKR, includes practical elements, but where there must also be a clear scientific foundation, and thereby unite theory and practice. In addition to this, every student is entitled to a workplace-based supervisor who guides the student through the WBL process.

Comparing WBL for computer science students with the profession-preparatory education for nursing- and teacher education there are several differences regarding the profession itself and the future employer. The future employers for nursing and teacher education students are a very homogeneous group, to the largest extent public sector employers, comparing to the IT-industry sector where most employers are privately owned companies and a very heterogeneous group. The IT-industry is a diverse industry, operating in many different markets, both national and international. This difference of the employers for computer science students compared to the profession-preparatory students makes the WBL concept more difficult to implement in a computer science education.

Furthermore, while WBL has several valuable values for certain professions, it is generally more difficult to implement in the highly specialized technology industry. Students do not come far enough to contribute during shorter periods of time, and companies are often limited in being able to provide resources for effective supervision. At the same time, the work situation in many industries seems to be changing and moving towards increasingly remote work. This in itself means that WBL also needs to be seen from new perspectives.

This contribution studies how to find forms of company-oriented teaching/learning principles for students in Computer Science educations at HKR, and at the same time fairly enough respond to HKR's profile regarding WBL. The study includes approaches to WBL in similar educations in Sweden, and in addition to this, two questionnaires have been conducted, where both companies and students have been asked about attitudes concerning WBL.

As a background to the study, the concept of WBL, especially as it is presented at HKR, and related concepts such as Work-Integrated Learning (WIL) will be investigated and problematized. By turning more to WIL, openings can be made that better suit the conditions for the computer science education. This includes industry-oriented working methods, such as in the context of CDIO, and meetings with company representatives online.

The study behind this contribution is furthermore based on two courses where well-known Software Engineering-based work processes are used, and where IT-oriented companies participate through online-based meetings with students. Surveys are performed in order to provide further information regarding attitudes towards WBL. As a result of those studies, it is presented how courses in Computer Science at HKR can be designed to meet requirements and ambitions regarding WBL at HKR.

BACKGROUND

The Swedish Council for Higher Education (UHR, 2021) defines WBL as *higher education located in the area of activity where the student is expected to work after completing their education.* Typically, teacher education and nursing education are also here examples where WBL occurs. That is, that definition, and that approach is much in align with that of use at HKR. Still, the WBL-concept at HKR is further explained to not only include practice at the workplace, but that learning activities should be performed from a perspective of the educational program- and course syllabi, clearly based on the foundation of the educational field. In addition to this, students must be offered five weeks of training at workplace. There must also be well-developed routines for collaborations with WBL-committed organizations, where the external part can receive and supervise students in work situations relevant to the education. Moreover, students can here contribute through development projects, and provide valuable reflections on the organization's situation and contribute with ideas on potential development and renewal paths. In addition, there must also be a close collaboration between supervisors in the external organization and teachers at the university, where the WBL-supervisor must be offered to participate in supervisor training.

Atkinson (2016), distinguishes between WBL and WIL, based on a main perspective in the learning process. WBL is here a platform for the students to develop practical and conceptual skills, while WIL rather has the educational curriculum as the prime point of view, for the development of new experiences and skills. In either case, besides for placement-based workplace, Atkinson opens up for a rather loose coupling towards practice where simulations of real-world work-activities may be considered. Moreover, actually, the cite (Atkinson, 2016) '*Simulations are most effective and beneficial to students when they are considered to be a realistic experience of the workplace or the commercial environment'*, may also be seen from a CDIO perspective.

CDIO aims to foster students in practicing real world-close, complex-enough projects. That is, with that perspective, and with the rich flora of the CDIO Syllabus learning outcomes, CDIO may be seen as a WIL-method, mainly based on simulations. Säisä, Määttä & Roslöv (2019), shows an example where students are practicing work in a learning environment called "theFirma", that provides *ICT-focused development projects to small and medium sized companies (SMEs) and third-sector organizations*. A focus of that paper is on the soft skills that were acquired by the students. Here, focal CDIO learning outcomes, such as, *Teamwork,* and *Communication*, are especially well met, but also further generic skills, such as, *Leadership*, *Problem solving, Presentation skills*, and *Time management*. It is thus interesting to see WBL/WIL not only from the perspectives of the workplace-close practice, but also from those of generic skills of interest.

In addition to the above, a rather new situation has occurred because of the pandemic, where the workplace in itself is critical. Einarson & Klonowska (2021), shows that more and more work within the IT-sector (but also elsewhere) will go online, and also points out the need for education to prepare students for such a change of future work. Furthermore, desired soft skills amongst students, based on a survey amongst IT-companies, are presented. Here the four top desired skills are: *Good communication*, *Good cooperation*, *Presentation techniques*, and *Structured documentation*. Moreover, today several articles can be seen that are debating on required skills for the future careers in remote working (e.g., (Klein, 2021), and (Smith, 2021)). A recurring theme does here seem to be that the top skills are *communicating and collaborating in a virtual context*, and furthermore, *work independently*, *manage their time*, and *show self-motivation.*

Computer Science at HKR has two undergraduate educational programmes, *Bachelor Programme in Computer Science and Engineering, specialisation in the Internet of Things*, and *Bachelor Programme in Software Development*, both 3-year programmes on 180 credits, where WBL must be included. In each of those two educational programmes, a course in the last year has been selected to have special WBL-elements. In total, there are about a hundred students, about half of whom are non-Swedish-speaking. Experiences say that it is generally difficult to find traditional WBL places for students at computer science. This is based, among other things, on the fact that it is difficult to find continuously established forms for collaboration with highly specialized companies in the IT industry, where these are driven by requirements regarding resources and competition. Furthermore, even though English is a common language within the IT-business, seen from a context with smaller companies within the local region, demands on Swedish speaking skills may be a critical aspect. Moreover, experiments have been made with an intermediary organization that has been responsible for contacts between the academy and the companies. Here a small number of volunteer students have participated in projects with low demands on participation from the companies (Einarson & Lundblad, 2014). At a larger scale, however, this is far more complex. In this context the future of remote work, is not only important from an educational perspective, but may also be seen as a possibility to approach WBL/WIL, where a smaller amount of industry representatives may collaborate online with significantly lower efforts than at a physical workplace.

SURVEYS

Documentation review

An online documentation review approaches a view of the state of the concept of WBL in educations in Sweden similar to those covered in this paper. There are 25 universities in Sweden, where 11 of those collaborate in the CDIO initiative, offer study programmes in computer science and/or computer engineering. The computer science/engineering-based educations at these universities show a variety of types of activities involving companies in the educations. It is interesting that no matter what form of activities, this is still seen as positive values for the students. Activities here include, study visits, guest lecturers, project work, and degree work, often with companies as customers. Three CDIO-universities offer Industrial Placement courses as program courses, while two non-CDIO-universities offer Engineering Training / Internship courses as optional courses, even during the summer (vacation) time. In all cases for all industrial placement courses the student him/herself seeks contact with companies, authorities, or organizations. This means that the home-department is not responsible for arranging the contacts, and probably neither responsible for the time it takes for finding an appropriate workplace, and the training period required for the student to be contributing. Only two universities provide education corresponding to the WBL or WIL concepts. These are Kristianstad University (WBL, information in Swedish) and University West (WIL).

It is interesting here to see that WBL and WIL are rare within the surveyed universities. Positive WBL values, such as study visits (contact with physical workplace), and guest teachers (contact with company representatives) are there, but not in a developed WBL form. Another common form is *labour market days*, where contacts are made between students and companies. Such an activity corresponds to the value of the employment opportunities within WBL. One possible conclusion from the survey, based on the low number of WBL/WIL examples, is that it is generally not an easy thing to arrange WBL in computer science/

engineering-based educations, as previously mentioned in this paper. Still, as shown, WBL-values can at least partly be achieved in other ways.

Questionnaires

A second study is based on two questionnaires sent, in the end of November 2021, to both companies and students. The questionnaires were essentially divided into three parts: (1) Cooperation between students and potential employers in our study programmes; (2) Content of student projects; and (3) Structure and content of future cooperation. These questionnaires are more elaborated on in (Frisk, Klonowska & Einarson, 2022). The questionnaires do not especially focus on WBL but more generally on meeting points between academia, students, and companies through different kinds of projects, and experiences achieved at the parts of the students on one hand, and companies on the other hand.

The first questionnaire consisting of 46 questions was sent to 30 contact persons in companies and organizations cooperating with our department. Below the companies and organizations will be referred as *employers* for short. The response rate from the employers was 37% (11 of 30), the significance can therefore be questioned. Traditionally, it is quite hard to get higher response rates from companies. A possible explanation to this may actually be at the core of the problem of this paper. That is, companies are driven by short-term requirements, and do not have the resources to prioritize the requests from the academy, even if there is a good will.

From the answers provided by the employers it can be seen that there is a satisfaction with the students' contributions. There is also a willingness to continue collaborations with the universities, for further future student projects. Mainly student projects have been performed in contexts of degree work, but other forms of projects are of interest. The employers are mostly interested in groups sizes of about 2 students, and where projects should be performed both on distance and at the workplace of the company. Furthermore, the size of a student project may vary from about 2 months to one full semester, and the amount of guidance varies from about two times a week to once a month.

In the questionnaire the employers were asked which collaboration concepts they are familiar with, which is seen in Table 1 below. Forms for WBL/WIL probably need to be further communicated with the university side before projects of that kind will take place. From the low number of responses, it is hard to draw further conclusions. Still, the low number may, as previously mentioned, actually strengthen the experiences concerning the difficulties in bridging the gap between industry and academia.

Table 1. Familiar cooperation concepts within companies

Concepts	# of positive responses
Work based learning (WBL)	5
Work integrated learning (WIL)	1
Co-op	1
Internship	11

The second questionnaire, consisting of 49 questions, was sent in the same time period to our first-, second-, and third-year students in both undergraduate programmes as well as to our alumni who have finished the programmes during the last five years. In total around 400 students and alumni were reached. Over 100 students and alumni have responded to the questionary, distributed as shown in Table 2. In this specific paper, the main interest is however on the third-year students, while more information is available also for the others.

Table 2. Number of responses from students and alumni

	Computer Engineering Programme	Software Development Programme	Total
Year 1	5	11	16
Year 2	11	23	34
Year 3	4	19	23
Alumni	8	23	31

Questions posed to the respondents, i.e., students and alumni include:

1. Do you think that the university should provide student projects at companies?
2. What kind of cooperation do you want with companies during the education?
3. How large do think a student project (in cooperation with a company) should be?
4. Where do you think company student project should take place?
5. How often do you need supervision, to make the project progress the best?
6. How many fellow students do you want to cooperate with in a student project at a company?

Responses from students and alumni on the above questions:

1. The answer was *yes* for 96% of the respondents, which in itself clearly shows the willingness from the respondents' side to have some kind of company contacts during their education.
2. The responses vary. While about 20% of them would like some kind of WBL/Internship, others more mention looser coupling towards companies, such as guest lectures, study visits, integrated projects (university-company).
3. This question refers to amount of time, and here 49% of the respondents prefers projects for a whole semester or longer, while 24% of those prefers projects for 3-4 months, and the rest less than that.
4. According to this question, 17% of the respondents prefer doing projects at the company, 53% of the respondents point out that they prefer both company and distance, while 25% mention that it depends on the type of project. The remaining 5% prefer to only work at distance.
5. Weekly supervision is wanted by 38% of the respondents, 30% want more supervision than that, while 14% of the respondents want less than weekly supervision. The remaining 18% of the respondents answer that the amount of supervision depends on the project.
6. About 60% of the respondents prefer smaller group sizes of about 1-3 respondents, while the rest would like to see groups of sizes 4-5, or even more.

Conclusions that can be drawn from this include that as a student there is a clear interest in preparing for a future career through some form of interaction with company representatives. The form can vary. However, it is mainly about projects where companies are involved. Other forms, such as, study visits and guest lectures are also of interest. With projects for companies, work is mostly to be performed independently and to some extent preferably at a distance.

Atkinson (2016) provides discussions on observed barriers towards establishment of effective WBL/WIL partnership. Such barriers include *financial constraints and the costs associated with hosting students*, *differing expectations about the outcomes and benefits of WBL/WIL*, and *lack of flexibility and responsiveness on the part of the education institutions to accommodate employer needs and the business cycle*, as well as *lack of a consistent understanding of WBL/WIL*, in itself. By acknowledging such inherent resistance, rather than forcing agreements that risk failing, new solutions with variations on themes of WBL/WIL may be found, as presented below. This may possibly suit all involved participants better, and still with an outcome of sufficient WBL/WIL-values.

DISCUSSIONS AND RESULTS

Swedish higher authorities for education strongly encourages universities' collaboration with the surrounding society, including industry and other organizations. From the meta-framework that governs the universities' educations regarding learning objectives, however, WBL is generally not mentioned (Still, exceptions from this can be seen for some obvious profession-preparatory study programmes). Therefore, WBL can rather be seen as an extension to such a framework, where the learning objectives still should be followed to motivate the WBL for the current educations. WBL does here contribute with values, such as, real-world experience for the students, and exchange of knowledge between the academy and industry.

This contribution addresses similarities and differences in concepts of WBL, WIL, (by Atkinson (2016)), and WBL as it is defined by HKR. While WIL has a stronger weight at the perspective of an education's learning objectives, than WBL, it is probably motivated to put HKR's WBL-concept closer to Atkinson's WIL than the corresponding WBL. Still, in any case WBL and WIL are generally tightly coupled to a workplace and engaged workplace-based supervisors, even though Atkinson also opens up for cases of university-based simulations of real-world occurrences. In that specific context, CDIO may be seen as WIL, but with a loose coupling between student and external part. Furthermore, preparing students for future Remote Work, such as proposed by Einarson & Klonowska (2021), brings new values to the discussion where the physical workplace no longer have the same meaning and significance.

At Computer Science, at HKR, two courses have been selected to include WBL elements, that is, *Systems Engineering,* and *Software Engineering.* Both courses, on 15 credits, have today developed contacts with industry and other organizations, to represent industry-related projects and processes ((Frisk, Klonowska & Einarson, 2022), (Teljega & Einarson, 2022)). Externals participate online, at a distance, where they have recurring meetings with student groups. This contributes to contacts between students and industry representatives, at the same time as valuable exchanges are made between teachers and these external representatives. Here, the industry representatives do not have actual supervisor roles, nor do they have to devote too many demanding resources to participate. In a modern context with the requirements and limitations that exist, this can be seen as a valuable contribution to WBL within a course, and within an educational program. The connection between student and workplace is loose but significant WBL-values can still be seen.

Regardless of which form of WBL is chosen, the learning objectives are essential to motivate the activities, as has been discussed. Articles that address WBL as well as Remote Work for students (e.g., (Einarson & Klonowska, 2021)), can be a guide in finding suitable learning objectives. Emphasis is especially on significant generic skills such as *Communication*, *Teamwork*, and *Planning skills*. These, together with other significant learning objectives, thus, become those that substantiate the syllabus, and the manifestation of the syllabus through a suitable WBL-model. Moreover, through the loose coupling, full examination is performed by university teachers, where this e.g., is manifested through mandatory meetings, reflection reports, and presentations.

Additional aspects that have emerged from surveys of other universities, companies and students lead to inspiration to shed light on several values for a new type of WBL-based course. Such aspects include study visits to give students a sense of a physical work environment, invitations to recruitment companies to respond to employment opportunities in the WBL, and guest lecturers from the IT industry to contribute expertise in selected subjects.

This leads to a summary of a possible WBL-based course with an approach based on the following aspects:

1. A smaller number of company representatives are invited to follow the students during their projects. The company representatives have a knowledge-significant role in the project.
2. The course has elements of remote education
   a. This trains students in a future remote work situation
   b. Business representatives can minimize their efforts in terms of resources needed
3. The course project has a sufficiently high degree of complexity, according to CDIO's principles
   a. Process models that are used are established both scientifically and within IT companies
   b. Appropriate generic skills are emphasized, where these are to be examined as part of the course
4. Invitations of additional company representatives
   a. Recruitment companies are invited to open up for employment opportunities for students
   b. Additional representatives from the industry (or other organizations) are invited to give guest lectures on valuable topics

In a perspective of HKR's definition of WBL, it can be seen that the main aspects of that definition are fulfilled. Furthermore, it can be understood that problems, that traditionally are present in WBL for computer science education programs, decrease. One point remains and is not met, the one that concerns external participants acting as supervisors. In this case, supervision, examination, and grading falls entirely on the teachers at the university. In fact, this can be seen as a consequence of that the students not being physically present at a company but rather following the educational structures in a more traditional way.

From the point of view of the courses in specific focus of this study, that is, S*ystems Engineering*, and *Software Engineering*, revisions have already started and furthermore been implemented. The points 1 - 3 are currently in large met, while point 4 needs to be further developed. Moreover, point 3 b is typically a point of further future need to be reflected on, and where CDIO learning objectives may be clearly contributing.

CONCLUSIONS

This contribution proposes a new form of WBL that strives after meeting problems seen in WBL in computer science education. For example, it is difficult to engage a sufficient number of industry representatives in general to act in WBL, and especially in the supervision of students with limited resources, and where the highly specialized activities are not suitable for students on a shorter course. By instead involving a few external company participants in the educations where they participate online on a smaller number of occasions, there still are WBL-values, such as, contacts between student and industry, as well as between teachers in academia, and industry. Furthermore, the new form of WBL takes inspiration from the need to train students in Remote Work, which is pointed out by many as the new way of working in the IT industry.

However, the primary importance, also within WBL, is still to meet the learning objectives that are included in a course and within an educational program, and that must clearly be considered. In this paper, it is argued that learning objectives, such as, regarding *Communication*, *Teamwork* and *Planning Ability*, among others, are essential and should be examined through the WBL-activities. In the proposed WBL-approach, the examination lies entirely on the teachers who controls it in appropriate ways.

The argumentation for this paper is seen from a perspective of two Computer Science courses at Kristianstad University, *Systems Engineering*, and *Software Engineering*, where the proposed WBL-approach has been partly developed and is seen as potential for the Computer Science educations, not least because it also trains students in future distance-based working methods. Further WBL-values, such as meeting points for possible employments, and study visits, have also been proposed, and will be seen as important and interesting elements of WBL-based activities of such courses.

For future work: While the concept of WBL traditionally relates to a physical workplace to achieve some positive values, the core of those values must be further elaborated on. What is here considered WBL, and what is not? Is an appropriate guest lecture considered WBL? Must there be one course in a study programme that has the WBL to make the progamme WBL-like, or can different possible WBL elements be spread over a study programme's different courses, to together meet the amount of required WBL elements? Future studies are clearly needed in the context of WBL (or WIL) to shed light on the understanding of the concept.

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EVALUATION OF IMMERSIVE PROJECT-BASED LEARNING EXPERIENCES

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ABSTRACT

Digitalization is transforming the real estate and construction (REC) sector and a key feature of this transformation is Building Information Modelling (BIM) - the virtual representation of all building-related information. By enabling the creation of digital twins of real buildings, BIM generates opportunities to do many things in new and better ways including education and training. Specifically, BIM offers the possibility of data rich virtual environments in which project-based learning experiences can be designed. Researchers at Tallinn University of Technology, Tampere University and the University of Bologna are currently developing a prototype BIM-enabled Learning Environment (BLE) with the intention of providing more realistic, immersive and integrated learning experiences. In addition to the BLE platform itself, pilot learning modules are being created to demonstrate the potential for this approach and, to determine their effectiveness, evaluation tools are being designed. This research investigates existing, applicable evaluation models and derives an evaluation model and tools specifically adapted for the immersive project-based learning experiences provided through the BLE. A literature review was conducted to identify existing evaluation models. A comparative content analysis approach was employed to identify their specific use cases, implementation requirements, advantages and disadvantages for deployment within the BLE context. The BLE pilot learning modules were analysed in terms of their defining characteristics and the key features of evaluation models applicable to them were identified. The identified features were then integrated to derive a new evaluation model and a corresponding set of evaluation tools considering the contemporary principles of Engineering Pedagogy.
The research results include:

1) Defining characteristics of the BLE pilot learning modules and the challenges these pose for evaluation.
2) Existing evaluation models and their applicability to the immersive project-based learning experiences of the BLE.

3) An outline of the evaluation model and appropriate evaluation tools for the BLE learning modules.

An evaluation model together with supporting evaluation tools are proposed that will assist educators and trainers in evaluating the impact of their activities for effective engineering education. This research also serves as a guide for the development of future BLE learning modules and for evaluating their effectiveness.

KEYWORDS

Engineering education, evaluation, project-based learning, virtual environment, CDIO Standards: 11, 12

INTRODUCTION

Digitalization is transforming the real estate and construction sector and a key feature of this transformation is Building Information Modelling (BIM) - the virtual representation of all building-related information. By enabling the creation of digital data equivalents (digital twins) of real buildings, BIM generates opportunities to do many things in new and better ways including education and training. However, educators now face the challenge of educating students to ensure that their professional competencies are properly aligned with the emerging, digitalised REC industry (Du et al., 2017; Hwang & Safa, 2017; Tranquillo et al., 2018). Fortunately, students' motivation, satisfaction, and academic and professional performance have all been found to improve when education is mediated through technological innovations such as BIM (Ferrandiz et al., 2018). Thus, BIM both imposes challenges for REC education and also opportunities for improving it as it offers the possibility of data rich virtual environments in which project-based learning experiences can be designed.

Researchers at Tallinn University of Technology, Tampere University and the University of Bologna are currently developing a prototype BIM-enabled Learning Environment (BLE) with the intention of providing more realistic, immersive and integrated learning experiences. In addition to the BLE platform itself, pilot learning modules are being created to demonstrate the potential for this approach. To determine their effectiveness, evaluation tools for these modules need to be designed. This research investigates existing, applicable evaluation models and derives an evaluation model and tools specifically adapted for the immersive project-based learning experiences provided through the BLE.

In the following section of the paper, the research methodology is outlined. The results of a literature review of existing evaluation models is then presented. The key characteristics and features of the BLE and each of the three pilot modules developed to be delivered with the BLE platform are then described. The common characteristics and evaluation need of the pilot modules are then analysed and a proposed evaluation model and tools are outlined before the findings are summarised and conclusions are drawn.

METHODOLOGY

A literature review was conducted to identify existing evaluation models. A qualitative, comparative content analysis approach was employed to identify and understand their specific use cases and implementation requirements as well as their relative advantages and disadvantages for deployment in the context of the BLE modules. The BLE itself and its pilot modules were then defined according to their contents, teaching methods, learning outcomes, etc. to allow their analysis in terms of their defining characteristics and the key features of evaluation models applicable to them. The identified, applicable features of existing evaluation models were considered in outlining an appropriate evaluation model and evaluation tools in light of the contemporary principles of Engineering Pedagogy.

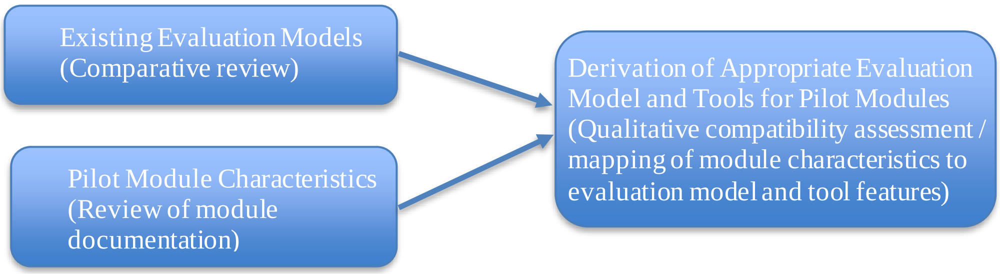

Figure 1. Flowchart of research methodology

REVIEW OF EXISTING EVALUATION MODELS

Olowa et al. (2021) found that the use of evaluation approaches in engineering education was generally low and little evidence of evaluation models being used in relation to BIM education interventions was available. This appears to be a long-term problem as Walder (2017) observed that, while the evaluation of pedagogical innovation is crucial, innovative pedagogical practices are usually not systematically evaluated. According to Walder (2017), professors who innovate frequently set the goal of developing additional skills that go beyond what they learned in traditional teaching, and it's critical to use the right evaluation methodology and avoid comparing what was done before with the results obtained after the pedagogical innovation has been implemented. Looney (2009) emphasizes that an evaluation approach that does not consider a program's original features may ignore important learning objectives targeted by this innovative program. Therefore, in the next section, the predominant contemporary evaluation approaches are reviewed together with their characteristics and relevance to evaluating BIM-enabled education.

Evaluation Models

Academic evaluation models are specific frameworks or methodologies which assist evaluators (researchers or practitioners) to design evaluation criteria and instruments for the purpose of measuring, ensuring, monitoring, controlling and improving academic related activities (Olowa et al., 2021). These activities are not necessarily limited to just teaching and learning which had been the case before the mid-sixties (Nevo, 1983) but encompass other incidental actors and actions within the context where they are performed. According to Stufflebeam (2003), academic evaluation is "…the process of delineating, obtaining, providing, and applying descriptive and judgmental information about the merit and worth of some object's goals, design, implementation, and outcomes to guide improvement decisions, provide accountability reports, inform institutionalization/dissemination decisions, and improvement decisions, and understanding of the involved phenomena". Evaluations are part of logical human activity and are similar irrespective of the approach adopted (Scriven, 1966). However, there are subtle and salient differences that are worth considering if the goal of the evaluation is to be realised. Many contemporary evaluation approaches have emerged and a selection of these are reviewed below.

Tyler's objectives-based evaluation

The objectives-based approach is particularly useful for evaluating programs that are narrowly focused and have clear, measurable goals (Stufflebeam & Coryn, 2008). Stufflebeam & Coryn (2014) opine that it is the most adopted approach among evaluators possibly because it is the easiest to use and appeals to common sense. However, what gives it its popularity is also its drawback in that it is considered too narrowly focused to be useful in evaluating a programme wholistically (Stufflebeam & Coryn, 2008). It is also not useful for formative evaluation as findings are only available at the end of the programme being evaluated. As such it cannot be used in process improvement and susceptible to giving a false positive (Stufflebeam, 1983).

Wheeler's model

Wheeler's model of curriculum development and evaluation is an amendment of Tyler's model (Cheng-Man Lau, 2001). Wheeler introduced the concept of continuity and developed a cyclic and flexible model of following steps: (1) define objectives and goals, (2) design learning experiences, (3) select course content, (4) organise learning experience, (5) evaluate.

Taba's inductive model

Taba's inductive model was first proposed by Hilda Taba in 1971 for curriculum design and evaluation, described in her thesis Curriculum Development: Theory and Practice in 1962 (Laanemets & Kalamees-Ruubel, 2013). The model considers the following six factors, to guide curriculum design and evaluation: (1) external factors (stakeholders), (2) content, (3) objectives, (4) teaching strategies, (5) learning experiences, and (6) evaluative measures. This model can be used in assessment and context and process evaluation, taking account of the expectations of stakeholders.

Context Input Process Product (CIPP) model

The CIPP approach was conceived and conceptualised by Stufflebeam in 1969 based on his experience with the funding and implementation of the Columbus project funded through the Elementary and Secondary Education Act of 1965 (ESEA). The perceived deficiency in applying the prevailing evaluation techniques at the time (especially the Tylerian model) informed the development of CIPP by Stufflebeam and his colleagues to include both context and process evaluations in addition to the input and product evaluations that were already in use (Stufflebeam, 1983). As such, the CIPP model allows for some sorts of interim procedural evaluations (formative evaluations) especially where academics cannot easily determine the change in students' behaviour due to an intervention. Although the CIPP model was primarily developed for projects meant to improve educational access to the less privileged and to overhaul the general system of elementary and secondary education in the USA, several authors and authorities have adapted the approach for evaluating different objects (Anh, 2018; Stufflebeam, 2003).

Scriven's consumer-oriented approach

Scriven (1966) suggests two roles of evaluation for curriculum builders and argued that the two are equally useful depending on the goal of the exercise. The first he referred to as instrumental and the second as consequential. Instrumental evaluation involves "…the instrument itself; in the case of a particular course, this would involve evaluation of the content, goals, grading procedures, teacher attitude, etc.," (Scriven, 1966). Consequential evaluation deals with "…examination of the effects of the teaching instrument on the pupil, and these alone. It involves an appraisal of the differences between pre- and post-tests, between experimental group tests and control group tests, &c., on a number of criteria parameters" (Scriven, 1966). He argues that substituting instrumental evaluation with consequential evaluation is not the best. He however emphasised that these are roles of evaluation and not procedures of evaluation. In giving processual outline of how to carry out evaluation, Scriven (1966) states that establishing the relationship between goals and course content, goals and examination content; and course content and examination content are important to a successful evaluation.

Stake's responsive evaluation

This approach was developed in the late 1960s as a replacement for "pre-ordinate" or experimental approaches, which paid little attention to the process and implementation of programs and had little engagement from stakeholders, including the beneficiaries, during the evaluation (Nyathi, 2020). The approach aims to expand the relevance of evaluation outcomes to a broader audience by de-emphasising goal-oriented approach to evaluation to provide different value perspectives of the stakeholders in reporting the success and/or failure of a program. According to Stake (1975) in Nyathi (2020), this approach is particularly useful during the early stages of a program, when stakeholders want to know what works and what doesn't, as well as how to improve program execution. Given the regular stakeholder communication and participation, one of the advantages of responsive evaluation is that practitioners do not need to wait for results until the evaluation is concluded but may start using findings during the process (Stufflebeam & Coryn, 2008).

Guba's constructivist, naturalistic evaluation

Guba's constructivist, naturalistic evaluation proposed a set of judgment criteria for constructivist evaluations that are akin scientific rigor, validity, and value standards (Stufflebeam & Coryn, 2008). The constructivist versions are credibility or trustworthiness, transferability beyond the studied context, dependability or reliability, and confirmability of data and data sources (Stufflebeam & Coryn 2008). One of the main points of these criteria is that the reliability and utility of an evaluation should be considered from the perspective of the evaluation report's users. Also, data are to be traced to their source and verified, and conclusions are to be assessed for logic, plausibility, and reasonableness. The strengths and weaknesses of this approach are well documented in (Nevo, 1983; Stufflebeam & Coryn, 2008).

Patton's utilization-focused evaluation

Stufflebeam & Coryn (2014) described Patton's utilization-focused evaluation as one of the four "eclectic" evaluation approaches whose use case is primarily informed by findings. Other forms of eclectic evaluations are Owen's evaluation forms approach; the cluster evaluation approach; and various participatory forms of evaluation (Stufflebeam & Coryn, 2014). Stufflebeam & Coryn (2014) further state that eclectic evaluation theorists get their ideas, style, and taste from a wide variety of places. Their methods are tailored to meet the objectives and preferences of a diverse variety of evaluation clients and evaluation projects, with the goal of analysing a program without being bound by the limitations of a single model or methodology. As a result, evaluators that take an eclectic approach use whatever philosophical foundation, conceptual structure, and methods most conducive to attaining specific evaluation goals and satisfying the needs of specific evaluation clients.

Experimental design

The goal of the experimental and quasi-experimental design approach to program evaluation is to arrive at unbiased findings about the success or failure of a program (Stufflebeam & Coryn, 2014). Individuals, groups, or other units are randomly assigned to one or more conditions; a special treatment is given to one group and none (or an alternative treatment) to another;

treatment conditions are held constant throughout the evaluation; and finally, a conclusion is reached (Stufflebeam & Coryn, 2014). Experimental and quasi-experimental design approaches have been used on diverse range of objects including employment; criminal justice; health care; cultural enrichment programs for children; preschool, elementary, and secondary education; distance education etc.

Case study evaluation
Investigators in case studies look extensively at the context, including program participants' demands, inputs, operations, intended and unintentional impacts, and any other processes (with all their intricacies) that are producing outcomes (Stufflebeam & Coryn, 2014). The portrayal of events, testimonies, stored data, and personnel participating in program implementation and direction are all prioritized so that stakeholders have the knowledge they need to understand the program and make necessary modifications. This data will unavoidably portray the multifaceted nature of the environment in which a program is taking place (Stufflebeam & Coryn, 2014). The authors surmised that an in-depth, noninterventionist investigation of a case and the issuance of illuminating report are the hallmarks of a case study evaluation.

Processes in evaluation approaches
Usually, evaluation approaches contain suggestions for several procedures or stages for implementing evaluation projects or programmes. The number of steps in the models varies, ranging from three to ten steps or processes (Olowa et al., 2021). These steps or processes are observed to be dependent of the philosophical background of the evaluation approach. Nevo (1983), in his review of major evaluation approaches in education, argued that there is no consensus among evaluation experts on the "best" process to use when conducting an evaluation. He, however, observed that most evaluators agree that all evaluations should include some level of interaction between evaluators and their audiences both at the start of the evaluation to identify evaluation needs and at the end to communicate the results. Nevo (1983) concluded that the technical activities of data gathering, and analysis are not sufficient for evaluation.

Evaluation Models in Engineering Education
In their review of over three hundred engineering articles and twenty-four general evaluation publications, Olowa et al., (2021) observed that engineering educators have been found to employ a variety of methodologies for evaluating engineering education for a variety of reasons, across a variety of time periods, and with differing degrees of complication. Major approaches they found include Accreditation Board for Engineering and Technology ABET, Baseline interview, longitudinal studies and portfolios, Web-based course for course evaluation questionnaires, Course panels and instructor reflective memos, QUESTE-SI (Quality system of European Scientific and Technical Education for Sustainable Industry), Student grades and SAPA (self- and peer-assessment). They further state that only the CDIO (Conceive-Design-Implement-Operate) standards, ABET, QUESTE-SI, and other educational board models appear to assist engineering education. The CDIO's creators argued that the model is more consistent, thorough, and detailed than other national and international standards such as UNESCO. The 12 CDIO standards form a solid basis for evaluation.

BIM-ENABLED LEARNING ENVIRONMENT AND PILOT MODULE DESCRIPTIONS

In this section, the salient features of the BLE and of the 3 pilot courses designed to demonstrate these features are set out.

The BIM-enabled Learning Environment (BLE)

The BLE is a web-based platform currently under development with the specific purpose of providing a host environment for learning experiences that leverage BIM for education and training. It does this by enabling the following types of function:

- BIM functions - such as: BIM model viewing, editing, sharing, data extraction, a common data environment for project data, simulation of the BIM work flow, example project data resources, etc.
- Virtual learning functions - such as: user registration, learning materials hosting, assessment, feedback, file upload, file download, etc.
- Collaboration functions - such as: group formation, communication channels, live interactions, collaborative file viewing and editing, etc.

The BLE is intended to enable immersive and integrated learning experiences on the basis of realistic project data and a realistic industry work flow that fully utilizes BIM. As BIM ensures comprehensive, organised and readily accessible project data that are mostly referenced to building objects (walls, beams, columns, windows, doors, floor slabs, pipes, etc.) represented in a virtual, 3D model of the building, project data can be easily visualized and understood. It thus enables realistic and quite complicated project scenarios to be presented to and efficiently grasped by students.

This supports experiential learning activities where data input to the learning activity is real (or, at least, realistic) project data and is drawn from similar sources as would be the case in industry. Of course, this project data must be prechecked and simplified to remove inconsistencies and unnecessary details which could confuse learners. By carrying out the learning activity, the project data is further processed and the output data feeds back into the BIM work flow. The project data are thus elaborated and the project progresses in a similar fashion as it would in the 'real world'. In this way, the learning activity resembles a meaningful task in a genuine work context.

An initial set of 3 pilot modules is being developed to demonstrate the BLE, its functions and, more widely, the concept of BIM-enabled learning. Each pilot module focuses on different aspects of the BLE capabilities and is being collaboratively developed under the leadership of one of the partner universities as follows:

1. Pilot Module 1 - BIM-enabled Construction Site Organisation - led by University of Bologna;
2. Pilot Module 2 - BIM-enabled Project Risk Management - led by Tallinn University of Technology;
3. Pilot Module 3 - BIM-enabled Design Management - led by Tampere University.

The pilot modules will be developed to systematically cover everything that the 3 types of users (instructors, learners, system administrators) need to know and they will represent the standard practice for future BLE learning modules. They are each described in more detail below.

A comprehensive evaluation model and tools are needed in order to establish whether these pilot modules meet expectations in terms of their efficient achievement of learning objectives, etc. and the current research aims to derive such an evaluation model and tools.

Pilot Module 1 - BIM-enabled Construction Site Organisation

This module addresses the benefits of applying BIM technology for the organisation of construction site organization and logistics. The module is delivered in four phases as follows:

Phase 1. Learners are introduced to the principles and theory of BIM
Phase 2. Learners are introduced to relevant software packages that enable them to apply BIM within the context of construction site organization.
Phase 3. Learners work in groups, each group assigned to a different building site case in order to determine an efficient construction site layout (crane types and positions, materials stores, site offices and facilities, etc.) for that building case.
Phase 4. Learners review, compare, discuss and reflect on their derived solutions.

It should be noted that, as BIM models and associated data are created and further elaborated in the course of the learning activities, they are then expected to be deposited into the model and data repository and thus increase the example project data resources available to users of the BLE.

Pilot Module 2 - BIM-enabled Project Risk Management

Learning activities for this module proceed as follows:
Initial instructions:

- Key steps in the process of project risk management;
- Instructions and information for participation in the learning activities.

The learning activities comprise a series of risk management workshops held at different project stages. Students work through a guided, detailed project risk management process (including both qualitative and quantitative risk analysis) on the basis of real project data within a BIM work flow.

Pilot Module 3 - BIM-enabled Design Management

This pilot module involves a multidisciplinary simulation of the concept design stage of a construction project, where students are organised into stakeholder groups (Client, Architect, BIM coordinator, etc.) and, to an extent, students' specialisations (architecture, construction management, structural engineering, etc.).

A single project scenario is given and the stakeholder groups work sequentially and in collaboration to analyse, simulate and integrate the building design using a BIM model and other available resources. Faculty members and industry mentors advise the students throughout the development process.

DERIVATION OF AN EVALUATION APPROACH AND TOOLS

The aim of an evaluation model and tools is to evaluate the following aspects of the teaching and learning process: the extent to which learning objectives are achieved, and the effectiveness of the teaching-learning experiences provided, identifying areas for improvement and supporting further development of the module design and implementation, realizing learning outcomes more efficiently.

Common Module Features, Teaching Methods and Learning Objectives

The described modules have common features based on multidisciplinary principles of problem-based learning, where students have to solve real-world problems and make informed decisions using simulations. Additionally, the principles of John Boyd's OODA-Loop (Observe-Orient-Decide-Act) for informed decision-making is one of the foundations of active learning in all modules. Accordingly, inductive teaching methods, like case studies, "just-in-time" teaching, "on-board" teaching, team-based learning, problem solving, and active learning methods are used for supporting critical and creative thinking, and meaningful learning. The learning objectives of the described modules should cover all the levels of Bloom's Taxonomy ensuring the acquisition of basic knowledge in specialty and supporting skills of analysis and evaluation along with collaboration and cooperation. While the assessment methods used rely mostly on self-evaluation, peer-evaluation and reflection, thus learning portfolios will be introduced along with the formative and summative assessment of an instructor.

Proposed Evaluation Model and Tools

A model for evaluation consists of three basic components: inputs (resources of the program: program staff, funding, time, partners, materials, etc.), outputs (the model, training, methodology, etc.), and outcomes (knowledge, attitudes, awareness, skills, behavior, educational quality, impact, etc.). Within the present research, both qualitative and quantitative evaluation tools may be used. The proposed tools will be elaborated with the aim of evaluating the described modules on the basis of CDIO standards and the integration of suitable evaluation models.

CONCLUSIONS

Development process of a prototype BIM-enabled Learning Environment (BLE) with the intention of providing more realistic, immersive and integrated learning experiences have been analysed. In addition to the BLE platform itself, pilot learning modules are being created and introduced to demonstrate the potential for this approach and, to determine their effectiveness, the principles of creation of evaluation tools are described. This research paper presented existing, applicable evaluation models and derived the principles of evaluation models and tools that will be specifically adapted for the immersive project-based learning experiences provided through the BLE.

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CHARACTERISATION OF EFFECTIVE DELIVERY AND SUPERVISION OF CAPSTONE PROJECTS

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ABSTRACT

Delivering activities that are well aligned to the CDIO curriculum can present many challenges and often the complexity of these activities can lie outside the skill set of any single individual. Student projects at the University of Liverpool are now more complex than they were 15 years ago and it was felt that critical reflection of supervisory practice would be of benefit. This paper studies how the topic, structure, delivery and supervision of Capstone projects at University of Liverpool has evolved over the last 10 years. Several gradual shifts are noted: towards sustainability themes, towards cross-disciplinary approaches, and towards extended industrial collaboration. This paper presents an analysis of professional skills development in Capstone projects; drawing on consultation with academic faculty, current Capstone students and graduates now in employment. The prioritisation of various learning outcomes is compared across these three groups: the diversity of these outcomes suggests that academic faculty alone cannot hope to deliver them. This paper proposes that the key to effective delivery of complex learning activities lies not in developing and equipping any one individual supervisor with a never-ending skill set, but instead lies in fostering effective partnerships between a number of diverse individuals (academic faculty, technical staff, industrial partners). The paper then explores best practice in Capstone project supervision through reflection on current practice, and consultation with academic faculty supervisors, students, technicians and industrial partners/supervisors. The benefits of involving technicians and industrial partners in the development and delivery of Capstone projects is discussed; and the use of recent graduates as industrial supervisors is explored. The concept of using 'Communities of Practice' to guide and support Capstone supervision is presented and described. In light of our recent experience of using Communities of Practice, we also explore how this has the potential to augment faculty development initiatives, and to improve the competency of staff delivering Capstone supervision.

KEYWORDS

Capstones Project Supervision, Technicians, Industrial Collaboration, Faculty Development, Community of Practice, CDIO Standards 7, 8, 9, 10

1. INTRODUCTION

Capstone projects are fundamental to the CDIO approach to engineering education; they are an effective platform for students to "*conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment"* (Crawley et al. 2014), and they are crucial to ensuring programmes can meet CDIO Standards 7 and 8. They focus not only on engineering science but on enhancing skills and experiences required of graduates entering into professional engineering.

A survey carried out by Brumm et al. (2006) shows that respondents rated the learning opportunities provided by Capstone projects second only to a placement in an engineering workplace. Students acknowledge that these activities are where they develop vital skills and demonstrate their employability. Of the students completing an MEng programme at University of Liverpool (UoL), of which Capstone projects are an integral part, 100% are in employment six months after graduating, 70% of which are employed as engineering professionals (HESA 2018). However, these can be the most difficult learning experiences to deliver; project topics can vary widely and supervisors are required to possess a range of practical, pedagogical, professional and scientific skills. It is therefore highly unlikely that any one individual instructor will possess this full skillset.

As Capstone projects at UoL have evolved to become more complex, then our supervisory practice has had to evolve to ensure effective delivery. Efforts have been made to broaden the pool of knowledge available to students by increasing the involvement of non-academic staff in the delivery of these projects. Although student surveys have shown an increase in satisfaction, and anecdotal evidence suggests that students are acknowledging the benefits of the complementary knowledge gained from other members of staff, it would seem sensible to take a more in depth look at our current practice. This paper aims to explore the assumption that a team approach to supervision can improve student learning in Capstone projects.

2. EVOLOUTION OF CAPSTONE PROJECTS AT UNIVERSITY OF LIVERPOOL

Capstones at UoL are 22.5 ECTS group design-build-test projects that run throughout the 3rd and 4th years of study. They have been a core component of 4-year MEng Mechanical Engineering programmes at the University of Liverpool for 15 years. During this time our approach to supervision and assessment has been refined; and the nature of the projects has evolved to reflect changes in the priorities of our discipline and in the interests of our students. Key developments have been:

2.1. Gradual Shift Towards Sustainable Development Themes

In the early years of Capstones most students worked on our flagship project - the Formula Student single seat petrol engine racing car (IMechE, 2022). Alongside this we ran other smaller projects such as the development of unmanned air vehicles and the laser marking of auto-body sheet aluminium. As the number of students taking the course increased (to approximately 140 per year currently) we sought to diversify our project portfolio to give students choice – reflecting their interests and the changing priorities of modern professional engineering. In short there has been a shift towards sustainability themes and Table 1 below lists the projects running from 2019-2022.

2.2. Increase in Cross-disciplinary Collaboration

In the early years of our Capstones, the projects only addressed 'traditional' Mechanical, Materials and Aerospace engineering themes. A weakness was that our students did not experience the cross-disciplinary collaboration that characterises modern professional engineering. Our current project themes (Table 1) have much greater interdisciplinarity, and our mechanical engineering students are therefore working every day with students and professionals from other disciplines: electrical, civil, chemical and nuclear engineering; industrial design; medicine; veterinary science; bioscience, retail. Thus, we are now better preparing our students for their lives and careers ahead.

Next year we will begin a new Capstone project in which our students will develop a cargo bike customised to allow a charity to support homeless people sleeping on the streets of Liverpool. The project team will include a group of sociology students who will explore the social and economic impact of our engineering. This is a critical development to enhance student understanding of all dimension of sustainable development, not just environmental.

Table 1: Current Capstone Project Themes

Project	Description
Formula Student Electric	International Competition
Velocipede – world human powered speed challenge	International Competition
12m land wind turbine for agricultural refrigeration in Africa	Industrial Collaboration – Siemens Gamesa Renewable Energy S.A.
Mobile vertical axis wind turbine for urban / events use	
Solar powered agricultural refrigeration in Africa	Academic Research Group Collaboration – Renewable Energy Research Group
Autonomous systems for hazardous nuclear environments	Industrial Collaboration – British Nuclear Fuels Ltd
Engineering systems for equine surgery	Industrial Collaboration – Leverhulme Equine Hospital
Automated leak detection in water supply & sewage systems	Industrial Collaboration – United Utilities plc
Systems to predict pipe corrosion and failure in hazardous chemical engineering	Industrial Collaboration – Inovyn Ltd
Autonomous vehicle for automatic detection and repair of road surface damage	Industrial Collaboration – Robotiz3D Ltd
Refillable technology for the supermarket of the future	Academic Research Group Collaboration – Hague University of Applied Science
Next generation folding bike for urban commuters	UK&I Region CDIO Competition

2.3. Enhanced Industrial Collaboration

In the early years of our Capstones, the projects were all delivered ‘in-house’ with academic faculty supervision and no collaboration with external professional engineers. Over the last five years we set ourselves the challenge of only introducing new projects if they are in partnership with engineering industry (whilst retaining our high-profile international competition projects) – see Table 1. Our Industrial Capstones improve student motivation and engagement with ‘real world’ engineering challenges; and they enhance student personal and professional development through working in partnership with practising professional engineers. The extent of industrial collaboration in our Capstone projects is at one of three levels to suit the partner company:

Industrial Project Concept: the partner company sets a current design-build-test challenge; briefs the students on the project context and background technology; and participates in periodic project reviews. See section 4.3 for an example.

Industrial Project Support: as above, but the company also assigns one or more professional engineers to act as 'consultants' to the project. These professionals are available on-demand to the students to inform, support and guide their work. In these projects the students also spend time working at the partner site.

Full Industrial Collaboration: as above, but the company also assigns one or more professional engineers to provide formal supervision and mentoring to the student team. These professionals are the primary project supervisors (supported by academic faculty) and typically hold 2-hour project meetings each week with the students. In these projects the students spend time working at the partner site and often take summer internships with the company.

Our ambition is that all new projects are based on full industrial collaboration because in this mode the students are most exposed to professional engineering practice: their professional and personal development, and ultimately their graduate employability, are most enhanced. Our current partnership with Siemens Gamesa Renewable Energy S.A. embodies this ambition: they are currently supervising two wind power projects and Figure 1 summarises the project structure and supervisory approach.

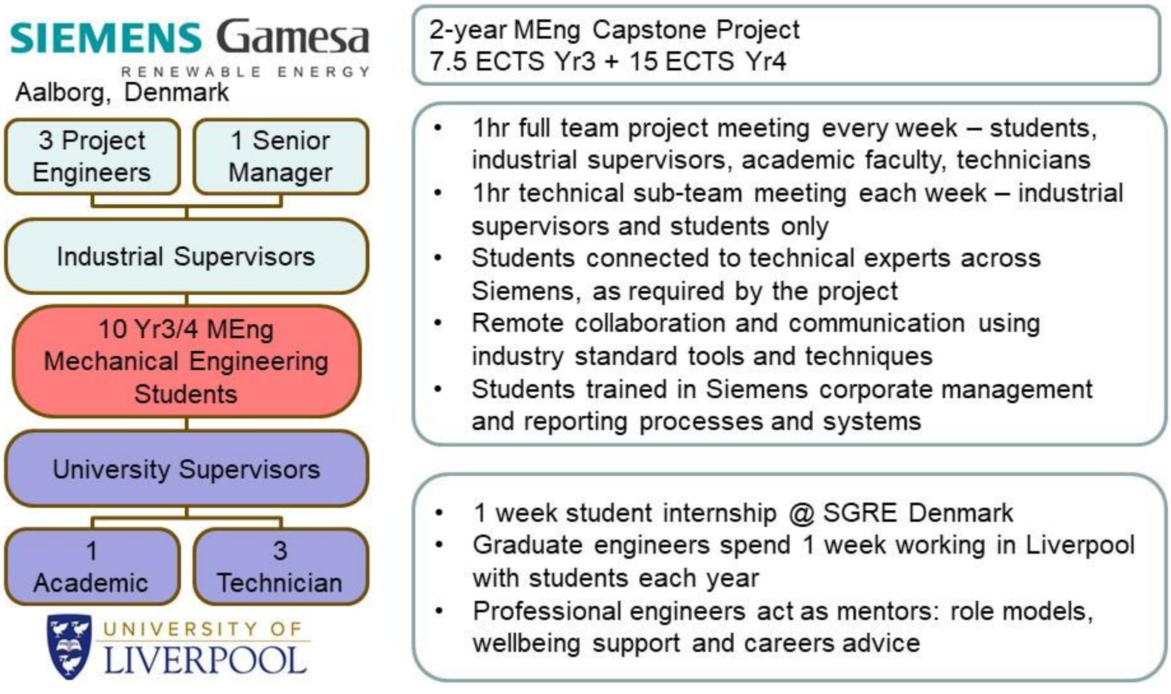

Figure 1: Project Structure and Supervisory Approach for Capstone Projects with Full Industrial Collaboration

3. REVIEW OF PERSONAL AND PROFESSIONAL SKILLS DEVELOPED IN CAPSTONE PROJECTS

In order to gain an understanding of the skill transference over the course of a Capstone project, a survey of current students and graduates was carried out. Of the ~60 individuals emailed the survey (8 graduates, ~50 students), 15 responded (5 graduates, 10 students). The survey presented respondents with a list of the published learning outcomes for the course (Table 2) and asked them to select any of the skills that they anticipated to gain, or had gained. They were then asked to rank the perceived importance of the skills they selected. Further to this survey, a consultation with academic supervisors of current Capstone projects (3 individuals) and technicians closely involved with Capstone projects (2 individuals) was carried out to gauge what skills they thought they were transferring to students and what they felt were the most important skills gained from Capstone projects. Table 3 compares the five most important learning outcomes identified by each stakeholder group, ranked by perceived importance.

Table 2: Course learning outcomes for Capstone projects (in no particular order).

Course Learning Outcomes	
Product & System Design	Communication (formal & informal)
Project planning & management	Technical record keeping
Design for manufacture, assembly, cost and sustainability	Professional reporting & progress presentation
Materials Science & Selection	Reflection on own & peer performance
Mechatronics	Problem solving
3D CAD modelling	Teamwork
Modelling and simulation	Manufacturing technology

Table 3: Professional skills gained from completing Capstone projects ranked by perceived importance

Rank	Professional Skill	
	Graduates (Survey)	**Current Students (Survey)**
1	Project planning & management	Teamwork & collaboration
2	Problem solving	Project planning & management
3	Design for manufacture and assembly	Problem solving
4	Teamwork & collaboration	Design for manufacture and assembly
5	Communication (formal and informal)	Communication (formal and informal)
	Academic Faculty (Consultation)	**Technician (Consultation)**
1	Teamwork & collaboration	Problem solving
2	Project planning & management	Design for manufacture and assembly
3	Application of engineering theory in system design	Communication (formal and informal)
4	Problem solving	Product & System design
5	Communication (formal and informal)	Manufacturing Technology

Although this data only represents feedback from 20 individuals, it is interesting that the selected skills are somewhat similar across all four groups. It should also be noted that the outcomes of this survey correlate well with the findings of Paul et al. (2015) on global graduate attributes (GA): specifically the desired learning outcomes of problem solving, team work, communication and ability to design (analogous to design for manufacture in our survey). We can also see that Table 3 overlaps with the skills outlined in the CDIO syllabus (Crawley et al. 2011), specifically sections; 2.1, 2.4, 3.1, 3.2, 4.4, and 4.5. The identified learning outcomes in Table 2, and the skills they overlap with in the CDIO syllabus and GAs, are difficult to deliver elsewhere in the programme so this work confirms the importance of Capstone projects and may offer insight as to why these projects can be difficult to deliver.

The survey of current students and graduates asked how Capstone students interacted with academics, technicians and industrial partners; and what they gained from these individual interactions. The responses confirmed that some skills were more likely to be gained from interaction with a particular group. Typical survey responses were:

- Academic Faculty supervisors were best placed to *"guide the project"*, offer support with "*project planning and management"* and provided *"expertise in a particular field"*;
- Technicians helped with *"design and problem solving"*, answered questions *on "the practicalities of [design] ideas"* and *gave "knowledge…on the right technology for the project"*;
- Industrial partners offered insight into professional practice of *"planning projects and presenting information".*

The survey shows that students place a high value on skills such as teamwork, communication and problem solving: skills that cannot be taught but only developed through experience. Students also appear to be learning different skill sets from different types of supervisor. In acknowledging these challenges, UoL has already moved towards a team approach to Capstone supervision where groups of individuals work together to deliver the full range of learning outcomes effectively. Efforts have been made to create proper working partnerships between academic and technical staff and these activities are now seeing a range of input from industrial partners with the aim of further increasing the educational benefit to students.

It is assumed that a team of supervisors, working in different roles, can be more beneficial than an individual faculty supervisor. To test this assumption, respondents of the survey where asked to define the ideal supervisor or supervisor team. Below are some of the comments received from both graduates and students:

- *"Ideal supervisor team would involve a mix of people with both academic skills (report writing, presentations, communication, etc.), and technical skills (DFMA, manufacturing, "hand-on" skills, etc.)."*
- *"I think a closer link with industrial partners would be really useful for more 'real world' expertise… But all individuals mentioned are important in my opinion, and bring different things to the project so make a good combination on a whole."*
- *"My ideal team would probably have academic and technicians available for support throughout the process alongside post-grads, individuals and industrial companies available during different stages where they are relevant"*

4. REFLECTIONS ON APPROACHES TO CAPSTONE SUPERVISON

The findings above confirm that Capstone students do gain some significant learner benefits from a team approach to supervision. To further explore this concept, we now reflect on our evolving approach to Capstone supervision by looking at the individuals involved in more detail.

4.1 Academic Faculty

A core component of the academic faculty role is the creation, supervision and assessment of student projects. Faculty have the appropriate technical expertise, pedagogic training and experience to supervise/assess *research-focussed* projects. Further, the Codes of Practice and quality assurance protocols of most universities require academic faculty to be the primary supervisor/assessor of all student work. Historically, academic faculty have been the sole supervisors of student projects providing scientific expertise; supporting project planning and management; teaching students formal reporting approaches; assessing and providing feedback on student work; and providing encouragement and guidance to students. Whilst Capstone projects might contain some scientific research, they are primarily group design-build-test projects and as such place more complex and varied demands on the supervisor.

CDIO Standard 9: Enhancement of Faculty Competence acknowledges that "*Engineering professors tend to be experts in the research and knowledge base of their respective disciplines, with only limited experience in the practice of engineering …*" Standard 9 also recommends that "*… Faculty needs to enhance its engineering knowledge and skills so that it can provide relevant examples to students and also serve as individual role models of contemporary engineers*". For many years CDIO collaborating schools have been seeking to develop their academic faculty competence in an effort to create the "ideal engineering educator" to supervise Capstones. For many years they have struggled.
Almost all collaborator self-evaluations against the CDIO Standards prove that Standard 9 is the hardest to make progress against.

4.2 Technicians

In our experience, Capstone project briefs designed without any input from technical staff would be more likely to falter as they progress to the Implement-Operate stage due to unrealistic expectations of in-house workshop capabilities. When technicians are involved in designing a Capstone project brief from the start, then more realistic targets can be set for the expected outcomes, ensuring that the scope of the project remains feasible. Having a proper working partnership between technicians and academics at all stages of the design and delivery of student projects is considered essential.

Technicians have a set of skills to offer that most academics do not possess; 90%+ of workshop technicians have vocational qualifications which are traditionally deemed better than university degrees for equipping people with practical engineering skills (Lewis and Gospel 2015). This skill set is invaluable to practical activities such as the ones discussed above: in fact, it could be argued that without knowledgeable technicians, students would struggle to progress their projects through the Implement-Operate phases. In their paper, Thomson and Gommer (2018) acknowledge that technicians *"are key partners in enabling these activities and ensuring successful outcomes for students."*

It is of course essential that technicians are not just involved in the design of Capstone project briefs, but also in the supervision of the projects. To help improve student understanding and project work, our technicians are now more accessible to them and more involved in the delivery and support these projects. Drop in appointments have been arranged, technicians meet with student groups at the start of the project and then meet regularly with them to review designs.

Lewis and Gospel (2015) note that a proportion of technicians are over-qualified and under-utilised; applying their skills and knowledge to a deeper involvement in the design and delivery of teaching could be a way fully realise the potential of this section staff. This reflects a growing sector wide movement to recognise the input of technicians in teaching and to encourage technicians to gain professional teaching qualifications (Bradley 2018).

4.3 Industrial Partners

Industrial partners can offer educational benefits beyond what is offered by academic and technical staff. Hurn (2016) suggests that working with industry on 'live' projects can significantly enhance student experience and improve engagement and performance. Wu (2017) notes that students can experience increased learning outcomes and points out that there is a growing trend in industry for graduates with cross-disciplinary competence and that implementing a CDIO approach to student projects could be the best way to achieve this. Engineering graduates will often be expected to work across disciplines in order to solve complex global problems (Tomkinson et al 2018) and Capstone projects can offer first-hand experience of this. A requirement of the CDIO syllabus (Crawley et al. 2011) is that students are able to work in cross-disciplinary teams and with non-technical members and teams. The UK engineering professional bodies requires that students have an ability to apply and adapt design processes and methodologies to unfamiliar situations (Engineering Council 2014).

As noted in *Section 2.3*, industrial collaboration in our Capstone projects is at one of three levels.

Concept partnerships are well suited to cross-disciplinary projects where the partner may have limited engineering knowledge.
For example, a recent project involved veterinary surgeons form the University of Liverpool Equine Hospital looking for engineering input to improve equipment used for post-surgery recovery. The partners introduced the brief, and helped the students become more familiar with surgical practice. The students gave regular updates to the partners and received feedback on the direction of their work, in the process gaining experience in communicating with non-engineers and translating design intent from non-technical explanations.

Support and Full Collaboration partnerships go further, offering an insight into professional engineering practice; and in providing a tangible demonstration of the link between scientific theory and engineering application. Eckert et al. (2013) note how important it is for the learning process to see theory implemented in practice. They go on to add that students can benefit from; a deeper understanding of company structures and routine, training in how to communicate with industry, and how to promote themselves to potential employers.

4.4 Alumni as Full Collaboration Partners

A new variation of the *Full Collaboration project* has recently started at UoL that could offer further benefits. The project brief was provided by an industrial partner (Siemens Gamesa) as usual, however the supervision team includes three graduate engineers who are alumni of Capstone projects. It was felt that having supervisors with recent experience of University education, in particular themselves having completed a Capstone project, would improve student learning by; empathising with the student project experience; offering accessible role models, wellbeing and life coaching; and employability and career support. The three alumni supervisors and their senior supervisor were interviewed as a group shortly before the start of the project, and then again after six months. Presented below is a summary of the most relevant comments made during interviews.

- It was noted how valuable the graduate supervisors found the opportunity to experience the entire CDIO project life cycle. The design of the project brief took this into account to ensure an achievable end goal that would reach the 'Operate' stage.
- They noted Capstone projects failed to pass on some of the essential soft skills they needed in their first year of employment. They hoped to include in this project more opportunity for the students to develop; project management skills, including specific project management tools; an understanding of the importance of how documentation is developed and implemented; and change management, adaptability and resilience skills.
- Graduate supervisors are currently working on their professional qualification, and are using that experience to enhance their capstone supervision and provide more structured professional development training for the students.
- The senior industry supervisor noted that it could be difficult to switch between supervising professionals and supervising students, sometimes having unrealistic expectations of the students. Having recent graduates on the supervision team helped to calibrate expectations and act as a medium between the needs of the students and the expectations of the professionals.
- It was noted that students had become more professional and organised during presentations and meetings. Students were initially disorganised and found it difficult to keep focus on the project aims but it was felt that it was necessary to allow the students to find their own way of working. Supervisors gradually introduced industry-standard project management concepts and tools which allowed the students to make a clear link between the incorporation of these tools and the improvement in their output.
- Graduate supervisors acknowledged the impact of supervising the project on their own professional development along with an improvement in their level of knowledge. In particular, supervision of this project was helping towards their professional qualification by providing management experience.

5. DEVELOPING BEST PRACTICE IN CAPSTONE SUEPRVISION

We have evidenced that different types of project supervisor can deliver different learning outcomes and benefits to Capstone students. However, to better understand how a team of supervisors could effectively work together to support students it was felt that reflection on current supervisory practice and a review of related literature was needed.

5.1. Reflections on Working Together Effectively

In considering the challenges faced when delivering these complex projects, it was useful to first reconsider what knowledge is and how it is transmitted. Northedge (2003) sets out the argument that viewing teaching as presenting items of knowledge to be internalised can create problems when faced with diverse student needs. Every Capstone project is different, every student is different and when we consider that some of the skills students value the most are teamwork, communication and problem solving, these discrete 'items' of knowledge become even more difficult to define, let alone transmit. Notrhedge goes on to argue that these challenges demand a more fluid concept of teaching which can be found in sociocultural theories of learning.

In light of this, we might then consider viewing the partnerships created between staff, industrial partners and students to work on these projects as a '*community of practice*' (CoP), defined by Wick (2000) as "*professionals that have similar responsibilities and disciplinary backgrounds that work to solve authentic problems*". Johnson (2001) notes communities of practice have roots in constructivism concepts: ill-structured problems that are authentic and complex; real-world problems that engage learners in collaborative group activities; and where leaners gain ownership of the problem through shared goals. The fundamentals of Capstone projects are similarly rooted in constructivism, it could therefore be argued that applying this sociocultural view to supervision is beneficial. Case (2008) advocates the usefulness of using CoPs as a thinking tool in engineering education, noting that it has always been implicitly present. Further adding that taking this line of thinking onboard can help these types of activities become more effective learning experiences, particularly in problem-based learning activities such as Capstones. Beckmann (2016) points out that thinking about teaching and learning in light of CoP is increasingly becoming a preferred strategy. Indeed, current practice within our School has already moved towards a CoP style of supervision, albeit an instinctive move born out of necessity rather than a conscious effort to employ these pedagogic theories.

5.2. Using a CoP Approach as a Tool to Improve Student Learning

Further benefits of operating within a CoP can be found by taking on board Northedge's (2003) perspective that knowledge "*arises out of a process of discoursing, situated within communities"* and that individuals can benefit in participating in this discourse, no matter what their level of understanding is; "*a discourse is a communal knowledge system within which all participants, in the process of participating, extend their repertoire of knowledge."* Each student within the group will have different levels of initial understanding and at the start of a project that level will be at its lowest. The specific terminology of engineering will be little understood by the student and the communication skills required to describe complex ideas and solutions may be limited. By participating in the discourse in a peripheral manner, students can begin to acquire the necessary skills. That is to say that by listening to the manner in which the academic, technician and industrial partner discuss work and the language used to answer students queries, the student's knowledge will increase. As the project progresses, student's knowledge will increase at different rates. However, *"if a course presents compelling flows of richly textured meaning, a wide range of students will be able to participate and will advance from their prior level of discursive skill."* (Northedge 2003).

By acknowledging that knowledge can be transferred as part of the group discourse and by encouraging this way of working, the supervisor can ensure that all students needs are met. This opportunity to participate in a rich CoP can also improve professional practice and employability opportunities. Northedge (2003) gives an example of a student being offered a job because they were able to *"speak the same language as the interviewers."*

5.3. Using a CoP Approach as a Tool to Aid Retention of Skills and Knowledge

This CoP approach can also offer a solution to managing the knowledge that is generated when solving discrete problems within a given project. Even though projects vary widely it is often found that the experience and knowledge gained from working on one project can be transferable to the next project. Knowledge retention becomes more vital for projects that run over a number of cycles and which focus on innovation and iteration. Wick (2000) describes how a social-centred approach to knowledge and the use of collaborative teams can be an ideal way to ensure that knowledge is captured and maintained within a department. This is particularly important in the context of supervising Capstone project; once a project is finished and the students graduate it can be easy for the knowledge and experience gained to leave with the students. If members of staff, particularly technicians who often only have limited interactions with a project, are not properly engaged and connected to the work, the knowledge that is generated can become diffuse and incomplete. By having staff fully engaged and working within a community of practice this knowledge can be retained and transferred again to new students at the formation of a new team. Gherardi and Nicolini (2000) stress the importance of this type of organisational knowledge, the knowledge and experience shared within an organisation is greater than the sum of knowledge held by its individuals. Wenger (2001) also acknowledges the benefits of employing the CoP mindset to knowledge retention, stating that *"Members of a community of practice develop a shared repertoire of resources: experiences, stories, tools, ways of addressing recurring problems – in short a shared practice"*.

5.4. Using a CoP Approach as a Tool to Improve Faculty Competency in Capstone Project Supervision.

In our experience of using a CoP approach, we have noted that working within a CoP could in itself become a form of professional development for staff. For staff new to CDIO principles or problem-based learning, working within a CoP with a more experienced colleague can help them to develop the skills needed to best support this type of learning. This 'training' is crucial to ensuring effective supervision; although using a team approach to teaching brings a net increase to the skills available, all team members should be familiar with supervising Capstone projects to improve the likelihood of successful outcomes. For example, it is common practice at UoL for more experienced staff to support less experienced staff by attending group meetings and presentations. The way feedback and guidance is given by the more experienced offers authentic examples of practice to the less experienced.

Further to this, forming effective CoPs could be a way to improve the overall competence of a department in delivering complex projects. As noted in *Section 4.1,* it is difficult to make progress in this area; the recommendations in Standard 9 can take a significant amount of time to plan, implement and fulfil. The CDIO community has presented papers that address improving faculty competence (for example; Bhadani et al (2017), Cleveland-Innes et al (2017), Marchand et al (2018), P. Papadopoulou et al (2019)) but most often they focus on the development of an individual. This can add to the difficulty in making progress as the onus is on the already time pressured individual to make personal improvements. Whilst it is important that individuals engage in professional development and have the skills to develop activities, learning outcomes and authentic assessments that align to the CDIO fundamentals, this focus can often neglect the wealth of skills and experience already available within an institute or the industrial community.

6. CONCLUDING REMARKS AND FURTHER WORK

We have confirmed our initial assumption that a team of different types of supervisors can be more beneficial than an individual academic faculty supervisor.

On reflection, the authors suggest we take a new approach to Capstone supervision: that we stop trying to create the academic faculty member with the perfect blend of skills & experience, and instead focus on proper partnership between faculty, technical staff and practicing professional engineers in the design and delivery of projects. We assert that such a team-based approach can enhance student learning and allow us to target the full range of required learning outcomes.

The paper also suggests it is time to rethink the traditional route to which faculty competence is improved, shifting away from the notion that an individual has unlimited time to continually develop and master an ever-expanding skill set, and instead focus on how to best cultivate a knowledge community (Northedge 2003) that can effectively utilise the collective skills of all staff.

Further work would explore the development of a well-defined framework, using the findings of this paper as a foundation, that would capture and codify supervisory best practice and enable this practice to be shared between partner institutions.

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BIOGRAPHICAL INFORMATION

Tony Topping is a Learning Technologist in the School of Engineering and a Master of Arts candidate in Academic Practice, both at the University of Liverpool. He has a technical background, having worked as Teaching and Research Technician for 15 years, where he developed and delivered authentic learning experiences. His current work focuses on blending pedagogic and technical knowledge; and the use of technology to enhance the teaching activities of the school.

Matt Murphy is a Senior Lecturer in Engineering Design and Director of Education at School of Engineering, University of Liverpool, UK. He is a metallurgist by background with a PhD and 10-year technical research career in the additive manufacture (3D printing) of metals. For the last 14 years Matt has worked primarily on learning & teaching and has held several leadership positions in the School of Engineering, with special responsibility for curricular and pedagogic reform. Matt teaches a range of courses in materials science & manufacturing, but most enjoys leading the group design project modules. He establishes and supervises a broad range of student projects in fields such as renewable energy, urban farming, sustainable transport; veterinary healthcare; circular economy; and the local recycling of thermoplastics. In recent years Matt has focused on developing authentic learning and assessment experiences that seek to replicate industrial practice within taught programmes.

Matt has been a CDIO collaborator for 16 years; was co-Chair of the UK & Ireland Region for 6 years; and has been a CDIO Council member-at-large for 5 years.

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ENGINEERING STUDENTS' INTERACTION WITH INDUSTRY REPRESENTATIVES

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ABSTRACT

The aim of this paper is to share and reflect on experiences of learning activities, in which engineering students meet with representatives from industry and public organisations to get acquainted with realistic engineering issues. The paper is based on experiences from two learning activities at Linköping University, which aim at making the engineering students familiar with realistic industrial issues. The first activity is a course in Lean production, in which a half-day conference is organised where representatives from industry and public organisations describe how they work with Lean in practice. The second consists of courses in Six Sigma, in which the students carry out Six Sigma and Quality Management projects in different companies. Data regarding the students' experiences, learning and opinion about interaction with industrial and public sector representatives during their education were collected through questionnaires and interviews. The industrial representatives' views were similarly collected through interviews and written evaluations. The findings are that the learning activities were highly appreciated. They gave a good picture of real working-life issues and were relevant to the students. In the Six Sigma projects, the students specifically described that they learnt a great deal, both about Six Sigma and about project management, how to describe their work in new ways, and how to solve practical issues. The industrial representatives expressed that they were satisfied with the students' work, their competence, and the final result. It was beneficial that the students looked at the company problems from an outside perspective and that they contributed to knowledge sharing within the company. Experiences of organising these learning activities include highly positive feedbacks from students and participating organisations. For the teachers, even though it implies a lot of work, it is also a very positive experience contributing individual insights and life-long learning.

KEYWORDS

Active learning, Real-world engineering issues, Quality Management, CDIO Standards: 5, 7, 8

INTRODUCTION

Earlier studies highlight the importance of developing higher education in engineering to support the students' understanding, problem-solving skills and ability to apply knowledge in real-world situations (Bishop & Verleger, 2013; Mason et al, 2013; Arrambide-Leal et al, 2019). By carrying out the engineering studies in realistic contexts the students learn about current issues in industry and public organisations and that engineering consists of solving complex, open-ended problems. They also learn how their own knowledge fits with reality, and they get some insight into possible future work directions. This can be achieved through different approaches that enhance the students' deep learning in which the students reflect on the meaning of ideas and theories and how these can be applied in real-world situations (Marton & Säljö, 1976). A deep approach may be encouraged through four principal factors (Biggs, 1989):

- An appropriate motivational context
- A high degree of learner activity
- Interaction with others, both peers and teachers
- A well-structured knowledge base

The high degree of learner activity is also referred to as Active learning. The students then generally receive instructions in the classroom for forthcoming learning activities that encourage student activity and require the students to be more engaged in their learning process and reflect on what they do (Prince, 2004). Active learning is also one of the CDIO standards (Standard 8), advocating that the students should be directly engaged in problem-solving activities. This can include small-group discussions, demonstrations, etc. and even be experiential when the students simulate professional engineering practice (CDIO, 2021). One type of active learning is problem-based or project-based learning, which has been adopted within engineering education to improve the students' skills in problem-solving and collaboration (Zhu et al, 2019).

The importance of supporting the students' ability to understand and apply knowledge in real-world situations is also highlighted in other CDIO standards, such as Design-Implement Experiences (Standard 5) and Integrated Learning Experiences (Standard 7). The idea of Design-implement experiences is to aid the students to integrate knowledge and skills to promote early success in engineering practice. This can evolve throughout the students' educational programme and in later courses be included in learning activities involving real-world issues, for example in different types of projects with external stakeholders. It is here important to regularly evaluate the design-implement experiences from students, teachers, and external stakeholders (CDIO, 2021). The CDIO standard Integrated Learning Experiences similarly highlights pedagogical approaches that combine professional engineering issues in contexts with other disciplines and issues. This can be done by elaborating on real-world cases, which help the students to be better prepared for the future demands of the engineering role (CDIO, 2021).

There are different ways to achieve realistic contexts for the students' learning activities. Keeping this in mind when designing courses, brings different opportunities depending on the students' prior knowledge and skills, course resources, etc. Within the courses in Quality Management at Linköping University, different means are used to support learning activities in which the students meet with representatives for industry and public organisations. In this paper, experiences from a course in Lean Production and project courses in Six Sigma and Quality Management are described. In particular, the aim of this paper is to share and reflect on experiences of learning activities, in which engineering students meet with industry representatives and get acquainted with realistic engineering issues.

METHOD

The paper is based on experiences from two learning activities at Linköping University that aimed at making the engineering students familiar with realistic industrial issues. The first activity was within a course in Lean production, in which a half-day conference was organised where representatives from industry and public organisations described how they worked with Lean in practice. The second activity was within Six Sigma courses, in which the students carried out Six Sigma and Quality Management projects in different companies. As the two learning activities were independent from each other and given by different teacher groups, the evaluation data were developed to fit each teaching activity.

Data regarding the first activity, the Lean conference, were collected through 17 student questionnaires, individual and group interviews with in total 12 students (8 students after a course with the Lean conference at the university and four students after a course with a digital Lean conference). Furthermore, reflection documents submitted by the students after the conference were also examined. The reflection document was a course assignment where the students reflected on what they had learnt from the Lean conference. The questionnaire was an evaluation of the Lean conference and how the content contributed to the students' understanding of real-world issues, how Lean is applied in practice, and the usefulness for the students' future professional role. Data from the questionnaire were quantitatively analysed using the statistics analysis software MiniTab. These findings were presented in a boxplot (see Figure 1) due to its usefulness in visualising data such as mean and median values as well as spread in a clear way. The group interviews focused on experiences, learning and the students' opinions about collaboration with working life during their education. The students participating in the group interviews included those who had performed their undergraduate studies in Sweden, southern Europe and Asia. Qualitative analysis of the data from the questionnaire, interviews and reflection document was conducted using thematic categorisation. Some of the themes from the questionnaire was adopted such as positive and negative learning outcomes and knowledge gained during the conference.

Data for the second activity, the Six Sigma and project courses, were collected through semi-structured group interviews with six students and three individual interviews with industrial representatives that had participated in Six Sigma projects. The students evaluated their project work, while the interviews with the industrial representatives focused on their experiences, prerequisites for, and requests regarding collaboration with the university. Feedback from 100 organisations participating in the Six Sigma project course during the period of 2013 to 2021 were also examined.

LEARNING ACTIVITIES

The course in Lean Production

The course in Lean production is given in English and has a case-based design. Many of the students taking the course study one of the Swedish engineering programmes or international master's programmes. Most years, more than 100 students attend the course. Due to travel restrictions during the corona pandemic, a lowered number of students applied to the university and thus the number of students in the course dropped to approximately 70 students in 2021. Lean production is a management philosophy that has its roots in the car industry in Japan. The philosophy thus has a strong industrial connection and tradition, which the course is designed to emphasise. The course is examined through four assignments - three mandatory group assignments and one optional individual assignment, that are connected to specific theoretical themes such as Lean principles and tools, Lean implementation, leadership and change management. Although the most prominent application of Lean is in the industry setting, the course also addresses how the philosophy has been introduced and translated into other settings, for example in public organisations. Each assignment is based on a fictious case organisation to provide the students with opportunity to relate the course content to different contexts. To further strengthen the connection to the industry and give students real-life examples of how Lean has been implemented in different organisation, a Lean conference is held at the end of the course.

The Lean conference is a seminar where representatives from industry and public organisations present how they work with Lean in their organisations and participate in a panel discussion. Based on the submitted questions, the conference moderator, usually the course director, sorts and selects relevant and interesting questions to be discussed by the panel. During the years, the format of the conference has varied in regard to location, time and presentations. It has been a physical on campus seminar as well as a digital seminar, lasting for 2,5 to 4 hours and containing 1-4 presentations and a panel discussion. After the Lean conference, each student individually submits a short reflection document about what they learned during the conference.

Courses in Six Sigma and Quality Management

The teaching of Six Sigma within the quality management (QM) department is organised as a two-stage rocket. First, after taking the basic QM courses, the students interested in Six Sigma must take the theoretical Six Sigma Quality course, and then, if they want to, they may take the Six Sigma project course, both being advanced courses. The number of students vary but around 60 students in the Six Sigma Quality course with four students per group and around 30 students in the Six Sigma project course, with two students per group. Half of the students are from Sweden and half from abroad. All teaching is conducted in English.

The reason for the two-stage rocket is that previous experiences have showed that students may have problems learning the Six Sigma project phases DMAIC (*Define-Measure-Analyze-Improve-Control*), including all the statistical and qualitative tools, and at the same time solve a real problem at a real organisation. The ‘basic’ Six Sigma Quality course is designed as a Six Sigma project with the five phases DMAIC, with lectures and seminars during five weeks, one week per phase. The students work on a project in groups investigating train delays for a fictious company called Easy Train. All groups get different data files that have been prepared to include different hidden root causes of delays. It has been set up so they will use as many tools in the DMAIC phases as possible. Also, the teachers know the hidden root causes the students are supposed to find.

Once they start their real projects at real organisations in the Six Sigma project course, they are told “*Now you know Six Sigma, now you need to use it in reality. This course is really on Project Management*.” The truth is that they do not fully understand all about Six Sigma yet, but they are well prepared to use it in a real project. Otherwise, it would not work, as we saw in previous experiences. The real projects are carried out at real organisations during the autumn semester. Needless to say, the teachers do not know the hidden root causes but if needed help the students to find them. The projects were set up during the spring semester by the examiner, who previously worked as a Six Sigma Master Black Belt at major companies, together with industry companies and official organisations.

In the end of the Six Sigma project course the students will be certified as Six Sigma Green Belts. They will also get university credits and grades, where the grades are somewhat influenced by the feedback from the organisations where they express whether the projects have fulfilled their expectations. During the last two years more types of QM projects, not only Six Sigma, have been carried out in the same way as described above. The other types of projects were Customer Focus, Lean, and quality management system projects.

INTERACTION – EXPERIENCES

The students' view on interacting with industry and public organisations

The Lean Conference

The findings showed that the Lean conference was highly appreciated, and many students described it as interesting, engaging and informative. The students considered that the Lean Conference enhanced their understanding of current issues faced by organisations as well as how Lean is applied in organisations. The content was perceived to deepen their knowledge in terms of enhancing their knowledge on application of specific Lean tools as well as broaden their knowledge in terms of understanding how Lean can be applied in wide variety of contexts. Challenges of implementing lean in organisations, the influence of cultural aspects and the importance of making contextual adaptations was given as examples of the new knowledge gained. Listening to real-life examples was also highlighted as a positive aspect as these examples made the theoretical knowledge gained during the course more concrete and 'come to life'. One student highlighted that it was valuable to get the opportunity to talk to industry representatives since it is not a part of all courses and that such exchange of experience is otherwise difficult for students to take part in. In addition, the content of the conference was also perceived to make the students better prepared for their future professional role both in terms of how to use their knowledge and what future professional directions could be pursued. One student highlighted that this learning activity motivated deep learning rather than surface learning by stating that "*You can apply your knowledge or the things you currently are learning, and thereby find a purpose and motivation for learning it for life and not just pass the course*." One student stated to prefer this type of learning activity over other activities by stating that: "*It is always great to put the things we learn into perspective. Usually laboratory work is meant to do that but talking to managers/employees of organisations that use the very thing we are taught was a better experience and learning way.*" A student mentioned that the placement of the conference at a late stage of the course was good since it could be related to the whole course content. Figure 1 shows boxplots of the results of the student survey.

Although the students who responded to the survey were generally very satisfied, some aspects that could be improved were also mentioned. Technical problems arose with the internet connection, which were considered to negatively affect the possibility to grasp the content and a few students stated to prefer to attend a physical conference. In addition, some students thought that the industry representatives should spend more time answering students' questions and go deeper into the real-life examples.

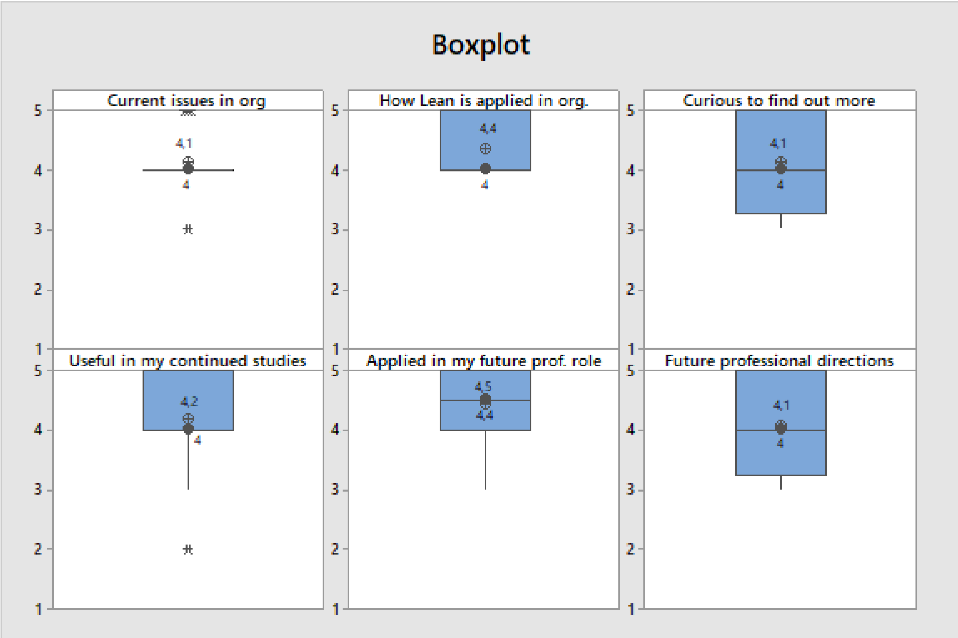

Figure 1. The results of the student survey on the Lean Conference

Note: The filled circle represents the median value and the crossed circle the mean value. The interquartile range box represents the middle 50% of the data and the whiskers that extend from each side of the box represent the ranges for the bottom 25% and the top 25% of the data values. * represents outliers i.e. data points that are far away from the rest of the data points.

Six Sigma projects

Regarding the Six Sigma projects, the students in interviews described that they learnt a great deal, not only about facts related to the course in Six Sigma, but also about project management, how to book meetings, how to describe their work in new ways, and how to solve practical issues. They also described that their learning was to a great extent related to their own behaviour. The courses on Six Sigma, both the basic course and the project course, have had high course evaluations from students during several years, with average evaluation grades between 4.0 and 5.0, often over 4.5, on a scale from 1 to 5 where 5 is the best.

The industry representatives' view on interacting with students

The representatives from the participating organisations, mostly Quality managers, expressed that they were satisfied with the students' work (see numerical analysis below), their competence, and the final results. Most projects were about reduction of defects and cost of poor quality, as well as increasing customer satisfaction and on-time delivery. The representatives emphasized the benefit of having students looking at the company problems from an outside perspective and that they contributed to knowledge sharing within the company. The main problem mentioned in the interviews was the lack of free time to spend with the students, even though it was not as time consuming as they had expected. Other ways of collaboration between industry and the university were also suggested.

In the end of each project the representatives were asked to give feedback on the projects. The feedback was given to the course examiner directly, then, after the course had finished, the feedback was distributed to the students.

In the survey the organisations were asked two questions:

- To which degree were your expectations about the *execution* of the project fulfilled?
  - Answer: Expectations not fulfilled (X), fulfilled (X), or exceeded (X)
- To which degree were your expectations about the *results* of the project fulfilled?
  - Answer: Expectations not fulfilled (X), fulfilled (X), or exceeded (X)

These evaluations were used in the total grading of the project course. The grading scale for the course is fail/3/4/5. If either expectation were not fulfilled it gave the grade 3 (the lowest grade to pass the course), fulfilled gave grade 4, or exceeded gave grade 5. These two grades were two of 25 grades in total, so they had a limited influence on the final grade.

By analysing the feedback grades one can see that

- The organisations are on average very happy by both execution and results with expectations mostly fulfilled or exceeded.
- The grading has low year to year variation. A minor dip is seen during the 'pandemic' year 2020, when the projects were mostly conducted on-line, and off-site.

See figures 2 and 3 below.

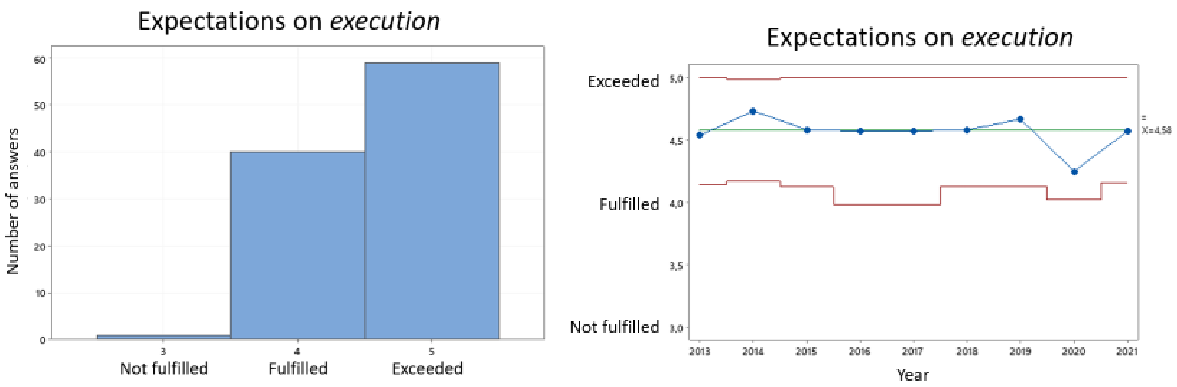

Figure 2. The freqency of the grades (left figure) and the mean grade given over the years (right figure) on Six Sigma project *execution* from 100 organisations. The numbers 3, 4, and 5 represent the grades given for the degree of expectation fullment of project execution.

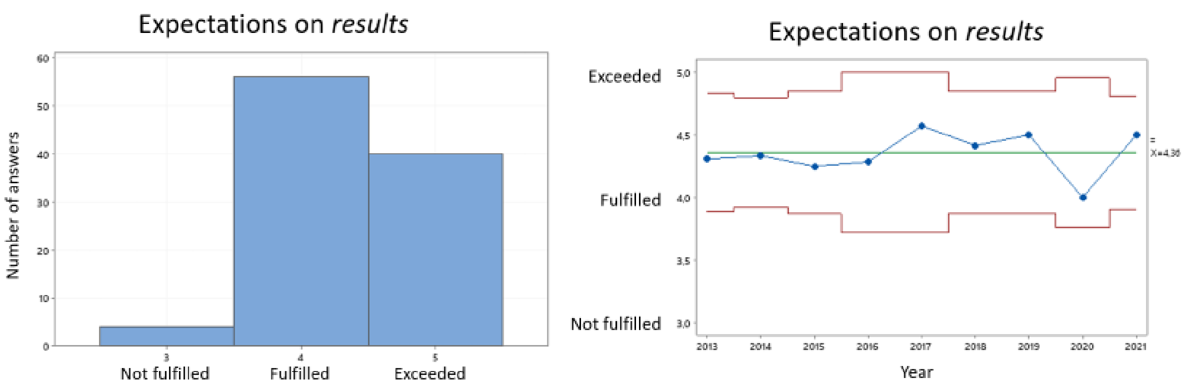

Figure 3. The freqency of the grades (left figure) and the mean grade given over the years (right figure) on Six Sigma project *results* from 100 organisations. The numbers 3, 4, and 5 represent the course grades given for the degree of expectation fullment of project results.

Organising interacting between students and industry and public organisations – the teachers' views

Finding industry representatives that want to present at the Lean conference has been difficult some years due to the presentations being given in English. Many of the industry representatives do not have English as their native language and presenting in English has seemed to be challenging to some. The representatives that do present at the conference often mention afterwards that it is a fun experience and that they are impressed by the insightfulness of the students' questions. Recruitment of industry representatives is facilitated by some representatives coming back to present year after year and if they are unavailable, they usually encourage one of their colleagues to participate in their place.

As previously mentioned, the students' questions submitted to the representatives from industry and public organisations are a central part of the Lean conference. This requires that the students ask comprehensive and relevant questions that can be discussed and that the representatives answer the questions exhaustively. However, sometimes the conference moderator run out of questions when there is still time left in the seminar. To prevent the seminar to end prematurely, the moderator can prepare additional questions in advance for example on topics that was not take up by the students. The moderator may also ask the students during the seminar for additional questions to be discussed. The teachers' experience is that the dynamic between the students and the representatives as well as between the representatives in the panel is often important for the success of the conference. However, this is usually not a problem as this learning activity seems to engage the students.

There is a lot of work for the teachers in the Six Sigma project course – more than regular classroom courses. During the spring semester the teachers are looking for possible projects at companies and public organisations. This takes a lot of time because the organisations are often not willing to admit that they have recurring problems, do not want students to solve their problems and do not understand the Six Sigma methodology. Hence, there is a lot of discussion and convincing to be done. However, the companies that have carried out projects very often return next and following years for more projects. Once the projects have started in the autumn semester, there is quite a lot of work for the teachers doing project coaching and 'toll gating'. Each project has five tollgates for the five DMAIC phases. The purpose of the toll gates is to check that everything is 'correct' and 'complete' in each phase. The results from the project should always be correct and complete, independent of the skills and ambitions of the students. One reason for this is to ensure a good delivery to and maintain good relations with the organisations since they have put a lot of effort and resources into the project and expect it to produce useful results. Another reason is to ensure that the students have a report that is correct if it is to be used as a guide for future Six Sigma projects. The upside is that, based on the feedback from the students, coaching and toll gates support the students learning. The downside is that it takes quite a lot of time for and effort from the teachers.

DISCUSSION AND CONCLUSION

The learning activities aim at familiarising the students with real world engineering issues and prepare them for their future engineering role. The students also put forward the value of meeting with industry and public representatives. Although personal meetings could not take place during the Lean conference during the pandemic, the students normally have the opportunity to approach the representatives in person with individual issues, such as internship. Asking the students to prepare questions before the conference is one way for them to reflect on the course content and how it fits with reality. This learning process is much more enhanced within the Six Sigma and QM project courses, in which the students for a longer time deal with real world issues with open ended answers. Not having a 'right' answer strongly encourages active learning for the students (e.g. Prince, 2004). However, the teachers have an important role in guiding the students in their problem-solving skills (Hmelo & Ferrari, 1997).

In these courses the students also increase their ability to communicate their results in a real context with stakeholders, which is emphasized in CDIO's Learning outcomes (Standard 2). This learning, along with learning how to run projects and collaborate with representatives for industry or public organisations, are learnings that add to the course context and constitute examples of Integrated Learning Experiences (CDIO-standard 7) where professional engineering issues are combined with other contextually based issues. The value of having contact with and collaborating with representatives for industry and public organisations may also have additional value for students who prior in their education may have had limited external contacts. From a Swedish perspective this is common to strive for and integrate also in early educational phases, but this varies among students depending on where they have conducted their earlier education. Furthermore, the Six Sigma project course demonstrates a Swedish way of work based on values of democracy and pragmatism. The value of integrating real world engineering issues within the university courses relates not only to the students. Also, the representatives for industry and public organisations gain from the outcome of the students' project outcomes. This was clearly shown in the evaluations from the companies that participated in Six Sigma projects where the expectations on execution and result were fulfilled or exceeded for a clear majority of the projects. Also, the lecturers in the Lean conference stated that they were impressed by the students' questions. In addition to value for the students and industry and public organisations, there is also a value for teachers to invite and collaborate with these representatives. It is one way of keeping up to date on current issues within the organisations, what is at stake at the moment and forthcoming issues. This can be an input to ongoing development of the course contents. The idea of evaluating the value for these three groups is further brought forward in Design-Implement Experiences (CDIO Standard 5) where these experiences should regularly be evaluated from students, teachers, and external stakeholders.

Experiences of organising these learning activities include highly positive feedback from students and participating organisations. For the teachers, although it implies a great deal of work, it is a very positive experience that contributes to individual insights and life-long learning.

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IMPROVING TEAMWORK WITH A ROTATING LEADERSHIP MODEL

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ABSTRACT

The Diploma in Integrated Events and Project Management (DEPM) course in the School of Architecture & the Built Environment recently started exploring using CDIO approach as a basis to enhance design of its curriculum. Teamwork and leadership are important interpersonal attributes desirable of graduates from the DEPM course. Events management work is multi-faceted in nature and requires event planners to work with various stakeholders to organise and implement events. Many times, event planners are also required to lead a team to complete tasks. The authors undertook an action research to investigate how teamwork and leadership can be integrated into a module in the DEPM course. The authors referenced the CDIO Syllabus for underpinning knowledge of teamwork and leadership; and use the relevant CDIO Standards to guide design of learning activities that enabled learners to work better in team settings and practise leadership skills necessary for planning and managing events (CDIO Standard 1). More specifically, the action research explore the use of a Team-Based Learning (TBL) strategy in an events marketing module coupled with a rotating leadership model to meet the intended learning outcomes (CDIO Standard 2) of working effectively in teams to complete tasks required in a marketing role. By providing opportunities for each learner to lead in the group coursework assignments, learners get to practise leadership skills in the context of events management (CDIO Standard 7). To evaluate students' learning experiences (CDIO Standard 11), an online survey, a reflection paper and a Self-and Peer Assessment (SPA/SAPA) from the Singapore Polytechnic's Teamwork Measurement Project were used to review learners' teamwork contribution; the online survey and reflection paper also provided insights on how learners could improve their leadership skills. Feedback garnered from these touchpoints showed that learners opined that the learning activities helped to improve teamwork, as they were more responsible with better contribution to the team and minimal free-rider issue. Learners also appreciated the opportunity to practise leadership skills through living the role as well as learning from others. This action research study also serves as an example to the DEPM course on how it could enhance its curriculum design guided by the CDIO Framework.

KEYWORDS

Rotating Leadership, Shared Responsibility, Teamwork, Team-based Learning, CDIO Standards: 1, 2, 7, 8, 11

INTRODUCTION

As part of continuous efforts to enhance its curriculum, the Diploma in Integrated Events and Project Management (DEPM) course in Singapore Polytechnic (SP) recently started exploring the use of CDIO Framework to strengthen its curriculum design. Although CDIO originated from engineering, it is a comprehensive educational model that can be used to design programs that better equip learners for professional work in any industries (Doan, Kontio, Leong-Wee, & Malmqvist, 2016). The DEPM course aims to equip learners who can function in the events industry which require interdisciplinary skills of teamwork and leadership; this is due to the multi-faceted nature of events management work that usually sees event planners working in teams comprising staff and volunteers. Graduates of this course have to work well in and/or lead a team. These competencies also resonate with SP's desirable graduate attributes of Competency & Versatility and Communication & Collaboration. As interpersonal skills in the context of professional work is one key element of the CDIO approach, it was opportune for the authors to reference CDIO Framework to improve learning of their module.

Marketing is a key aspect of event management work that usually entails a team planning, organising and executing event marketing strategies. The Marketing module in the DEPM course equips learners with the knowledge and skill sets for this role. Referencing the CDIO Syllabus for underpinning knowledge of teamwork and leadership, and the relevant CDIO Standards, the authors undertook an action research to better design learning activities in the module. The authors focused on team leadership within 3.1.4 Teamwork Leadership of the CDIO Syllabus due to limited time and curriculum space. The action research explored the use of a Team-Based Learning (TBL) strategy, coupled with a rotating leadership model, to meet the intended learning outcomes (CDIO Standard 2) of working effectively in teams to simulate planning and organising of marketing activities (CDIO Standard 7). Learners will be able to improve their competencies in a marketing role through working and collaborating in small teams.

LEADERSHIP IN TEAM-BASED LEARNING

Team-based learning is an active learning strategy that emphasizes individual and group accountability in small group settings to achieve intended learning outcomes. Carefully designed activities with feedback could lead to effective, self-managed learning teams (Michaelsen & Sweet, 2011).

Leadership in Self-Managed Teams

Self-managed teams are also commonly known as self-directed teams or autonomous teams. They refer to teams with diverse knowledge and skills, and who collectively take actions to decide how to achieve team goals (Magpili & Pazos, 2018; Hoch & Dulebohn, 2017). At first glance, it might be assumed that self-managed teams are leaderless; however, various literature has pointed out otherwise. A self-managed team does not have a formally appointed leader and as stated by Solansky (2008), it is "allowed to designate its own leader"; Taggar, Hackett, and Saha (1999) pointed to the organic emergence of a leader in autonomous teams. Literature had also posit that leadership is even more important in a self-managed team due to task-related issues and team development issues (Barry, 1991).

A common theme in literature on leadership in self-managed teams centers on shared leadership in such teams. The traditional notion of leadership sees an individual who is more superior exerting a top-down influence in the team. Shared leadership, in contrast, sees leadership distributed among individuals in the team, with the aim to lead one another to achieve team goals. Influence within the team exhibits facets of peer, upward and/or downward hierarchy (Pearce & Conger, 2002). Hoch (2013) sees shared leadership as reflecting "a situation where multiple team members engage in leadership and is characterised by collaborative decision-making and shared responsibility for outcomes". In essence, this resonates with the concept of team-based learning and self-managed teams. Shared leadership has existed since ancient times but has gained traction as organisations moved from hierarchal structures to team-based structures (Kocolowski, 2010). Its prominence, in part, could be due to literature reviews, which indicated that shared leadership is able to improve team and organisational performance and team effectiveness (Hoch, 2013). As shared by Pearce and Sims (2002), "poor-performing teams tend to be dominated by the team leader, while high-performing teams display more leadership patterns, i.e. shared leadership". However, shared leadership is not a mutually exclusive leadership approach; it can co-exist with other forms of leadership such as the traditional top-down approach.

Rotating Leadership

The most probable type of leadership models in learner teams is the designated leadership where the team leader is appointed by the lecturer or the learner team. Occasionally teams might use an emerging leadership model whereby a learner with potential leadership qualities and who is personally motivated would emerge to be the informal leader (Seers, Petty, & Cashman, 1995). More exception than norm, learners might deploy a leadership model whereby each member takes turn to be the leader; this is known as the rotating leadership model, which sees leadership being distributed or shared among team members (Carson et al., 2007). In the first two leadership models, the leader is accorded with responsibility to get the team rolling, set directions and guide the team to complete the task, make decisions and is accountable for the team's success. He/she usually also receives the most credit should the team do well. In the rotating leadership model, however, these tasks rotate to the learners who takes on the leadership role at designated/agreed juncture (for example, rotate after every three weeks or based on skills set required). Credit is also likely to be shared due to the rotation of leadership.

Research on rotating leadership yields mainly positive reviews; Mohrman, Cohen, and Mohrman (1995) stated that rotating leadership generates a climate of shared ownership and positive contributions to team's performance. Echoing Pearce and Sims (2002), research by Cohen, Chang, and Ledford (1997) found that learners would be more involved and engaged using a rotating leadership model, possibly resulting in better team performance. A quasi-experiment conducted by Erez, Lepine, and Elms (2002) showed that team members were more motivated to make effort and cooperate towards achieving team goals when given the opportunity to experience the leader's role and responsibilities. Markulis and Sashittal (2006), however, reported that while the rotating leadership model was more effective for better communication and cooperation among team members, the designated leadership model was more useful for ensuring equitable contribution towards team goals; in addition, their study found that there was no statistically significant difference in the three team leadership models (designated, emerging and rotating) and team project performance.

Beyond the classroom, shared leadership through a rotating leadership model have found favour in organisations the likes of Huawei and Zappos; given today's increasingly disruptive business environment, it is suggested that organisations with such rotating leadership models are likely to be better positioned to thrive (Ismail, 2018).

Given the benefits of a rotating leadership model on better teamwork as well as the opportunity for all learners to practise team leadership role, the authors decided to implement it with the team-based learning strategy in an action research study in the Marketing module.

IMPLEMENTING ROTATING LEADERSHIP IN TEAM-BASED ASSIGNMENTS

The Marketing module in the DEPM course, offered in Year 1 Semester 2, equips learners with the knowledge and skills to plan and organise marketing activities in the events industry. Learning activities included case studies and a team-based assignment in the form of a marketing plan that required learners to conduct market research for a target audience, brainstorm ideas, design features and activities to meet needs and/or wants of the target audience, prepare a communications plan and set prices for a proposed event. In previous runs of the module, teams were self-formed and leaders decided based on consensus or volunteered.

In the action research study, the authors re-designed some learning activities whereby learners will work in teams to complete tasks that better simulate what graduates will likely do in a marketing role (CDIO Standard 7). Some learning activities added include designing of marketing posters and planning of activities to engage class in the form of a teaching assignment. Learners will discuss and agree on their roles and responsibilities within the team, as a team member and as a team leader; and be committed and accountable to achieving team goals. Learners would also have the chance to practise and improve on their leadership skills.

The team assignments were conducted using Team-based Learning (TBL) coupled with a rotating leadership model. TBL is an active learning strategy (CDIO Standard 8) widely used by various educational institutes as well as one of SP's key initiatives. The rotating leadership model was implemented for the suite of team-based assignments spanning the whole semester. The module team discussed and grouped the various assignments into separate coursework packages based on the expected amount of work (effort and duration); each package comprised assignments that spanned a few weeks or would have assignments that were scheduled at different weeks throughout the semester. The intent was for learners to be more committed and stay on their leadership role as far as possible rather than be the leader for just one assignment for one week. This design provided room for learners to learn from each other in the process with opportunities to improve themselves.

Each learner was required to lead a package of assignments as shown in Table 1.

Table 1. Distribution of Learning Packages for Teams of 4 or 5 Members

	Teams of 4 Members	Teams of 5 Members
Leader 1	Marketing Plan Project (content & presentation) *[week 1 - 12]*	Marketing Plan Project (content & presentation) *[week 1 - 12]*
Leader 2	Team documentation *[week 1]*+ Teaching assignment *[week 3, 4, 10 or 11]* + escape games 1 & 2 *[week 2 & 6 resp]* + assistant Project Leader (executive summary) *[week 12]*	Team documentation *[week 1]*+ Teaching assignment *[week 3, 4, 10 or 11]* + assistant Project Leader (executive summary) *[week 12]*
Leader 3	TBLQ1 *[week 1]* + Poster 2 *[week 3]* + Poster 4 *[week 14]*	TBLQ1 *[week 1]* + escape game 2 *[week 6]* + Poster 3 *[week 9]*
Leader 4	Poster 1 *[week 2]* + Poster 3 *[week 9]* + TBLQ2 *[week 14]*	escape game 1 *[week 2]* + Poster 2 *[week 3]* + TBLQ2 *[week 14]*
Leader 5	-	Poster 1 *[week 2]* + Poster 4 *[week 14]*

Learners were grouped using the SP-recommended team-based learning framework as explained in previous work (see Soo-Ng & Tao, 2021). Team composition was formed by using the GRumblr software that distributed learners into diverse teams based on criteria such as their Grade Point Average and gender. Tutors briefed learners on objectives of the team-based learning framework with the rotating leadership and the criteria for effective team learning. This information was also put up on the school's learning management system (Blackboard) for their reference. Thereafter tutors explained what each assignment entailed. Learners were given some time to discuss and decide on who would lead which coursework package as well as consensus on each team member's role and commitment to the tasks. The distribution was then documented and sent to learners for reference.

The authors used a variety of assessment tools (reference CDIO Standard 11) to evaluate if the rotating leadership model could lead to better teamwork. In addition, the assessment tools could elicit information on how learners could have improved their leadership skills using this model. Learners had to complete:

- an online survey which asked learners to rate the use of the rotating leadership model, provide information on what they like/dislike about it and how their rate their commitment to teamwork
- a reflection paper where learners reflected on the use of the rotating leadership model on their teamwork contribution
- a Self- and Peer-Assessment (SPA) tool using SP Learning Activity Management System (LAMS), which provided information to learners on how they had performed on their teamwork competencies as well as areas of improvement. As explained in length in other works (see Cheah, 2021; Soo-Ng & Tao, 2021), learners gave each team mate a score of 1-5 for five categories of teamwork competencies – Contributing to the teams work, Interacting with teammates, Keeping the team on track, Expecting quality and Having relevant knowledge, skills and abilities – as well as provided feedback on what they appreciated of each other and areas of improvement for their team contribution. Two rounds of SPA were conducted. Tutors provided feedback to learners on possible areas of improvement based on the results generated. While the SPA scores do not directly provide information on leadership, it sheds some light on what learners appreciated of good leadership.

FINDINGS AND DISCUSSIONS

Key summary of findings and discussions are as follows:

Online Survey

The response rate was 90% (90 learners). Quantitative and qualitative responses are tabulated in Table 2:

Table 2. Summary of Findings and Discussions for Online Survey

Questions	Findings and discussions
Rate the method of rotating leadership roles among team members (1-5 stars; 5 stars being the best).	An average rating of 4.17 showed that learners were very receptive of the method.
What do you like about the rotating leadership model? (open-ended)	67% of learners cited that they welcomed the opportunity to have a go at leadership; the balance were either neutral or did not directly answered the question. Insightful responses suggesting better teamwork &/or leadership are as follows: • Reduce issues of slackers; shared responsibility and commitment (33%) • Reduce burden and stress on one person (10%) • Good experience – engaging, better learning experience (8%) • 20% of learners liked that the model enabled them to showcase or improve their leadership skills. About 5% of learners felt that the rotating leadership model has no significant impact as it was not an efficient method due to possible confusion; one learner felt that it was not necessary as there was "coordinated group effort" within the team.
Are you more committed to the team after you had a chance to be a leader and a member? Briefly state reasons for your answers. (open-ended)	An estimated 55% of learners felt that their commitment to the team were similar regardless of their roles, possibly due to a strong sense of accountability. However 45% of learners felt that their commitment were higher due to more responsibilities as a team leader.
Would you recommend that all team-based activities should have rotating leadership? (Net Promoter Score of 0 – 10; 0 being Not at all likely & 10 Extremely likely)	Interestingly opinion was split equally between those who would recommend (Promoters; 28%) and those who would not (Detractors; 27%); the remaining 45% of learners whose responses were 'Passive' gave a rating of between 7 – 8 (Figure 1). This suggested that learners were quite receptive to the idea of rotating leadership and its intent.
Any comments / suggestions on the rotating leadership model for team-based activities? (open-ended)	Of the 17 responses received, some might shed light on why learners were not in favour of using the model for all team-based activities: • Might be confusing or chaotic as learners do not remember which package of activities they were in-charge of (29%) • Suggestions on different ways to rotate leadership – i.e. rotate by month, in sequence or by assignment type (17%) • Have feedback on leaders after activities (12%) • Let teams decide who lead instead (6%) • Highlight flaws of learner who could not lead (6%)

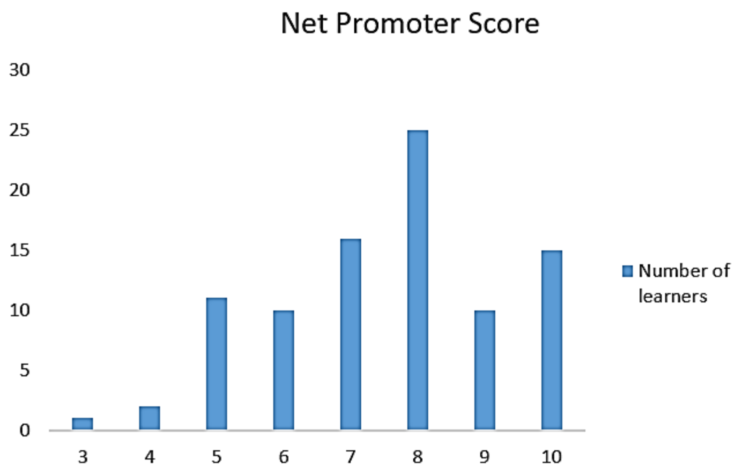

Figure 1 - Breakdown of NPS

Reflection Paper on Implementation of Rotating Leadership

As mentioned prior, learners wrote a reflection paper on the use of the rotating leadership model on their teamwork performance; below summarised common themes synthesized from a review of the reflection papers:

- Active engagement in discussions

Learners felt that the model gave everyone a “voice” as everyone had to step up, took initiative and speak out. This was especially welcomed by learners who were more introverted or who were weaker in communication skills. Although forced out of their comfort zone, they were motivated from positive feedback on their contributions. The model thus set the stage for everyone to be heard and as no one was dominating the team, learners were more comfortable with each other, creating a more amicable learning environment.

- Learning about oneself and learning from others

Most learners cited that they had to improve on their communication skills and active listening to work well in teams. By observing others and reflecting on their own team and leadership skills, learners felt that they could contribute better to the team.

- Fair method

Majority of learners felt that there was better teamwork with shared responsibilities, equal distribution of workload and fewer slackers or free-rider issues as everyone had to take on the leadership role. Some learners noted that this method sent the message that everyone is of equal importance and the collective empathy acquired.

The following are examples of extract from the reflection papers (name removed for confidentiality reasons):

Student A, class 1B02:
“All of us had a chance to be in charge of either an assignment/ project, this not only helped to ensure all of us are contributing, but also made members feel more involved”

Student B, class 1B03:
“Personally for me my leadership style is more of autocratic whereas my friend she’s more of a democratic so I actually learn from her that sometimes we should give others the opportunity to take part in decision making, we should learn to trust our teammates and give them an opportunity to grow”

Student C, class 1B04:
“During the meeting discussions, everyone was participative and continuously giving opinions, I greatly feel that this is because everyone was given a chance to be the leader and that our team take everyone in the team as leader. This led to us being open-minded to everyone's opinions and evaluate it accordingly instead of the leader calling for the decision him or herself and everyone just listen with minimal comments as we are afraid to step up”

Student D, class 1B04:
“Occasionally, I would feel a little confused about whose turn it is to take the lead because there were so many tasks to differentiate between and we eventually lost sight of the rotating leadership aspect of tutorials and projects. So, eventually the “natural” leaders slowly went back to taking charge because things were not progressing as quickly or efficiently as it could be….”

Student E, class 1B05:
“.. empathy is my biggest takeaway as in the past, I would not really understand why the leader is acting this way as I'm often the team member rather than the one leading. Therefore, throughout this semester of working with my teammates, I had the chance to actually put myself into someone’s else's shoes (of being a leader) before complaining about the leader nagging and rushing us to complete the assignments without noticing the due date”

Through the reflection papers, learners also provided insights on shortcomings of the rotating leadership model. As with the online survey, the key theme highlighted was the confusion on whose turn it was to lead the team due to constant changes in leaders; the confusion was amplified for some learners as their leadership role was not in sequential order. On some occasions, learners forsake the instructions as they felt that the method was not efficient enough. This resonates with the findings from Markulis and Sashittal (2006) mentioned prior although learners opined that rotating the leader could result in equitable contribution as well.

Self- and Peer-Assessment Feedback (SPA/SAPA)

A review of learners’ self- and peer-assessments conducted yielded four key points:

- More than 70% of learners attained an average SPA score of above 4 (out of 5)
- When compared with the first round of SPA conducted, an estimated 45% of learners saw a slight improvement in their average SPA score (about 8%) in the second round; about 20% had the same score and the balance 35% saw a slight dip of about 5%
- Majority of learners with the highest SPA score in their respective team consistently received positive feedback for his/her efforts to remind on deadlines and ensuring the team was progressing/on track. This shows that learners value this competency in team settings
- For self-improvement, many learners highlighted the need to have better time management

Findings from the above three touchpoints are largely positive, suggesting that teamwork could be improved with a rotating leadership model in team-based assignments as the shared responsibilities lead to more commitment to team goals, reduce the issue of free-riders and active engagement leads to better team contribution. In addition, learners gained insights on how to improve their leadership skills by the leading opportunities and learning from each other.

LEARNING POINTS AND FUTURE PLANS

As pointed out by some learners, rotating the leader within the team created some confusion that might hinder productive work. In addition, the rotating leadership model may put learners who are not as adept at leadership skills in a bad light. However, in the post-module review, the teaching team discussed and agreed that the current manner of packaging assignments and use of the rotating leadership was effective to achieve the intended learning outcomes of better teamwork. Coupled with the opportunity for each learner to explore and practise leading a team, this is a skill set valued by the workplace. Thus future iterations in the Marketing module in terms of teamwork would include coaching learners to better manage their time and "leadership schedule", such as creating a schedule and setting reminders. The teaching team will provide more guidance to foster a safe learning environment; besides activating prior knowledge on teamwork and leadership, learners could consider their strengths as well as organise themselves such that those who lack confidence or are not as skilled at leadership could take on the role for assignments due in later parts of the semester so that he/she could learn from others. The online survey would also incorporate more targeted questions to gain insights to help learners improve their leadership skills. As good teamwork and leadership skills need practice, suitable modules in each year of study in the DEPM course should include learning activities integrating these skills so that learners could build up these skills progressively. Examples of such modules would be the Integrated Project module in year 2 and Experience Management module in year 3, as these are modules with team-based assignments/projects that enable learners to work with industry stakeholders, providing them the platform for an integrated learning experience.

CONCLUSION

To better prepare graduates for their future, the CDIO approach to education recommends, among others, learning outcomes incorporating disciplinary knowledge with interpersonal skills such as teamwork and leadership. This resonates with the desirable graduate attributes of the DEPM course where event planners usually work in a team with responsibility to lead in some aspects of the event management process. The use of a rotating leadership model in a team-based setting could result in better teamwork and learners could benefit by improving their leadership skills through practice. It is also recommended that relevant modules in subsequent years of study develop suitable learning activities integrating teamwork and leadership skills so that learners could progressively build up such skills in an environment simulating the workplace. The action research, guided by relevant CDIO Syllabus and Standards, serves as an example of how the DEPM course could enhance its curriculum design using the CDIO approach.

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THE DESIGN OF SOFTWARE ENGINEERING COURSES FOR FUTURE REMOTE WORK

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ABSTRACT

The pandemic has forced teaching as well as as the Software Development industry, to be performed remotely. The educational institutions are therefore facing the situation of training and steering the students in, not only complex work, but also in remote-based work and it processes. Specific challenges here relate to project work with larger groups of developers, with testing, and integration of technical components for complete solutions, but the psycho-social factors come into play as well. This paper considers the situation that has arisen as a consequence of the pandemic and regards how project-based courses should be adapted to 'The New Normal'. In focus is a course in Software Engineering, where a large-scaled project shall be developed remotely. Representatives from IT-companies act at the course remote, and at specific occurrences. The course is observed by the teachers to see its outcome, as well as different aspects on attitudes towards future remote work. Interviews and surveys regarding attitudes of students, as well as involved company representatives are presented, where the focus is on process, productivity, work environment, interest in remote work, as well as social aspects. The main findings, based on the surveys, motivates hybrid solutions for university courses, to meet the corresponding companies' way of future working style.

KEYWORDS

Remote work, Group dynamic, Teamwork, Social aspects, CDIO Standards 5 - 10

INTRODUCTION

As a consequence of the pandemic, many indicators address that working remotely will most likely be applied as a future way of working in IT-companies (Einarson & Klonowska, 2021). Preparing students for remote practices means that teachers as well need to adopt and run project course activities remotely. Here, benefits include training students to be the best version of a future employee, but also guides teachers on how to design course activities that train students abilities to work both remotely and at office. Moreover, close and continuous contacts with industry are here considered important, to understand the real-world conditions.

The course *Software Engineering 2* is a course for third year students in the International Software Development Program at Kristianstad University in Sweden (Einarson & Teljega, 2021). The main course project consists of bigger project groups, where each of those is further divided up into 4-5 subgroups with the purpose of developing sub-components to be integrated to fulfil the project, as a whole. What teachers especially have observed during many years of providing this project on campus, is that the communication is crucial to achieve a successful result. Currently, the course runs remotely, and as such, it is considered important to observe what tools are used by students for remote communication and what tools support remote development process. Company representatives are involved in the course, acting as a bridge between the industry and university, and, among other things, share information on what tools are used at companies and how working remotely in reality is performed.

The study behind this contribution observes both students' and companies' points of views on future employee/employment situations, as well as on how the university can prepare students to work remotely. It could be seen that companies believe that future work will result in hybrid solutions, where employers can let employees work remotely several days in a week. Still, variations occur, such as, where some companies only offer working fulltime at office, while, for instance, "Gig–employees" have shorter employments and can be working remotely globally.

Remote working does furthermore point out needs for reflecting on psycho-social circumstances (Einarson & Teljega, 2021), and discussions with students on this matter have also been taken place. For instance, observations performed in this study show that students believe that working remotely is best suited for personalities that are a mix of both introverts and extroverts, while company representatives claim that introverts are best suited to work remotely. Another observation is that there are some parts in the working process which are not satisfying when performed remotely. For instance, when there is a lack of information during online meetings where perception of body language is not available.

Conclusions, based on students' and companies' points of views, contribute to pedagogical developments, where teachers should be prepared to design course activities that train the students' abilities to work both remotely and at office.

The rest of the paper is outlined as follows: A background will provide the context and a project-based course of this study. Thereafter the method, based on the investigations, will be presented, followed by the result of the investigation. The paper will then discuss the outcomes and add with further teacher-reflections, and after that provide conclusions.

BACKGROUND

The Context

According to (Saul, 2021), a direction towards remote work has actually been a long-running process, with changes towards digitization of workplaces, the expansion of remote and flexible work, and virtual education. The pandemic has only helped to accelerate this process. There are several examples of how teaching even before the pandemic was conducted remotely (such as (Zhuge, Brodie, & Mills, 2012), and (Meikleham, & Hugo, 2017)), and that this form of teaching also works well in the context of CDIO-based education (Lucke, Brodie, Brodie, & Rouvrais, 2016). Furthermore, for example, Asatiani, Hämäläinen, Penttinen & Rossi (2018), show how technology industry also even before the pandemic adopted remote forms.

In this context, there is also a debate about how teaching should take into account the preparation of students' skills in order to function well in a possible transition in industry to remote work (including (Smith, 2021), (Paykamian, 2021), and (Somashekar, 2021)). Furthermore, Einarson & Klonowska (2021) conducts a preliminary survey of a number of companies to see how they themselves have coped with a forced remote work situation, and what they want from students' skills to function well in such contexts. Several generic skills are pointed out as desirable, including: *good communication and cooperation*, *work ethics*, *self-discipline*, *presentation techniques*, and *tools knowledge*. Furthermore, Einarson & Klonowska (2021) shows a shift from traditional Agile working style to the DevOps methodology which, among other things, enables greater transparency in each other's contribution to a specific project under development. This has been seen as especially valuable in cases of remote work with less space for informal discussions through physical meetings.

A Course of Study

In the autumn of 2020, the course Software Engineering 2 (SE2) was given at a distance, as a consequence of the pandemic. The course has a focus on one main project, where up to 60 students shall develop Smart Home-techniques in project groups of approx. 15 participants. A project group is then divided up into subgroups of about 3 to 4 students to solve subtasks of the main project. Due to the remote situation, special challenges lie, for example, in controlling and steering the process, testing and integrating subcomponents to form a whole, as well as functioning socially and communicatively.

Einarson & Teljega (2021) further describes the course, and presents a survey towards the students regarding their attitudes to the course and the forced circumstances. Among the discussions that took place between the teachers (the authors of that contribution, and this contribution), and the students, it emerged, among other things, that one could see a possible game-changer for more future remote work. These insights, along with the positive outcome of the course, inspired the teachers in a direction towards consciously providing courses of this kind to prepare students for such a game-changer. During the autumn of 2021, the course was therefore given as before, but with this special condition. An addition to the previous course opportunity, was to invite representatives from the IT industry to act within the course, to further make a situation with remote work training a reality.

METHOD

The contribution of this paper addresses views on remote work, both from students' point of view, and from company point of view. A purpose is here to increase the understandings at the teacher perspectives, to plan for future actions when developing courses for remote work even further. To puzzle together the whole picture, survey, interviews, as well as teacher observations were used as research methods.

- The survey consists of opened questions, with qualitative nature. The survey is answered anonymously. In some cases, it was easier to validate the answers if they were answered anonymously. The questions were answered by both the students (53) and the participating companies (4) where the companies answered through email which means that teachers know what answers are connected to which company.
- The interviews are preformulated by the teachers and collected during the project meetings and during the midterm and final project presentation, where students could answer individually but also respond as a group. The interviews are performed 7 times.
- The observations are simple notetaking during the whole project timeline, done by teachers and reflecting on how working on distance is affecting the project work, the teamwork, and the product result itself. The observations are overt, meaning that the students know they are observed.

The collected answers from the three research methods are analyzed and used to validate the results, and give suggestions for the further working. It shall here be clarified that the students have been through about one and a half year of remote work. They are used to the situation, also in contexts of project-based learning. Still, previously project groups have been on sizes of maximum 4 persons, while here several groups cooperate in larger groups of about 15 students. The discussions with students are done at zoom-based project meetings.

Unfortunately, as also for other types of meetings, those are not enough to give most precise answers, since only a restricted number of students act in the discussions.

INVESTIGATION

The investigation is structured in several sections, each presenting answers to specific topics. Following sections are answering questions about what students think about the *course running remote*, *remote working* as a future reality, what *tools are used during the development*, on *different personalities*, how a *project-based course should be designed for working remotely*, and how *new 'normal' working week should look like*. Below an excerpt from the result of the investigations provided.

Students on the remote course

Some students believe that there seems not to be any specific needs for physical meetings, since students are quite used to the way that they interact. Good to see each other occasionally, but that's all. Messenger, Discord, Zoom, WhatsApp and other platforms seems to be sufficient enough to maintain a social contact with one's colleagues. You can have online 'fika' coffee breaks, or/and online afterwork and of course the video should be turned on! Still, as claimed:

- *'It would be good to have weekly or bi-weekly meetings in person.'*

But students think that there is absolutely a difference in meeting physically and only being seen at distance, for example if working on hardware together then this is better in physical meetings. Some like better to work close to others and can clarify on things better that way. Mixing online and physical meetings is preferable in some cases.

- *'using tools like Zoom is completely doing the same job as physical meeting without wasting any extra time such as travel time. It is best way to participate without any hassle, even possible to participate while being sick'.*

Still, distance takes away some personality, get more separated, was amongst the comments from students. Some of the students enjoy working alone and do not feel they need to interact socially with people every day, because the social part is only energy consuming. Still, close to the finishing phase of the project, quite different comments came from students pointing out several risks. Misunderstandings can lead to anger and in the end, lead to the project collapsing. Suggested solutions for handling the possible risk is to work both remotely and physically.

What students have noted during the project is that the trust is important - you are trust dependent! Trust between developers, developer and project manager, and trust on digital tools.

Students on remote work

Students believe that remote work is here to stay. It will be a normal way of future working where companies may recruit talents from outside that do not have to be in place. It will be more and more like this. Still, social points are also important. Remote work may cut off costs for offices. Perhaps there will be work at office some days, but not 5 days a week. Work at home is the new office. Probably it will be mixed between remote and in companies' offices. Employers may find local talents, but if not, they may hire globally, and then also save office costs.

Amongst the risks with remote working is mentioned (also pointed out above) that misunderstandings can lead to anger and in the end, lead to the project collapsing. Furthermore, for introverted people it can be even harder to reach out to which is not so good for his/her project manager and can lead to delays. If not meeting colleagues regularly the ideas will rarely be shared. Moreover, feeling that you are stuck and work alone for others who are not contributing may lead to not meeting the deadline. Suggested solutions for handling that possible risk is to work both remotely and physically. For a junior developer at a company, one should have in mind that it can take longer time and be more difficult to come on board.

While discussing with students about how programming, testing and integration of the code works from distance, students agreed that some things are hard to integrate remotely. And that meeting physically could improve such situations. Working globally have been claimed to work, without loss in productivity. But communication is essential, this may be supported by good-enough tools. Remote work works for talents recruited worldwide. Students also express that the risk on remote work was decreasing after a while, while you got used to it.

Many IT-companies use DevOps processes (Einarson & Klonowska, 2021) to accomplish the whole process starting from planning, developing, integrating, testing, marketing; supporting the creation of the product and getting it out to the customer and supporting the customer with possible bugs fixing due reporting back to the development team to handle the bugs (Sommerville, 2020). As well companies that contributed to this project stated that they are using DevOps practices in their work. Students argue that they used DevOps processes as it gives a whole picture, instead of material passed over to different roles. Responsibility for what has been done was visible and clear through tools for DevOps. DevOps as well contributed to seeing what is going on between the subgroups.

Development tools used during remote work

Different programming tools have been used for different kind of work; if working with Android applications, Android Studio was used that is a part of IntelliJ. Many groups have been using GitHub[1] and IntelliJ[2] as main tools for coding and sharing code. Those have many good features, especially the newest update for the platform where there is a possibility to code with others in the team at the same time and also make a video, and sound calls during the coding[3].

Tools used for code integration are several with different opinions if they are good or not, where amongst many are GitHub, Collaborator (can be integrated with Jira[4]), and CodeScene[5]. Jira[6] was suggested by teachers to be used in this project because companies connected to this course also use Jira. On the positive side with GitHub was that students could share good ideas and, in that way, can synchronize their work. Students also expressed that it was easier to contribute to the source project, documentation, integration options, and track changes in the code across versions. On the negative side was that there was no restriction on pushing code so that even if the code was pointless, students can also do push it.

[1] GitHub: Where the world builds software · GitHub
[2] IntelliJ IDEA: The Capable & Ergonomic Java IDE by JetBrains
[3] Code With Me Beta: Support for Audio and Video Calls | JetBrains News
[4] JIRA Integration | Collaborator Documentation (smartbear.com)
[5] Software Quality Visualization - Tech Debt | CodeScene
[6] Jira | Issue & Project Tracking Software | Atlassian

Tools used for code testing are also different depending on what the development group is working with. Some have used Junit[7] and GitHub, and it worked well when it was set up right. Some subgroups have used GitHub actions[8] and Cypress[9] mainly. And some students have used Junit and manual testing when working with GUI[10]-parts of the application. Other testing tools that have been used are Firebase Robotest[11], Mockito[12], and Postman[13]. Much of the coding have been tested during the coding, but students suggest that you can also let another student look at your code before you push it to GitHub.

During the project, students learned about new integration and testing tools and suggested to teachers to look at if they were good enough to use in project courses. Students suggested as more specific tools that could be used, like Telerik TestStudio[14], Watir[15] and Ranorex[16].

Personality styles

Amongst the tasks during the course covered in this paper, students took personality tests, answering questions related to how their personality types can be used in teamwork, as well as if they think that introvert, extrovert or mix of both[17] is best suited to working remotely. Also, the participating company representatives gave their view on that situation, explaining what tools are used to manage employees and how they see the future work with respect to personalities.

Results from companies and students present slightly different views on who is better suited to work remotely. No students see themselves as extroverts. 75% of students see themselves as introverts and 25% as mix of both. Even if ¾ of students are introverts, 43% of students believe that working remotely is best suited for personalities that are a mix of introverts and extroverts because communication between workers is important to develop a correct product and different personalities complement each other. Introverts do not need to socialize as extroverts to gain energy and can work more effectively by themselves. Extroverts can satisfy their socializing needs by keeping in touch with their remote team by using live streams and video chats as Zoom or Teams. Company representatives, on the other hand, claims that introverts are best suited to work remotely because introverts can handle isolating during longer periods of time. Moreover, amongst those that have leading positions at companies, are 25% seen as introvert, 50% as extroverts and 25% mix of both.

Overall, how do you look at the universities' educations to prepare students for future working methods with remote work at Companies?

According to the investigation, students believe that it is not realistic to say that universities can prepare students 100% to work online in IT-companies. Some other reasons communicated by students are that students needs a lot of internships and constant practical work. Students point out that it is different to work remotely and learn remotely.

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7 JUnit - Wikipedia
8 Features • GitHub Actions · GitHub
9 JavaScript End to End Testing Framework | cypress.io
10 Graphical User Interface
11 Get started with Robo tests | Firebase Documentation (google.com)
12 Mockito framework site
13 Postman API Platform | Sign Up for Free
14 Web & Desktop Automated Testing Software That Just Works | Test Studio (telerik.com)
15 Watir Project
16 Test Automation for GUI Testing | Ranorex
17 Ambiversion is a concept used for the spectrum between being introvert and extrovert: What is an Ambivert? Are You an Introvert, Extrovert or Ambivert? (scienceofpeople.com)

Suggestions to teachers when designing next year project course include that there should be further scope to communicate with others, for instance, with representatives from the IT-industry. Those should share following information with students:

- ‘How they are really synchronized, what are the demand in the marketplace now.
- Possible internship to help training the students and prepare them for future job market.
- What are they looking for, how can we stand out, how it is to work as a software engineer workflow, schedule, company etc., what are skills that we need to improve on that are not readily apparent.
- Practice places, free positions, type of work, salaries, techs that they are using.
- They should give us more suggestion based on their work, for example if anyone is interested in particular companies, they should provide specific information about the skills they are looking for.’

Moreover, students pointed out that project work should be rotatory. The meaning behind this is that there should be guarantees that everyone, for instance, got training in significant tools for test or integration of code.

How should ‘a new normal’ working week look like?

Working remotely 5 days a week?

Both students and the participating company representatives answered questions regarding demands if the employee should be at the workplace 5 days a week or work remotely 5 days a week, or to work from home more than 1 day in a week. Another interesting demand reflects whether the employer should offer ergonomic solutions for the home office.

How do you relate to demands from an employer regarding:

- That you should be at the workplace 5 days a week
- That you should be remote 5 days a week

The students’ point of view is that employers should not have requirements on presence at office all days, and that today we have new attitudes that should be accepted. Some students point out that, depending on personalities and the work, 5 days at office bothers a lot, because working only at office is not so efficient, so working half the time in a week at office and half from home is the best solution. Working at office can be very time consuming, while working from home can save traveling time as well as traveling costs. The idea with flexible schedule and mix of both ways of working gives a freedom to plan the hours of the day so it fits the employee. Furthermore, if working as a developer it can be silly to demand working from office 5 days in a week. Still, meeting frequently like 2 days in a week for checkups and meetings and to meet colleagues is fine. Still, as one statement points out:

- *‘Rather remote 5 days a week than 5 days at the workplace. Unless there are reasons to be present everyday’.*

The companies’ point of view is also suggesting a combination of both ways of working. If the company is a consultant company it means that the company needs to be flexible to meet demands from the customers. This also means that the employee-contract may say that you should work 40 hours a week at office, and that cannot just be changed. Sometimes the customer demands that the work should be done from the customers office, but sometimes customer doesn’t care where the workers are sitting, as long the work is done. But companies strive to discuss different possibilities with the customers and in that way keep the flexible way of working.

- *‘Already today, some teams have decided to work from office (even they do not need), while other teams decide to work from office on Tuesdays and Thursdays, and the rest of* *the week they can decide by themselves where to work from. If both the teams and the customers are happy, we do not need to make any changes. However, we want all to come to office during certain frequency space to check how everyone is doing. So, working all 5 days remotely is not considered at this company for the moment.'*

How do you view demands made by employees regarding:
- Must work from home more than 1 day a week
- That the employer should offer ergonomic solutions for the home office

The students' points of view take up different aspects on responsibilities to offer home office solutions. Some students believe that it is a freedom to work from home and that employees should be responsible for the ergonomics. Working 2-3 days from home would be enough to request the employer for a home office solution. Some students think that the employer should offer an initial budget for the office equipment and a yearly stipend to maintain the office equipment for example computer, desk, chair, and the cost for the extra room. Offering home offices is cost effective and a smart idea.

Students also point out that already today there are some examples where companies buy chairs for their employees. But the situation where employees make a demand reflects a split situation, where some employers may demand for some conditions, and some employees for some others, and meeting each other's demands is the best solution.

- *'The more work from home the better. If there is a demand to work from home, the employer should provide the tools to do that. If it is voluntary, the responsibility might not be on the employer.'*

The companies' point of view is that working from home 5 days a week, is not considered right now, based on the employee contracts, because of the need to physically meet all to see how everyone is doing. And that is the same reason regarding working 1 day a week. As stated before, the companies are striving to be flexible, and if customers or employees have demands on distance or at office working, they will discuss and come to flexible solutions. During the pandemic some companies states that they drove home to the employees raise and lower desc, and chairs. As well, companies believe that they need to look more into it to give best ergonomic solutions for their employees when working from home. Some other companies, though, are not at all interested in having employees working from home and because of that they are not interested right now in offering home office solutions.

DISCUSSIONS

The course Software Engineering 2 was during autumn semester 2020 forced to go remote, and during 2021 the teachers (also authors of this paper) made the choice of providing the course remote, no matter the state of the pandemic. The purpose was to prepare students for the predicted future remote work within the IT-industry. The course will later undergo some revisions, and observations of the current course, as presented in this paper, will be used as input to those revisions.

Even though many students argue that remote is enough during the course, the hybrid solutions are probably more suitable, both for the sake of the course, and for the sake of realistically correspond to the most probable future work situation. In either case, the hybrid contributes both to project precision, and to social needs. No matter what, a process style clearly suitable for the remote working style must be of use, and supporting tools, as suggested in the above section, as well.

Participation of company representatives have been considered clearly valuable. They have contributed by being a bridge between industry and academia, and with their technical competences, as well as experiences on remote work. Many discussions between teachers and students have considered remote work, and a reflection from the teachers' side is that those discussions in themselves have brought awareness to the students on such themes. Therefore, input to the revised Software Engineering course is that discussions on remote work should be especially emphasized, not only as a part of a process model, but as a concept of discussions.

CONCLUSIONS

Several sources show that the after-pandemic situation brings a 'New Normal' that means that much work within the IT-industry will be performed remotely, and it is essential to address this specific situation also in education. That is, students should be trained in this new normal, and it is necessary to address ways of supporting this at educational institutions. This contribution has elaborated further on those themes via student surveys on attitudes towards remote work, where students worked on a large-scaled project, that can be seen as especially challenging to develop remote. Representatives from IT-companies have acted at the course to contribute with expertise on techniques and project work.

The surveys, where 53 students and 4 companies answered, observations and interviews, generally show a readiness from the company side in approaching a future remote work situation, even though a hybrid solution is mostly preferable. This corresponds well to many of the students' anticipation upon their future careers, that is, part time work at office, and part time from home. Things that must be considered is choice of process model, and tools that support remote- and yet transparent work. Here, the DevOps process model is the choice from both student and company perspective, and several tools are mentioned, such as, GitHub, and a variety of tools especially for purposes of testing and code integration. Moreover, the psycho-social situation has been reflected on, and from such perspectives, generally it seems as both remote and physical meeting points are essential, even though in some cases show that there are, more or less, no needs for physical meetings.

While the course covered in this paper was provided completely remote, a final observation is that a project course to prepare students for future remote work, should be done in a hybrid way, with more weight on the remote work. This probably corresponds best to future working situations and is beneficial for communication and process agreements, as well as social aspects. DevOps should be used as process model, and students should be trained in tools, such as, GitHub. Furthermore, discussions should be performed on themes of remote work, especially with collaborating company representatives as further contributing values.

The design of courses for remote work shall contain remote meetings where deliverables are discussed with teachers. We suggest that companies contribute after the students have done ¼ of the project and can formulate the questions based on their work. It is recommended for the companies to join major meetings during the project but also give their own presentations on working processes and what tools are used by the companies. Companies and students can both benefit from connection trough social platforms such as Discord and exchange questions and answers.

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BIOGRAPHICAL INFORMATION

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CONNECTING ACROSS DIFFERENCES TO DEVELOP ENGINEERING SOLUTIONS TO SUSTAINABILITY CHALLENGES

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ABSTRACT

Study abroad has long been promoted to aid the development of intercultural confidence, adaptability, and context awareness, necessary to work cross-culturally and in different environments. International travel, however, is increasingly at odds with the broader objectives of sustainability due to its climate impacts and uneven global availability. Collaborative online international learning (COIL) offers a potential solution to this issue, creating opportunities for students to engage with peers in a wide diversity of locations, increasingly reflective of contemporary team-based engineering environments. To provide students with an opportunity to collaborate globally, the Department of Engineering at Nottingham Trent University introduced a virtual Engineering Research Online Summer School (EROS International) in 2021. EROS International connected engineering undergraduate students across different disciplinary backgrounds from Canada, Malaysia, India, Taiwan, and the UK, to collaboratively complete a one-week sustainability challenge on energy consumption and energy management. Students worked in multi-cultural groups across different time zones supported by an academic mentor. This paper explored the outcomes of this project by drawing on evidence from students' pre- and post-activity self-assessments. At the beginning, students had little or no prior experience of sustainability in their engineering curriculum and limited understanding of engineering challenges associated with sustainable development. EROS International helped participants to increase their knowledge of sustainability and to recognise the importance of international collaboration for developing engineering solutions to sustainability problems. Students experienced challenges related to online and distributed workspaces but were also able to recognise the opportunities for sharing complementary knowledge, contextualising technical knowledge, and building strong communication skills.

KEYWORDS

Collaborative Online International Learning, Online International Learning, Connecting Globally, Sustainability, Standards: 1, 7, 8, 10

INTRODUCTION

In this paper we examine the potential for models of collaborative online international learning (COIL) to enhance Engineering education and facilitate the embedding of CDIO standards into the Engineering curriculum. Working in internationally and in culturally diverse teams has long been a feature of the work of Engineers, but connectivity has intensified and increasingly takes place online, in remote offices and digitised workspaces, particularly since the start of the COVID-19 pandemic in 2020. Working in such environments requires confident intercultural communication skills, and this is reflected in the inclusion of such skills in the recommendations of accreditation agencies, such as the CDIO (Standards 7 and 8) and the Accreditation Board for Engineering and Technology (ABET). Collaborating in virtual environments also requires additional skills to navigate cultural differences through verbal and on-screen communication, while also managing time differences, varied levels of connectivity, and access to online communication platforms (Zaugg, and Davies, 2013).

Virtual Exchanges, such as those enabled by COIL initiatives, provide opportunities for students to gain international experience, develop intercultural awareness and global citizenship skills, as well as improving digital literacy (King de Ramirez, 2021; de Wit, 2016; Guth, 2013). The global pandemic has increased interest in this type of activity. Additionally, the need to address climate change and the carbon footprint of higher education institutions, and a continued desire to improve equity in access to international experiences, will likely sustain interest in the possibilities of international learning independent of mobility in the longer-term (Ward 2017; Leask and Green, 2020; Kahn, 2020; Munoz de Escalona et al., 2019). While there is a growing body of evidence to indicate the possibilities for intercultural learning via virtual exchanges, there has been much less attention to the benefits of online international collaboration for knowledge development in specific disciplinary fields, such as engineering.

Evidence from studies of collaborative learning highlights that collaborative settings create opportunities for students to develop effective communication skills as well as richer understandings of engineering problems, as students are encouraged to listen, learn, reflect, and critically appraise new and established knowledges. CDIO Standard 8 recognises the importance of such active learning styles that mimic the engineering workplace, requiring students to develop and apply knowledge with the goal of solving a specific problem.

In this paper, we explore the outcomes of EROS International, an optional study module developed by the Department of Engineering at Nottingham Trent University to provide opportunities for NTU students to experience international collaboration and for partnership students to experience teaching and learning at NTU before engaging in longer-term exchange or study abroad. EROS International was first introduced in Summer of 2021 and brought together students in five countries to work collaboratively to complete a one-week sustainability challenge on energy consumption and energy management. This focus on sustainability provided participating students opportunity to use the collaborative mode to share and exchange knowledge but also to consider responses some of the challenges future engineers will be required to address. Drawing on evidence from student pre- and post-activity self-assessments and a faculty focus group, we reflect on if collaborative online international learning can enhance engineering students' knowledge of sustainability in national and global contexts, whilst also building confidence to design and test engineering solutions in culturally diverse and geographically distant locations, characteristics that are in alignment with a CDIO-based education.

METHODS

The Project

In 2021, the Department of Engineering (DoE) at Nottingham Trent University (NTU) established a virtual Engineering Research Online Summer School (EROS International) to connect engineering undergraduate students with different disciplinary backgrounds from across the globe to collaboratively complete a one-week sustainability challenge. The aim of the activity was to provide an opportunity for NTU students to connect with partner students to develop their international perspectives on engineering, to enhance their intercultural communication skills, and to use the opportunity to enthuse engineering students in the topic of sustainability. Although the activity was not co-designed with teaching staff at partner institutions, as is typical of COIL projects, it was developed by NTU staff from multiple engineering backgrounds and involved academics at partner institutions in the delivery of guest lectures. A total number of 45 students participated in EROS International. Participating students came from five different partner institutions in five countries, which enhanced the opportunity for each student to collaborate with peers from a wider range of backgrounds than is normally possible with bi-lateral COIL projects. To encourage collaboration and active learning from diversity, students from the United Kingdom (NTU), Malaysia, Canada, India, and Taiwan were separated into groups of five. Each group contained representatives from different participating countries and different disciplinary backgrounds (Table 1). Hence, students worked in both multi-cultural and multi-disciplinary groups across different time zones.

Table 1: Participants for EROS International in 2021.

Country	**Participants [#]**
Taiwan	2
Malaysia	6
India	1
Canada	11
United Kingdom	25
Academic Background	**Participants [#]**
Mechanical Engineering	7
Biomedical Engineering	11
Electronic Engineering	3
Sport Engineering	4
Aerospace Engineering	6
Computer Engineering	7
Polymer Engineering	2
Electrical Engineering	1
Engineering	2
Intelligent Systems and Automation Engineering	2

During this one-week sustainability challenge, each group was supported by an academic mentor who met with the group daily to discuss the groups' progress and to guide students through the tasks they were given. Through NTU's Blackboard-based virtual learning platform, groups were provided with a range of sustainability problems around energy management and energy consumption from which they had to choose one topic. This topic was then researched by the teams to identify the background of the current problem, current solutions, and their limitations; to then develop a novel engineering solution. Students researched on energy storage technologies for future power grid, the potential of artificial photosynthesis as a sustainable energy source, nuclear energy as a sustainable energy source for future generation, space-based power stations for renewable/non-renewable energy, among others. Students' research and learning were underpinned through international guest speakers (synchronous and asynchronous), a carbon literacy training and energy management game (both synchronous) spread over the weeks' programme. The group's findings were then presented as power point presentation at the "EROS International Showcase" on the final day to share and discuss findings and innovative solutions with all peers and academic mentors (synchronous). Students completing the required work were awarded a digital badge that they could share on social media platforms, including LinkedIn. All interaction between academic mentors, students and guest speakers took place on MS TEAMS. Channels were set up in the EROS International MS TEAMS team to facilitate communication among group members. Students also chose to communicate via social media platforms and email.

EROS International coincided with NTU's Global Summer School, which in 2021 was offered exclusively online. Hence, EROS International participants were able to join over 400 students from 44 countries in a comprehensive social and cultural programme, which included an intercultural communication workshop.

The evaluation methods

Pre-and post-activity self-assessments were carried out via MS Forms, where students were asked to answer several graded, non-graded and open-ended questions to reflect on their own knowledge and understanding of sustainability in Engineering, prior and post EROS International. Additionally, students were asked to provide feedback about their experience after completion of the sustainability challenge. Completion of the pre-and post-activity questionnaires was voluntary and had no influence on participation in EROS International. All contributions were anonymised to ensure confidentiality of responses. Approximately 53% of participants took part in the pre-activity and around 29% in the post-activity self-assessment (Table 2).

Table 2: Responses of participants who completed pre-and post-activity questionnaires.

Country	Pre-Activity (# Responses)	Post-Activity (# Responses)
Malaysia	6	5
India	1	1
Taiwan	2	0
Canada	6	2
United Kingdom	9	2
Unknown	0	3
Total (Number)	**24**	**13**

PROJECT OUTCOME

Integrated learning experiences through COIL

Most virtual exchanges focus on the development of intercultural competencies and other non-discipline specific knowledges such as those associated with global citizenship, though it is acknowledged that COIL projects have the capacity to broaden and deepen understanding of course content (Guth, 2013). Ramírez's (2019) study of a COIL project involving second language students at institutions on both sides of the US-Mexico border, for instance, reports how students who initially knew very little about their neighbouring countries increased their intercultural confidence; and developed knowledge of each other's countries and the past and present socioeconomic connections between them. While this type of knowledge was an important part of the ambition for EROS International, the aim was to also use collaborative international working to deepen students' specific understandings of the significance of sustainability for engineers and engineering. As set out in CDIO Standard 7, the intention was to achieve personal development in tandem with knowledge development. The intention was further that students should not simply use the activity to learn more about other places but to also use their encounters with other places to reflect on their own contexts for engaging with sustainability.

When students were asked about how knowledgeable they were about general sustainability issues and sustainability issues relating Engineering prior to EROS International, most participants replied, "not at all", "slightly" or "somewhat", though this varied by country (Figure 1). Around 66% (16/24) of students reported being "not at all knowledgeable" or only "slightly knowledgeable" of the specific issues of energy management in their home country, with much less variation by region observable. Despite their lack of confidence in their knowledge, students appeared to have good general understanding about sustainability. Students reported having studied polymer degradation, plastic recycling/reuse; clean energy sources and materials; carbon footprint and the United Nations (UN) Sustainable Development Goals (SDGs), in both core and elective modules. Results from the pre-activity survey revealed that 58% of all participating students did not have prior knowledge of sustainability through their engineering curriculum, which may help explain a lack of confidence in some students (Table 3). Most students from the UK were exposed to general sustainability issues through their undergraduate studies, followed by Canada and Malaysia.

Table 3: Assessment of understanding and knowledge of Sustainability through the Engineering Curriculum.

Country	Positive Responses [#]	Negative Responses [#]	Positive Responses [%]
Malaysia	2	4	33
India	0	1	0.0
Taiwan	0	2	0.0
Canada	2	4	33
UK	6	3	67
Overall	**10**	**14**	**42**

Despite the short duration of the course, students reported feeling much more knowledgeable about sustainability issues, both in general and as related to engineering after their week of study (Figure 1). After the activity, around 90% of participants reported a “moderate” or “extreme” level of knowledge for each general and engineering sustainability, no students reported this level of confidence in their knowledge in the pre-activity survey.

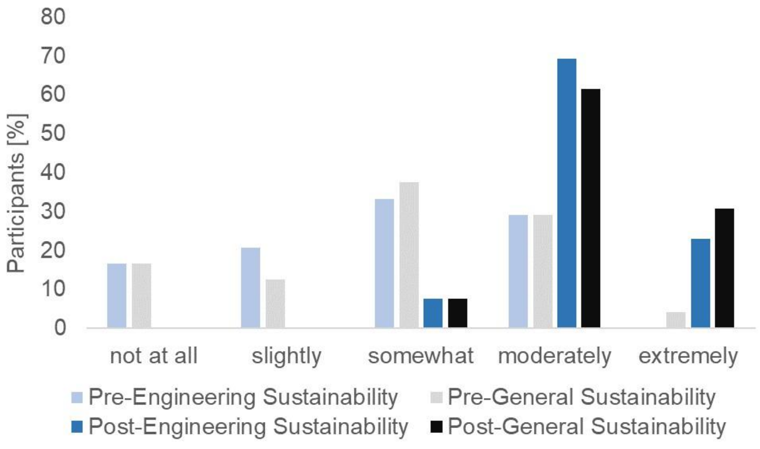

Figure 1: Knowledge level of participants. Knowledge and understanding of general and engineering sustainability issues prior and post EROS International.

One example that helped students increase their sustainability knowledge was the energy management game. During the game, students within their groups were tasked to build a 24-hour energy profile using price information from a Smart Meter. Students had to discuss within their groups the use of base loads (e.g., TV), cooking loads (e.g., rice cooker), wet loads (e.g., washing machine), heating loads (e.g., radiators) and cold loads (e.g., fridge) based on their own energy consumption behavior throughout the day (Figure 2). Energy profiles from all groups were compared and the team with the lowest overall energy price and carbon footprint won.

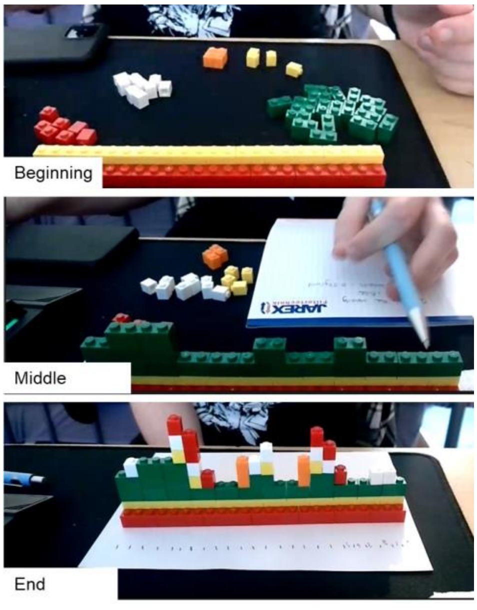

Figure 2: Energy management game. Students within their groups build energy profiles based on their own energy consumption behavior. Students used building bricks as energy units.

To provide insight into how students understood sustainable engineering problems, participating students were asked pre- and post-activity to reflect on what they thought an engineer should consider when working on sustainability challenges (Figure 3). Pre-activity, 58% of students reported that non-Engineering knowledge should be considered “Often” or “Always” in Engineering projects but 42% suggested this was necessary only ‘Rarely’ or ‘Sometimes’. Post-activity 92% of students felt it was ‘Often’ or ‘Always’ necessary for engineers to consider non-Engineering knowledge when considering engineering solutions to sustainability challenges. A similar pattern was evident in views on the importance of non-technical issues, with students being more aware of the value of taking account of non-technical issues post-activity. These findings suggest an increased acknowledgement amongst students for the need for engineers to take account of a breadth of information when seeking solutions to complex and integrated problems. This openness to multiple knowledges and sources of knowledge is a feature of global citizenship but also associated with contextualizing the work of engineers. This broadening of student understanding of what constitutes relevant engineering knowledge is further reinforced by shifts in student evaluation of the importance of both local and global contexts to engineers working on sustainability challenges, both of which students reported as more important post-activity than they had before they joined the programme. Potential features of the external contexts in which engineering challenges are situated include political and social issues, factors that STEM disciplines have traditionally excluded or downplayed in relevance. Yet, having competed EROS International, student views moved significantly on the relative importance of political and social issues, indicating, as Mejtoft, et al (2021) suggest “that international online collaboration between engineering students "addresses issues as cultural differences, the roles of the engineer in a larger context and also touches upon the impact of engineering on other parts of the economic and societal system” (203).

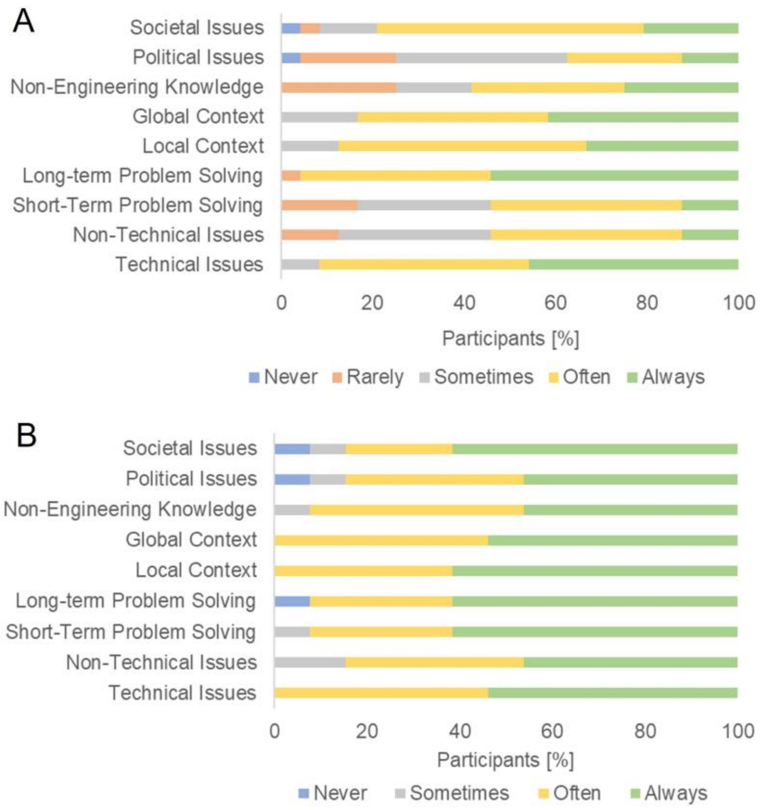

Figure 3: When working on solutions for sustainability problems, engineers should consider a variety of areas. Responses of students before (A) and after (B) participation in the activity.

Awareness of benefits and challenges of international collaboration

The evidence to suggest students were more open to contextualising engineering practice was also complemented by a shift in the perceived importance of collaboration to solve engineering problems. Prior to the activity, students felt that engineers should collaborate internationally “sometimes “(~8%), “often” (~54%) or “always” (~38%). A clear shift was observed post-activity when more than 50% of participants recognised the need to “always” collaborate (Figure 4).

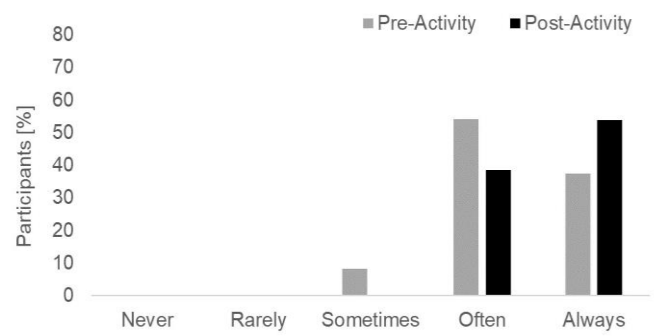

Figure 4: The need for Engineers to collaborate internationally to solve sustainability problems.

One of the key benefits of engaging with cultural diversity through Virtual Exchanges and COIL projects is that they provide opportunities for students to learn from different perspectives, to have previously held knowledge qualified in relation to both the challenge under consideration and the different contexts in which it is being explored. Even pre-activity students from all countries were aware of the benefits of international collaboration for sharing resources, knowledge, data, capabilities and perspectives. They also suggested collaboration was key to longer-term solutions and effective problem solving. Some of the benefits to collaboration that students noted, such as cultural and country differences, also appeared in responses to the question regarding the challenges of collaboration. This suggests students were aware of the benefits of working across different cultures and contexts to better understanding engineering challenges but recognised that working across different knowledge systems was not always easy, particularly with additional challenges around the practicalities of communication – of time zones, communication technology, language etc. (Figure 5). The post-activity survey did not include questions designed to encourage students to explore the issue of collaboration in relation to their own experience though EROS International. This would have been a useful insight for evaluating the success of the programme and will be included in future post-course evaluations.

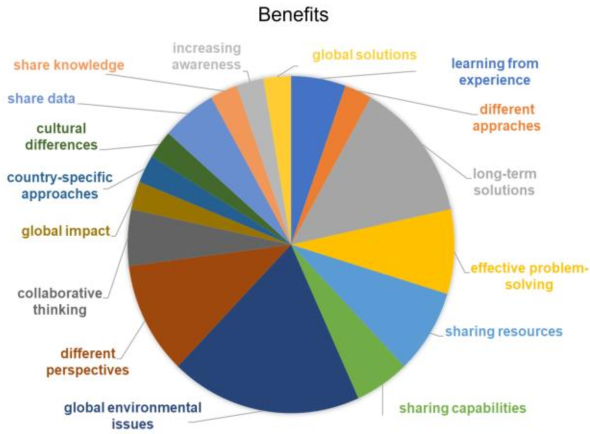

Figure 5: Benefits of engineers collaborating internationally on sustainability problems. Combined responses of students from the pre-and post-activity survey.

In addition to understanding the significance of international collaboration for engineers as professionals, working on sustainability, findings also pointed to students increased appreciation of the importance of taking account of sustainability issues in their daily life. Sustainability impacted decisions for daily life in almost all participants either "often" or "always" prior (~53%) and post (~99%) EROS International (Figure 6).

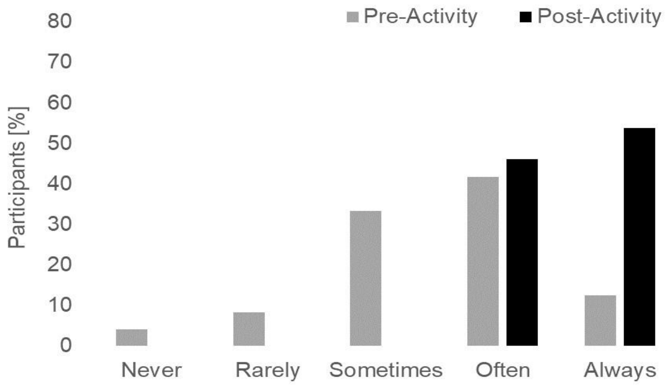

Figure 6: Impact of sustainability on decisions of daily life.

Enhancing faculty competencies in providing integrated learning experiences

CDIO Standard 10 recognizes the specific importance of opportunities for engineering staff to develop and improve competencies in new approaches to integrated and active learning. The shift to online delivery necessitated by responses to COVID-19 has required staff to rapidly develop confidence in navigating online communication platforms and to employ new approaches to content delivery and student engagement. COIL projects, however, require staff to have competence in digital, collaborative, and international pedagogies.

The organisation and delivery of EROS International brought together a team of academics from different engineering disciplines, namely Biomedical, Mechanical, Electronic and Electrical Engineering, many with different cultural backgrounds e.g., German, Sri Lankan, Pakistani, Iranian and British. This facilitated collaboration, as well as cross-disciplinary and intercultural communication among staff.

Since students were experiencing similar situations and challenges within their groups, staff members were able to better relate to students and guide them during the daily mentor meetings. Since different activities were led by different academics, staff were able to take responsibility and gaining leadership creating a sense of belonging. Additionally, one of the main challenges experienced by staff, was to timetable synchronous sessions, e.g., guest lectures, games and the showcase, so that students' attendance and staffs' session delivery was possible at reasonable times. On the other hand, daily mentor sessions and the showcase on the final day proved to be some of the highlights of the activity. These sessions provided opportunities for staff and students to learn from each other about engineering concepts, solutions, but also about cultural differences and customs.

EROS International provided a virtual field trip for students and staff alike. It enhanced staff's ability to communicate across differences, sharpened the awareness for different educational needs and backgrounds, and provided the opportunity to hone skills for navigating challenging situations in the virtual classroom.

CONCLUSIONS

The EROS International activity discussed in this paper was short in duration and limited to a small number of participants (<50 students), however, it provided a valuable pilot for exploring the potential of online international learning pedagogies for developing specific skills and aptitudes required by professional engineers. Combing collaboration with online and international engagement creates scope for enhancing group-working skills, developing intercultural confidence and building digital literacy in a context of multiple practical challenges. In addition, as this project demonstrates, with its focus on sustainable engineering challenges, such activities also have the potential to create opportunities for students to develop their knowledge and their ability to apply it in different contexts.

The Engineering Department at NTU plans to develop their online international programme with a continued focus on sustainability challenges. To deepen the international collaborative dimensions, faculty at international partners will be more actively involved in design and delivery, further embedding comparative and diverse content and perspectives. The pre- and post-activity surveys will also be developed to better enable students to reflect on their own learning through the programme, support them to articulate their skills to future employers.

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COLLEGIAL LEARNING DURING THE PANDEMIC: REALIZED ACTIVITIES AND LESSONS LEARNT

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ABSTRACT

The CDIO initiative, through its twelve standards, provides a well-structured platform for creating optimal teaching and learning opportunities. While most of the standards focus on students and their learning process, two standards focus on the teachers. While standard 9 centers on enhancing faculty competence in personal and interpersonal skills, product, process, system, and service building skills, as well as disciplinary fundamentals, standard 10 centers on enhancing faculty competence through integrated learning experiences, in using active and experiential learning methods, and in assessing student learning. Recent CDIO papers have indicated that standard 10 is one of the least researched standards.

This paper addresses a challenge that many universities have faced during the pandemic outbreak in the spring of 2020; how to identify and share positive and negative experiences acquired by teachers during the rapid transition from campus to digital education. The paper outlines how standard 10 has been applied on a group level among the teachers at the School of Engineering at Jönköping University. The objective is to demonstrate how a scientifically founded group and collegial learning perspective could increase the focus on standard 10 and its importance to the CDIO platform.

The Covid-19 outbreak led to a transition of pertinent teaching forms and the teachers' pedagogical mindset. The urgent question to many higher education teachers was how to swiftly adapt teaching and learning to the new situation. Hence, the pandemic forced an abrupt transition from campus to online activities, something that affected most teachers. To support this transition, the role of the pedagogical development group (PED) changed from inviting experts to share knowledge, to the group members themselves becoming experts through building competence within digital education. The barriers and difficulties in the transition from campus to online education were identified, and best practices, as well as pedagogical experiences, were shared among the teachers through learning activities, such as online seminars with a particular focus on online teaching and assessment. This also led to the identification of new topics for competence development. Student engagement and online examination forms were identified as primary areas for further competence development, and a team activity was initiated based on previous pedagogical research. This resulted in an increase in the awareness of choosing adequate examination forms to optimize student engagement within a course. Future possible directions within collegial learning at the School of Engineering are also outlined.

KEYWORDS

Collegial learning, Online teaching, Student engagement, Teacher competence development, Teacher team building, Standards: 10

INTRODUCTION

Pedagogical development has been an essential cornerstone of the engineering education at the School of Engineering (JTH) at Jönköping University (JU), Sweden. The focus of this development has been through the CDIO initiative which was recognised through a group from JTH entering the CDIO network in 2006. A permanent group was subsequently formed in 2007, working with the CDIO principles alongside educational development which is known as the Pedagogical Development group (PED group). The PED group consists of teachers as representatives from all of the departments at JTH, as well as the Head of HI EDUCATION whom represents the educational division of the student association at JTH (HI TECH.) The PED group is thus a diversified team with perspectives from a broad range of teachers with different engineering backgrounds, as well as the student representative. The group is chaired by the Quality Coordinator at JTH, but has shared leadership and reports to the Head of Education at JTH. The role of the PED group, until 2020, has been primarily focused on arranging pedagogical activities for the staff through pedagogical seminars with invited speakers from JTH with a focus on engineering education, as well as a yearly conference with pedagogical experts.

The research presented in this paper started with, but did not end with, the direct effects of the breakout of the Covid-19 pandemic in 2020. In common with many higher education institutions, Jönköping University was forced to move most of its education online almost overnight, and to maintain a mix of online and physical education for a considerable timeframe through several waves of changing restrictions.

Two challenges were particularly pertinent during the transition from campus to online teaching which identified as the research problems. The first challenge was becoming more proficient in online teaching as an organisation with an uncertain timeline. The second challenge was how to retain or enable student engagement in a new setting where online education could create barriers to student engagement (Almusaed, Almssad & Rico-Cortéz, 2021). There was an urgent need for pedagogical competence development relating to online education at the individual teacher's level, and a great need for organisational learning. For JTH, however, one way to address the problem was at the team level. The role of the PED group members was transformed from being coordinators inviting and sharing the knowledge of experts, to become the "experts" at department levels themselves. This transition was enabled through teamwork, by sharing expertise and experiences among colleagues both in the PED group and on the faculty level, as well as through activities to strengthen the competence in the PED group regarding student engagement and the role of examination in online teaching.

THEORETICAL BACKGROUND

Teams are a valuable organisational approach in pedagogical development. There are some notable features of teams as a concept that is used in the present paper. A team is often defined as a small number of people who are committed to a common purpose. Teams differ from other forms of working groups because they require both individual and mutual responsibility. The team members have complementary skills and teams generate results through the joint contributions of their members. (Katzenbach & Smith, 2008).

Previous studies have shown that members in professional development teams achieved new pedagogical knowledge, especially by learning new concepts and improving their understanding of known concepts that have been discussed during meetings (Gast, Schilddkamp & van deer Veen, 2017). The new knowledge gained would occasionally lead teachers to begin experimenting with new ideas. Splitting the team up into smaller temporary groups to work on separate tasks and bring their results back to the group has been found to be a successful factor in team learning (Gast, Schilddkamp & van deer Veen, 2017). In organisational psychology and innovation management, it is often highlighted how team learning is a cornerstone in organisational learning (Decuyper, Dochy & van den Bossche, 2010).

Three essential team learning behaviors are identified by Decuyper, Dochy & van den Bossche (2010). These are sharing, constructive conflict, and co-construction. Sharing is defined as "the process of communicating knowledge, competencies, opinions, or creative thoughts of one member to other team members, who were not previously aware that these were present in the team". Constructive conflict is "a conflict or an elaborated discussion that stems from diversity and open communication and leads to further communication and some kind of temporary agreement" (Decuyper, Dochy & van den Bossche, 2010). Co-construction is the process of building new knowledge or modifying an original offer. For a team to succeed, it needs to deal with both understanding and agreement, and there needs to be space for constructive conflict and co-construction to reach shared knowledge (van den Bossche, Gijselaers, Segers & Kirschner, 2006).

Decuyper, Dochy & van den Bossche (2010) distinguishes between two types of learning processes in teams - basic and facilitating. The basic processes describes what happens when teams learn. They are the essential communicative actions that are necessary for team learning. The facilitating processes includes collectively reflecting on team actions, experimenting with new ways of working, and looking for feedback from people outside of the team. The facilitating processes can give the right direction and focus for the team. For a team to learn effectively, it needs to clarify what are the teams goals and how to reach them (Decuyper, Dochy & van den Bossche, 2010).

The CDIO Standard 10 "Enhancement of Faculty Teaching Competence" is defined as actions that enhance faculty competence in providing; integrated learning experiences, using active experiential learning methods, and assessing student learning.

A literature study identified a research gap that the CDIO standard 10 has only been the focus of very limited research and few published articles (Malmqvist, Hugo, Kjellberg, 2015; Edström, 2017; Meikleham, Hugo, Kamp & Malmqvist, 2018; Malmqvist, Machado, Meikleham & Hugo, 2019). More generally, there is little research performed on the role of permanent teacher teams in individual and organisational learning, especially under rapidly changing conditions. What we present herein represents the learning process of the team, and how the team itself developed its understanding and competence during the first stages of the pandemic. Hence, the purpose of this paper is to demonstrate and analyse how team learning can take place in a fast-changing context.

METHODOLOGY

The purpose of this paper is to demonstrate and analyse how team learning can take place in a fast-changing context. This implies a context of discovery where a significant amount of the problem domain is not yet defined, and where there exists several new elements such as a specialised pedagogical team and time-critical events. Hence, we seek to develop a common understanding rather than testing a predefined problem domain.

To describe the process as it unfolded, as well as the context in which it took place, a case study approach is appropriate. Case studies have been described as a choice of what to study rather than how it is studied (Yin, 2018). Here, the object of study is the PED group and its response to the new demands introduced by the Covid-19 pandemic and the need for online teaching with high student engagement, thus representing a single case study in one organisation. The context of this response is clearly relevant and is included in the case study description. This might be described as an exploratory case, demonstrating a situation of particular interest in itself without extensive prior knowledge (Yin, 2018).

The data in the case study is qualitative, which is particularly relevant where there is a need for "rich data" to uncover meanings and interpretations. The case description is effectively based on two types of qualitative data in combination. First, a set of detailed minutes from the activities of the PED group which have been stored on a shared cloud service throughout the entire period, making it possible to track developments and analyse the effectiveness of the implemented changes over time and reconstruct particular events when necessary. The second type of data relates to the artifacts produced by the group, such as summary presentations and material developed for internal dissemination. Finally, all participants were able to read and reflect on the case description and add their input or corrections.

In 2021, 16 meetings were held that gathered the whole PED group. In addition, meetings were held on April 12-13 with all PED group representatives and the individual heads of departments. An unknown number of smaller meetings also took place with sub-teams that were formed throughout the year for the study and discussion of specific topics, however these will not be discussed here. The majority of meetings were held in a digital format, but two physical meetings took place towards the end of the year. 10 out of the 16 meetings took place in the spring and 6 in the autumn. During spring, the meetings were long, covering up to four hours. Considerable time was therefore devoted to PED group activities during the spring as a means for the group members to get to know one another and to work with the topics discussed.

CASE STUDY

"Confidence through competence" – the new way of working in 2021

The work conducted by the PED group used to be oriented towards inviting subject experts to various activities offered to staff at JTH, such as seminars. The PED group had an important role in promoting pedagogical development at JTH, but it was indirect as the PED group members mainly engaged in the practicalities linked to organising activities which hosted invited experts. Starting in 2021, the PED group instead started a journey towards becoming experts in the field of pedagogical development, starting with the topic of digital education. An overview of the PED Goup actions in the learning process is presented in Figure 1.

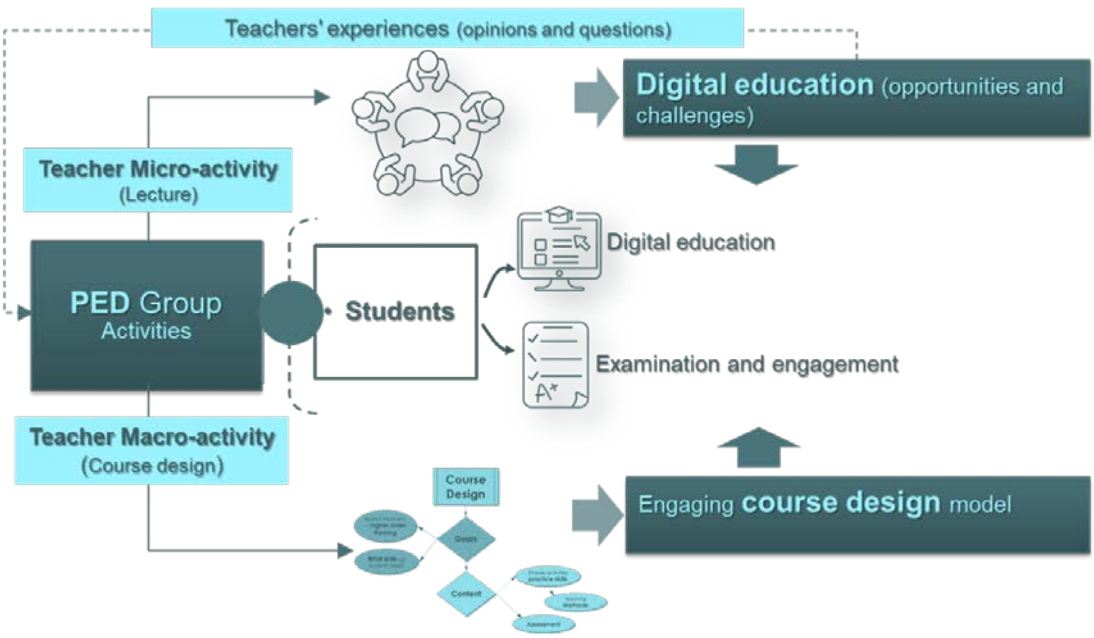

Figure 1: PED Group activities in a crisis environment

In line with CDIO standard 10 that discusses integrated learning experiences, the PED group aimed to build competence by studying literature and performing research within digital education.

Instead of *inviting* experts, the PED group started the journey towards *becoming* experts. Within the PED group, the members spoke of gaining the confidence needed to be able to assist colleagues in pedagogical matters through competence development, *confidence through competence*. This deliberate seeking of new knowledge is referred to as "primary" team learning by Decuyper, Dochy & van den Bossche (2010, p. 120), and was an essential characteristic of the PED group work in 2021.

The PED group functions through all members being active and taking responsibility. In order to address the challenges during this time, several activities where combined to achieve rapid competence development in a team environment. These activities include:

Study of information on digital education

The first activity was to study the information on digital education which already existed at the Jönköping University (JU) level. The PED group divided itself into sub-teams that reviewed different sections of the available information on JU's intranet, discussed them in the sub-teams, and then convened and discussed them with the whole PED group (meeting notes February 3). The same method of studying in sub-teams, as well as in the full group, was repeated throughout spring (meeting notes February 24, March 11).

Study of examination and engagement

The topic of examination was highlighted as a specific area of interest at the beginning of the year (meeting notes February 24). A few months later, examination was again discussed together with the topic of student engagement, and the same procedure was used as reported in the previous section with sub-teams in charge of studying the two topics (meeting notes April 13). The findings of the two sub-teams were presented to the whole PED group, followed by group discussions. The literature studied in relation to engagement was presented for the benefit of all PED group members (meeting notes May 3). The workflow is presented in Figure 2.

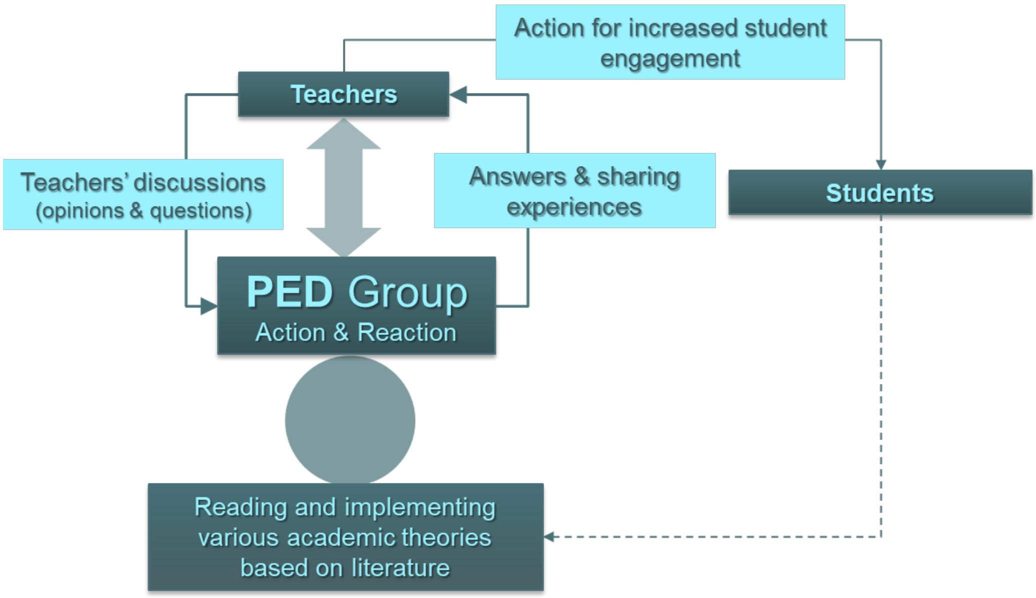

Figure 2: PED Group actions and discussions

Reaching out to colleagues to seek input on challenges linked to digital education.

An idea from one PED group member was for each member to reach out to colleagues in their respective departments to learn about challenges they had faced linked to digital education through a simple survey. The whole PED group was very favorable to the idea which was pursued, and findings were subsequently discussed and analysed (meeting notes March 11, March 23, May 26). It was apparent that a lot of the challenges perceived by teacher colleagues were linked to the lack of engagement among students.

Establishment of a commonly produced model for engaging course design

Towards the end of the spring, the meeting notes describe a shared view of main concepts regarded by the PED group as particularly important to provide engaging education (meeting notes May 26). One PED group member suggested that the group make a "visualisation" of the main concepts and showed an example of what such a visualisation could look like. The visualisation was further developed based on comments from the whole PED group during the same meeting. It became apparent to the PED group that the model did not only cover digital education, but was sufficently broad that it also reflected on campus and blended education (June 15). The model is presented in Figure 3.

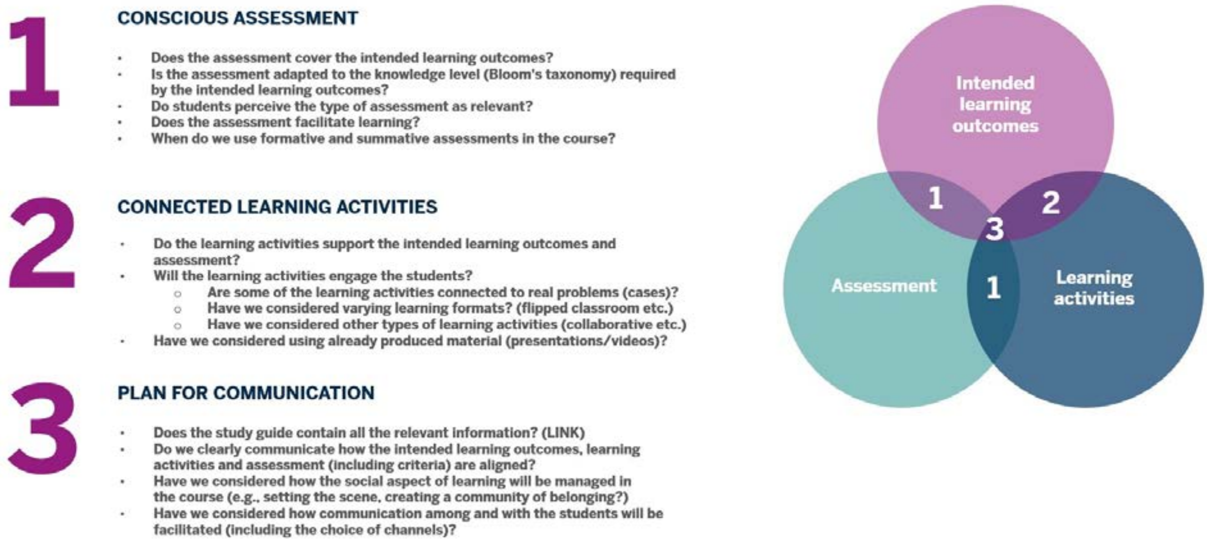

Figure 3: Model for course design for digital and campus education

Reaching out to the departments and engaging in department meetings

During the spring, meetings took place that mixed departments to ensure that PED group members might learn about activities in another department and about the expectations of the heads of departments. PED group members met with teachers and programme managers in different fields to provide and receive feedback related to the survey, which took place throughout the autumn.

Preparations for the CDIO article

While the idea of writing an article for the CDIO international conference in 2022 was first discussed with suggestions for topics presented during the spring (meeting notes March 23, May 26), it was not until the autumn that preparations were made by the whole group. As a result of this work, the PED group has gained relevant knowledge related to pedagogical development at higher educational institutions, e.g., the lack of research in the CDIO community in relation to faculty development and how the work of the PED group may be presented as a model for team learning.

ANALYSIS AND FINDINGS

To analyse the PED group activities described above, the team learning processes as described in Decuyper, Dochy & van den Bossche (2010) are used: basic team learning processes and facilitating processes. Basic processes are divided into sharing, constructive conflict, and co-construction, while facilitating processes are divided into team reflexivity, team activity and boundary crossing. The authors claim that their model "describes what teams do when they learn" (Decuyper, Dochy & van den Bossche, 2010, p. 116). Using their model is therefore a way of analysing the PED group activities and a test of the model itself.

Basic processes

Sharing: As shown in the activities section above, the PED group members shared their ideas about different topics and complemented each other coming from different backgrounds. As mentioned by other scholars, psychological safety is essential for team learning (see, e.g., Vangrieken, Docht & Raes, 2016) so that all members feel free to express their opinions. For most activities that took place, the element of sharing was prominent. The meeting notes repeatedly described discussions around different topics, often following the division into sub-teams and discussions and preparations. New knowledge was thus acquired by the PED group members through shared knowledge, by sharing of thoughts and ideas and ensuing discussions and adjustments to previous suggestions.

Constructive conflict: The team learning process constructive conflict is also easily identifiable in the material as described above, understanding the definition as respectful negotiating and listening to one another. This was key to identify the critical new knowledge required to achieve the goals during the rapid-changing environment. The material shows several examples of discussions and negotiations taking place, allowing the PED group to reach a deeper understanding of complex issues and arrive at shared knowledge. For instance, work in relation to the model was preceded by discussion and negotiations leading up to the model described in Figure 1.

Co-construction: The co-construction processes includes all of the discussions and negotiations that took place and that led to shared knowledge. The PED group meetings were productive and led to shared knowledge both in relation to digital education but also to campus education and to team learning in general. Co-constructed knowledge related to digital and campus education is exemplified by the model for course design in Figure 1, while co-constructed knowledge related to team learning is provided in this CDIO article.

Facilitating processes

Team reflexivity: The meeting minutes show several examples of team reflexivity. One important example was the realisation within the group that further competence development within examination and assessment was needed, resulting in additional studies of these topics. Another example of team reflexivity is the gradual realisation that the jointly shared knowledge covered not only digital education but also campus and blended education.

Team activity: In addition to communicative activities that have been reported in the previous section, team activity in the form of *experimentation* (Decuyper, Dochy & van den Bossche, 2010) has also occurred. An exciting discovery was how two PED group members had made similar changes to their examination forms independently of one another based upon the acquired shared knowledge. It was possible to track the changed practice to the primary learning that had taken place in the group and to observe that the change was well received by the students, as identified by the positive increase in engagement by the teachers and subsequently shown in the course evaluations. Naturally, ongoing evaluations over a longer period are required and will be studied to track the long term response from sudents and teachers from any implemented changes. Relating (positive) output to a particular input is often difficult, but in this case, the relation between output and input could be clearly identified.

Boundary crossing: Structurally, the PED group crosses boundaries as it consists of members representing the different departments at JTH. In the PED group meetings, representatives of different department cultures and practices convene for joint discussions and reflections. In addition to this structural boundary crossing, the meetings with two departments simultaneously, and visits by two PED members to the department of one of the members, are other examples of such boundary crossing. In these instances, boundary crossing has occurred through a PED group member getting a glimpse of the culture and knowledge of another department.

DISCUSSION

In summary, we believe that the model for team learning by Decuyper, Dochy & van den Bossche (2010) has been useful and has helped the members of the PED group identify and structure the type of learning that has taken place. Identifying, however, that the label *constructive conflict* does not adequately describe the negotiations that took place. Instead, we would like to propose the label *constructive compromise*.

The results from the new way of working in 2021 has led to a number of changes within the organisational operation of the PED group, as well as the outcomes. The key actions that led to these outcomes can be identified as follows. The PED group set out to increase the competence of its individual members on the topic digital education. This goal was reached. The PED group members felt greater confidence in providing help to colleagues in this field than previosuly, although continued competence development should continue. What is noticeable is that several results were reached that were not initially identified as goals but have, nevertheless, been produced. These results include competence development covering not only digital education, but also campus and blended education, the co-construction of the model for course design for digital and campus education, and changes of practice. The work with the CDIO article has also produced knowledge in the group on its capacity for team learning, as well as an artifact on the same topic in the form of this article.

Finally, we believe that three factors in particular have contributed to the PED group reaching the goals and the non-intended results mentioned above. These factors are *primary team learning*, *organisational aspects*, and *shared leadership*. The focus on *primary team learning* is the most specific change of the work of the PED group in 2021 as compared to previous years. The fact that all members studied the same topic meant that they got a common language and mindset about highly complex issues. This, in turn, led to the development of homogeneous knowledge in the group in several areas, as discussed here. The second important factor is related to the *organisational aspects* of the PED group. Funding and support from management, and the habit of the whole PED group to meet every two to four weeks for joint discussions have been in place for several years. This means that the PED group has developed into an arena for discussions on pedagogical development (see e.g., Roxå, Mårtensson & Alveteg, 2011). The third factor we believe to be of importance is *shared leadership*. As discussed by several scholars, shared leadership is of great importance for team learning (Decuyper, Dochy & van den Bossche, 2010, pp. 125-126; Koeslag-Kreunen, van der Klink, van den Bossche & Gijselaers, 2017 p. 196; Roxå & Mårtensson, 2015). Shared leadership relates to leadership taking place among, and stemming from, the members. As the team members in this way take responsibility and decide on activities, results and decisions will have a robustness to them, increasing the likelihood of being implemented and therefore contributing to organisational change.

CONCLUSIONS

Our case study has shown how teams can be used to facilitate competence development in rapidly changing environments. The formulation of the purpose is rather general, but our natural focus is on pedagogical development which sharpens the study. While the case study is of a single group in one organization which could produce different results elsewhere, the model from Decuyper, Dochy & van den Bossche (2010) was very helpful in structuring the discussion and appropriate as a basis for analysis. Further, we show a model for how competence development can take place, which should also have relevance for other higher education institutions. The use of more permanent teams, as demonstrated in the paper, could be a complement to pedagogical centres for teaching and learning which are necessarily more resource demanding. For the members of the PED group it has been very interesting to see how the work represented through numerous meetings and smaller tasks can be framed in terms of competence development and contribution to the organisation.

There are numerous interesting avenues for further research. One is temporal – the team presented in this study was very well established and there is an inherent assumption that this was an advantage due to organisational memory and existing ways of working, but it is possible that younger teams can have a similar effect on learning if the management support is sufficient. The team composition is an important element – the representativeness in terms of different departments can be explored in terms of the nature of the team itself and how more focused teams perform. The level of learning – that is the micro, macro and meso of the organisation could be explored in several ways since the focus here has been on the team itself. Finally it would be of great interest to see the consequences of this type of team learning for the organisation itself in the longer run, and the success will be evaluated through teacher and student evaluations.

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CDIO APPLIED IN THE BRAZILIAN ENGINEERING EDUCATION LAW IMPLEMENTATION

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ABSTRACT

The relevance of the new Brazilian Curriculum Guidelines (new NCGs) for engineering undergraduate courses coincides with the expectations of the academic community, companies employing this qualified workforce and the need to update education in the country, aiming to meet future demands for more and better engineers. In this sense, given the transformations that are taking place in the world of production and work, the new NCGs can stimulate the modernization of engineering courses, through continuous updating, centering on the student as an agent of knowledge, greater integration school-enterprise, the appreciation of inter and transdisciplinarity, as well as the important role of the teacher as an agent for conducting the necessary changes, inside and outside the classroom. However, engineering undergraduate courses find it difficult to adapt to the new NCGs, as they have had teaching practices based on lectures for many years, where the teacher transfers knowledge and the most important intellectual skill of the good student is the memorization of academic content and its repetition in tests. The purpose of this article is to present the implementation of the new NCGs through the CDIO approach. This implementation represents a change in the teaching and learning process, maintaining the excellence of the academic content, reorganizing the pedagogical project of the course, integrating new academic practices, and adding skills and competences necessary for the modern engineer. The implementation is shown through a case study involving the Mechanical Engineering undergraduate course at the Military Institute of Engineering and the initial results demonstrate an increase in student's motivation, innovation and problem solving in new academic activities of practical and active learning. Furthermore, this study demonstrates that the CDIO approach is a methodology aligned with the proposals of the new NCGs for engineering courses and aims to motivate other Brazilian universities to use CDIO.

KEYWORDS

Constructive alignment, academic implementation, innovation. Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

Scientific and technological knowledge is advancing rapidly and undergraduate courses in engineering must prepare professionals to solve the demands of modern society and industry.

In Brazil, for projects and services involving engineering to have competitiveness and innovation in the international scene, it is necessary to graduate engineers with solid technical-scientific qualification, endowed with the skills and competences necessary for the creation and improvement of innovative products and processes, at the frontier of knowledge.

However, according to the National Education Council Report (Brazil, 2019a), the national productive sector finds it difficult to recruit qualified professionals to work at the frontier of knowledge, which, in addition to technique, requires its professionals to master skills such as leadership, teamwork, planning, strategic management and autonomous learning, which are known as soft skills. In other words, professionals are increasingly required to have solid technical knowledge, combined with a more humanistic and entrepreneurial vision.

Thus, considering that the engineering activity is essential in the generation of knowledge, technologies and innovations, and the consequent need to improve the quality of engineering undergraduate courses offered in the country, the National Council of Education edited the new National Curriculum Guidelines (NCGs) for engineering courses (Brazil, 2019b).

According to the National Education Council Report (Brazil, 2019a), the new NCGs for engineering courses have flexibility and diversity, guiding towards the integration of theory with practice, and teaching with research. They also represent an opportunity to propose new curricular organizations in Engineering. The new Pedagogical Course Projects (PCPs) must align the accumulated experiences of the faculty with the development of competences in the graduates of the courses, considering regional and institutional specificities. The following are some important considerations for implementing the new NCGs in engineering courses: involvement of professors and managers in the process of preparing new PCPs, which should provide innovation and flexibility in the teaching-learning process; development and/or revision of curricula, having as a starting point the desired competences for the graduates; teacher training to provide new teaching practices that provide active learning, required by the new NCGs; adaptations and investment in infrastructure to intensify active learning, such as: new teaching and learning environments, improvements to the laboratories for integrated projects, adequate teaching material, etc; management of student assessment and competency-oriented learning process instead of the content vision; and permanent interaction between academia and industry, all undergraduate degree in engineering.

However, the academic questioning of the various engineering undergraduate courses is how to carry out the necessary adaptation to the new NCGs and improve engineering education in the respective institution and in the country. In this context, some Higher Education Institutions (HEIs) in Brazil are adopting the CDIO approach (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014) to plan and carry out such changes in engineering education in their respective courses.

The Mechanical Engineering course at the Military Institute of Engineering (IME) uses this CDIO model to adapt to the new NCGs, motivate its academic staff and, finally, make the future mechanical engineer capable of carrying out professional activities within the new demands and challenges of the industry and modern society (Cerqueira, Rezende, Barroso Magno, & Gunnarsson, 2016).

CDIO APPLIED IN A MECHANICAL ENGINEERING COURSE: CASE STUDY AT IME

The mechanical engineering undergraduate course in the Military Institute of Engineering (IME) has the basic contents for mechanical engineering, such as Thermodynamics, Fluid Mechanics, Dynamics, Solid Mechanics and Machine Projects. The academic period for the student to become a mechanical engineer by the IME is five years, divided into ten semesters. The first four semesters are the basic contents. Only after the fourth semester mechanical engineering students will have contact with the specific content. The mechanical engineering program has 3,600 hours of activities in engineering education.

The mechanical engineering at IME, to improve and transform its PCP, must agree with the new National Curriculum Guidelines (NCGs) of the Ministry of Education (BRAZIL, 2019b). Thus, a study was carried out to assess whether the academic premises of the new NCGs (BRAZIL, 2019a) were compatible with those proposed by the CDIO Standards, with the objective of an initial validation of the approach. The result of this preliminary comparison was that the use of the CDIO approach was appropriate, relevant, and aligned with the new NCGs. Table 1 shows the comparison topics.

The result shown in Table 1 motivated the application of the CDIO approach in the pedagogical improvement of the IME mechanical engineering courses and in their respective adaptation to the new NCGs. Thus, to implement the approach (Ulloa, Villegas, Céspedes, & Ramírez, 2014) the adoption process proposed by the CDIO Initiative (CDIO, 2021) was used.

Table 1. Alignment of the new NCGs propositions with the CDIO Standards, for the PCPs.

Propositions for PCPs by NCGs	CDIO Standards
Induction of innovative institutional policies	CDIO as context
	Program evaluation
Focus on teaching through skills development	Integrated curriculum
	Learning outcomes
Emphasis on managing the learning process	Introduction to engineering
	Integrated learning experiences
	Learning assessment
	Engineering workspaces
Relationship strengthening with different organizations	Design-implement experiences
Innovative teaching methodologies	Active learning
Valuing faculty training	Enhancement of faculty competence
	Enhancement of faculty teaching competence

The following subsections present the actions taken to adapt the mechanical engineering course to the CDIO Standards and, consequently, to the new NCGs.

CDIO Standard 1 (the context) and the new NCGs

Through presentations and meetings with mechanical engineering program faculty, the problems that generated the lack of motivation for the engineering learning and the current needs of the industries and the society were shown. The following subjects were discussed: very theoretical courses; lack of practice in disciplines; demotivation for learning; need for integration between disciplines (interdisciplinarity); there is no provision of improvement courses in teaching of higher education in engineering; and the current needs of the engineering professional, considering the skills and abilities proposed for the mechanical engineering course at the Federal Council of Engineering and Agronomy (FCEA), NCGs and CDIO Syllabus (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014). In this context, the CDIO approach (CDIO Standard 1) was introduced as a solution, providing to the future mechanical engineers the ability to perform their engineering skills with a more mature assessment of how a product meets the real needs of the industry and society.

CDIO Standards 2 and 3 (learning outcomes and integrated curriculum)

The selection of the knowledge, skills, and attitudes that engineering students must have when leaving university is the next step in the development of the new PCP (CDIO Standard 2). Table 2 shows the context of Brazilian competences correlations.

Table 2. Correlation of competences between the Brazilian aspects and the CDIO Syllabus.

Competencies established by the NCGs and by FCEA		***CDIO Syllabus***
Apply mathematical, scientific, technological, and instrumental knowledge to the engineering	➡	*Disciplinary knowledge and reasoning*
Design and conduct experiments and interpret results	➡	*Personal and professional skills and attributes*
Planning, supervise, elaborate, and coordinate engineering projects and services		
Identify, formulate, and solve engineering problems		
Develop and/or use new tools and techniques		
Understand and apply professional ethics and responsibility		
Assume the posture of permanent search for professional updating		
Communicating effectively in written, oral and graphic forms	➡	*Interpersonal skills: teamwork and communication*
Work in multidisciplinary teams		
Conceive, design, and analyze systems, products, and processes	➡	*Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context – the innovation process*
Supervise the operation and maintenance of systems		
Evaluate the impact of engineering activities in the social and environmental context		
Evaluate the economic feasibility of engineering projects		

The mechanical engineering program began the curriculum design process through a careful study of the CDIO Syllabus, to compare it with the learning outcomes established by the Brazilian education laws, the engineering companies and society (Table 2).

For mechanical engineering higher education, the Brazilian law determines the learning outcomes are in accordance with the NCGs (Articles 3rd, 4th, 5th) for engineering courses (Brazil, 2019b). To exercise the mechanical engineer profession, the Federal Council of Engineering and Agronomy (FCEA, 2005) establishes the activities, abilities, and responsibilities of the engineer. The knowledge, skills, and attitudes, determined by the National Curricular Guidelines of Engineering Undergraduate Programs (Brazil, 2019b) and by the Federal Council of Engineering and Agronomy (FCEA, 2005), present a strong similarity. In this way, Table 2 correlates the demands of National Guidelines and FCEA with the skills and knowledge proposed by the sections of the CDIO Syllabus.

Table 2 shows that the CDIO Syllabus addresses all the needs of Brazilian education laws and the exercise of engineering activity in companies (FCEA requirements). Given that the CDIO Syllabus is a current document, covering the needs of the modern engineer, the mechanical engineering program decided to adopt the CDIO Syllabus completely and without any customization. In this way, the CDIO Syllabus has been translated into Portuguese and is being submitted to the faculty for further development of the integrated curriculum. To this end, it is intended to use the tools called matrix ITUE Matrices and Black Box exercise (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014). The need to improve engineering education in Brazil through an integrated curriculum is present in Article 6th of the new NCGs.

Standard 4 (introduction to engineering)

The discipline of Introduction to Engineering Project (IEP) was designed to be carried out in two periods, that is, in the third and fourth periods of the second year. The IEP courses are common to all the IME programs because students only start in their specialty from the fifth semester in the third year. The introductory engineering discipline is one of the guidelines contained in the new NCGs (Article 6th , Paragraph 4th). IEP I & II were implemented in 2018. The core of both courses is the theory and practice of Project Management (PM); active learning through project-based learning (PBL); design-build activities; teamwork strategies; and specific content for oral and written presentation development (Passos, Arruda, Vasconcelos, & Ferrari, 2019). During these two semesters, the practices become increasingly complex, always considering the student's level and knowledge. Figure 1 shows IEP I & II.

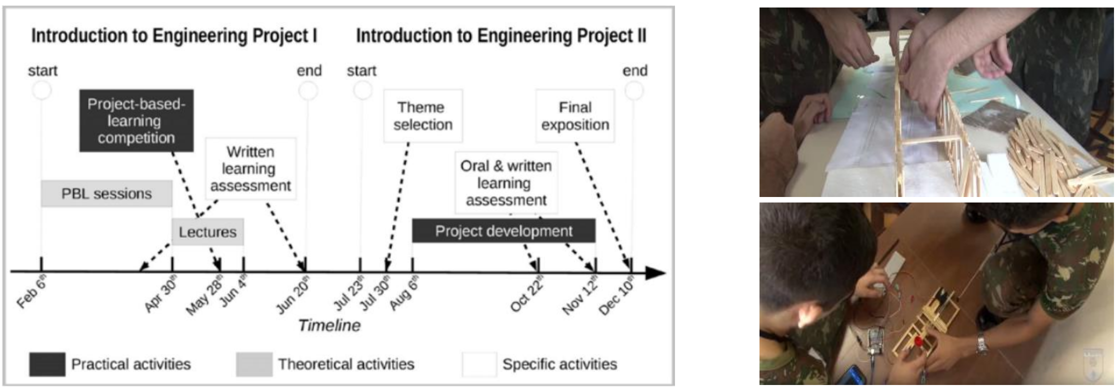

Figure 1. IEP timeline and IEP academic projects

Table 3. Teaching plan - Introduction to Engineering Project I.

DIDACTIC UNIT I - BEST PROJECT MANAGEMENT PRACTICES PRACTICES		
Teaching methodology: PBL - Project Based Learning (active learning). ***Learning assessment***: evaluation of the active method used in each class.		
Subjects	Specific objectives	Duration
1. Basic concepts of project management.	- Use the project management language. - Know the set of PMBOK best practices.	3 hours
2. Environment where projects take place.	- Know the main organizational structures of project offices.	3 hours
3. Integration management	- Know the main integrative processes of project management.	3 hours
4. Scope management.	- Describe the main tools and artifacts of project scope planning.	3 hours
5. Time management.	- Apply the main time management tools applied to project management.	3 hours
6. Risk management.	- Understand risk management and its main tools.	3 hours
7. Cost management.	- Understand the challenges of mounting costs and their relationship to other project activities.	3 hours
8. Quality management.	- Understand the meaning of quality management for project management.	3 hours
9. Resource and acquisitions	- Understand the importance of resource management and acquisitions for project management.	3 hours
10. Communications management.	- Describe the communications tools and challenges for the project.	3 hours
DIDACTIC UNIT II - PROJECT MANAGEMENT IN PRACTICE		
Teaching methodology: lectures will be given by people specialized in each area. ***Learning assessment***: Analysis of the oral and written presentation of the project report.		
Subjects	Specific objectives	Duration
1. Application of projects in the real world.	- Understand, through real cases conducted by experts, that the techniques studied in the classroom are useful, applied and are responsible for the success of projects.	3 hours
2. Preparation of scientific papers and texts.	- Know basic concepts of the scientific method and understand how this affects the construction of the scientific text.	3 hours
3. Making good presentations.	- Know the main techniques for oral presentations	3 hours
DIDACTIC UNIT III - COMPETITION AND CHALLENGE BETWEEN GROUPS		
Teaching methodology: PBL - Project Based Learning (active learning). ***Learning assessment***: evaluation of the active method used in each class and the		
Subjects	Specific objectives	Duration
1. Execution of the competition project selected.	- Practice: project management skills, project report building and teamwork through one-time project execution quickly.	6 hours

In 2018, the practical activity of IEP (Figure 1) was the competition of popsicle-stick bridges, following the specifications provided by the teaching team. In 2019, the practical activity of IEP was the competition of catapult controlled by Arduino. In both projects the students following the specifications provided by the teaching team.

For example, Table 3 shows the teaching plan of the discipline Introduction to Engineering Project I. Such discipline is typical and recommended by the CDIO.

Standard 5 (design and implement experiences)

The Mechanical Engineering program decided to include two design-build disciplines. One in the 6th and 7th periods, called Initiation to Research (IR), and another in the 9th and 10th periods, denominated Final Project of Course (FPC). This decision was based in the successful academic experience at Linköping University – LiU (Svensson & Gunnarsson, 2012). At LiU there are three design-build disciplines. Similarly, IME's mechanical engineering has three such disciplines: IEP, IR and FPC. These activities are encouraged by the new NCGs (Article 6th, Paragraphs 2nd and 3rd). In both disciplines IR and FPC, students use previously learned project methodologies and perform activities to properly meet project requirements within the established deadlines.

In 2018 an experimental design-build activity for IR course was offered to the mechanical engineering students that was a competition for Aerodesign (Figure 2).


Figure 2. Aerodesign design-build academic experience.

The proposed design had simple requirements, such as maximum span length, maximum payload for in-flight transport, deadline for flight test, and final written and oral presentation. For FPC, the “Integration Seminar between IME and Brazilian Defense Industry” has been inserted since 2015 in the IME´s calendar. From this event many design-build projects are being proposed for the FPC course so that students can solve real industry engineering problems, providing better opportunities for developing IME students' skills and competencies. With these different activities, it was possible to perceive the enthusiasm, the application of the theoretical concepts learned in the conception and construction of the prototype, the organization for teamwork and, most importantly, the consolidation of the mechanical engineering learning.

Standard 6 (engineering workspaces)

The mechanical engineering laboratories have space and resources for the development of practical activities and projects. Being multidisciplinary spaces used by all engineering. The implementation of the CDIO initiative in the undergraduate mechanical engineering courses of IME provided several important aspects for this Department. Improvement of laboratories within the scope of the new Program Pedagogical Project. About eight hundred thousand dollars were invested in the restructuring of the spaces and the purchase of equipment. Here are some improvements in the workspaces of the mechanical engineering course at IME: new didactic stands for innovative academic activities in the Engines Laboratory; new didactic benches for academic activities integrated in the Thermoscience Laboratory; new subsonic wind tunnel for the Aerodynamics Laboratory; new Industrial Robotics and Defense Laboratory; complete reform of the staff room; and replacing classroom furniture.

Standard 7 (integrated learning experiences)

Integrated learning experiences are implemented in courses across the curriculum. In IME mechanical engineering integrated learning experiences are called complementary activities. Complementary activities are usually performed outside of class time, whether provided for in the academic calendar, being compulsory or voluntary and developed individually or by groups of students.

The course curriculum highlights the inclusion of the themes of Professional Ethics and Human Rights in the Armed Forces, under the perspective of International Humanitarian Law, as well as the National Curriculum Guidelines for the Education of Ethnic-Racial Relations and for the Teaching of Afro-Brazilian and Indigenous History and Culture, through activities listed here, as well as subjects regularly included in the IME military training curriculum: Languages Project; Directed Study; Operation Ricardo Franco (ORF) in Amazon region; Integration IME industries event; Humanistic Vision Cycle; Technical Visits to Engineering Military Organizations; Technical Visits to Companies and Engineering Research Centers; Scientific Initiation; IME Action - community entrance exam project; Academic Engineering Competitions; IME student exchange; and Supervised Internship and Professional Practice.

Standards 8, 9, 10 (active learning and faculty enhancement)

The Military Institute of Engineering has been investing since 2015 in the preparation of faculty to apply active learning in their classes. There are currently several academic activities at IME where teachers explore various active learning methodologies in their classes. The active learning methodologies reported by these teachers are PBL, peer review, flipped classroom and jigsaw.

At the Military Institute of Engineering there is the Pedagogical Update and School Administration Internship (PUSAI). PUSAI was just an annual meeting to show new teachers IME standards and the functioning of the academic system. Experiences at Linköping University and KTH University have shown the need to change and make better use of PUSAI (Gunnarsson, Herbertsson, & Örman, 2019). In this way, it was created the opportunity for teachers to upgrade through the complete restructuring of the PUSAI. Contents were inserted for correct application of active learning methodologies (PBL, flipped classroom, etc.). Such methodologies provide students with experiences oriented to the development of skills and competences foreseen in the learning of the respective course. The restructuring of PUSAI has scope for all IME faculty and more meetings have been included in the institute's official academic calendar. There are currently about 12 meetings for PUSAI. At the restructured PUSAI there are lectures, workshops and hands-on teaching and motivating faculty to adopt best teaching practices and active learning in their classes.

Furthermore, the Military Institute of Engineering performs actions so that faculty can develop personal, interpersonal, product, process, and system building skills. Following are the main actions: Journey IME integration with Defense Segment Companies; and agreements and registrations with companies and educational institutions. The companies and IME are committed to leading and guiding the different end-of-course projects, proposing topics of mutual interest. This synergy has provided new learning experiences and the opportunity for faculty to guide work with real engineering problems by developing the competencies and skills constant at CDIO Syllabus.

Standard 11 (learning assessment)

Most IME courses were assessed by written tests, with a few exceptions. With the ideas of CDIO approach implementation, it occurred an adapt student assessment. The direction was the assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge. This way, the assessment methods were updated for the laboratory and design-build courses. The following IME evaluation standards have been updated: Internal Standards of Special Works, Internal Standards for Learning Measures and Internal Standards for the Assessment of Experimental Disciplines, were updated and adapted. Currently, at the time of assessment of laboratory and design-build courses, teachers fill out forms that assess the competencies and skills predicted in the learning outcomes of the course. This evolution provided more interesting works and aspects of student development that were not previously noticed in the Institute. There is a substantial improvement in the teaching-learning process with the change in assessment methodology and this process is still in development. This was beneficial for the mechanical engineering course.

Standard 12 (program evaluation)

IME has its own Institutional Evaluation Committee. The actions of this Committee are being restructured to get feedback from students, faculty, staff, program leaders, alumni, and other stakeholders to improve IME's academic activities based on the CDIO approach (Brodeur & Crawley, 2005).

To assess the current situation of the CDIO Initiative in the IME's mechanical engineering, a questionnaire was applied to the mechanical engineering course teachers (around 20 professors) to survey perceptions about the evolution of the implementation of actions related to the CDIO initiative. Figure 8 shows the result of this CDIO evolution in IME.

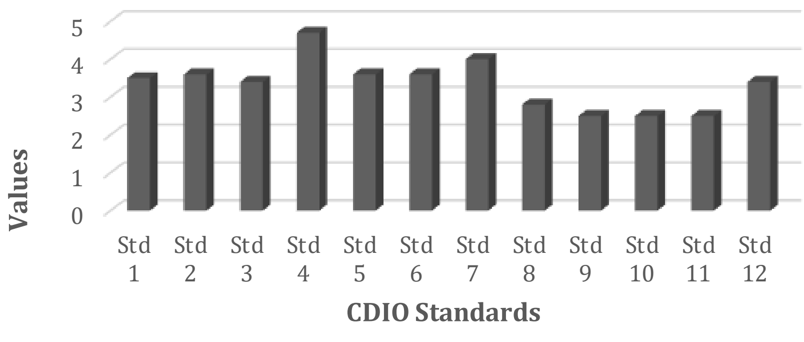

Figure 3. Shows the result of the CDIO evolution in IME's mechanical engineering.

The result in Figure 3 shows that the implementation of the CDIO approach in the mechanical engineering course at IME is progressing satisfactorily. It is perceived that there is a need to improve the preparation of teachers, which was hampered by the occurrence of the COVID-19 pandemic.

FINAL REMARKS

The application of the CDIO approach to the evolution of mechanical engineering teaching at IME was motivated by the Brazilian Army's project of innovation and entrepreneurship, by student feedback on the need for new teaching methodologies at the Institute, and by the need to adapt the pedagogical project course the new National Curriculum Guidelines. Following the CDIO Adoption Process Diagram, mechanical engineering course faculty have successfully implemented the CDIO Standards and transformed their engineering education. Feedback from faculty and students has been particularly good, with reports of classroom and laboratory improvements, different active learning practices, innovative assessment methods, and evident development of skills and competencies from the CDIO Syllabus.

Given the national academic recognition of the IME and the successful development of the CDIO implementation, there has been interest from other national educational institutions to include the CDIO approach in their respective pedagogical projects. IME faculty have been invited to give lectures and provide information about the CDIO Initiative and its implementation. Therefore, in this context of success and evolution of the teaching of mechanical engineering through the CDIO approach, the Military Institute of Engineering was accepted as a member institution of the CDIO Initiative in January 2020. In this context, the mechanical engineering of IME can contribute more effectively to improve engineering education at the Institute itself, in Brazil and in other countries around the world.

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SCHOOL-WIDE STRATEGIES FOR ASSESSMENT OF LEARNING DURING COVID-19 PANDEMIC

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ABSTRACT

Institutes of higher learning (IHL's) face unprecedented, restricted movement challenges during the COVID-19 pandemic. This paper describes how the School of Electrical and Electronic Engineering of Singapore Polytechnic undertook the re-design of teaching and learning practices and remote e-proctoring of assessments, in such an environment. The pandemic accelerated the switch to blended flipped learning, with all face-to-face lectures, replaced with asynchronous e-learning contents. A structured school-wide approach for teaching and learning to help both staff and students to adapt to the new learning environment was implemented. For Academic Year 2020/21, the School mounted large-scale e-proctored remote online assessments, with carefully considered measures to preserve academic integrity and rigour, to satisfy various stakeholders' needs. Semester 1 saw more than 100 staff, 2400 full-time and part-time students, and over 100 modules involved. In Semester 2, more than 400 full-time students and 31 modules were involved. Communication and training of the staff were carried out to prepare for the new way of assessment, and also to guide them to help their students for this. The use of a student response system (SRS) for diagnosing student learning of the asynchronous learning contents in-class was introduced. Survey findings show positive results generally, and these included real-time performance data analysis and immediate feedback, checking understanding, and appropriate learning interventions. Similarly, survey findings on the online assessments to engage students in their learning and progress are also shared. A comparison of the overall academic performance of students, pre-pandemic, against those conducted under the remote e-proctored conditions in the changed learning environment, suggests minimal impact. This paper concludes that SEEE's school-wide strategy supports the learning engagement of the students in the new teaching and learning practices, with the total switch to flipped learning for the diploma engineering courses it offers.

Assessment, Active learning, Diagnostic, Summative, E-proctoring, Standards 2, 8, 10, 11

INTRODUCTION

Since 2003, when SARS (severe respiratory syndrome) caused Singapore schools to close, annual home-based learning (HBL) exercises, typically of short duration, have been in place for the institutes of higher learning to prepare staff and students with online learning platforms for unforeseen closures (Goh, 2020). However the COVID-19 pandemic resulted in unprecedented prolonged campus closures.

Figure 1 illustrates the School of Electrical and Electronic Engineering's strategy to support student learning engagement that covers the learning management system for students to access the asynchronous learning contents, to the conduct of the synchronous lessons and practical, and finally, the assessments. This paper focusses on the areas highlighted (yellow), namely, the knowledge check and self-reflective quizzes, incorporated into the asynchronous learning contents, students' attempting self-reflective tutorials before the conduct of the synchronous tutorials and the exit polls at the end of such sessions, and those of the assessments which were conducted remotely with e-proctoring, after the series of synchronous lessons have been completed.

Specifically, knowledge checks are integral in all asynchronous learning contents to help students to be aware of their understanding in self-directed learning. Before the synchronous face-to-face (F2F) or online tutorials, they are expected to complete the topical self-reflective quizzes. During such sessions, the students, after facilitation by their lecturers to clarify their understanding and to seek deeper learning, will undertake to complete their tutorials. Before the lessons end, they will indicate their understanding through the exit polls as highlighted (Figure 1).

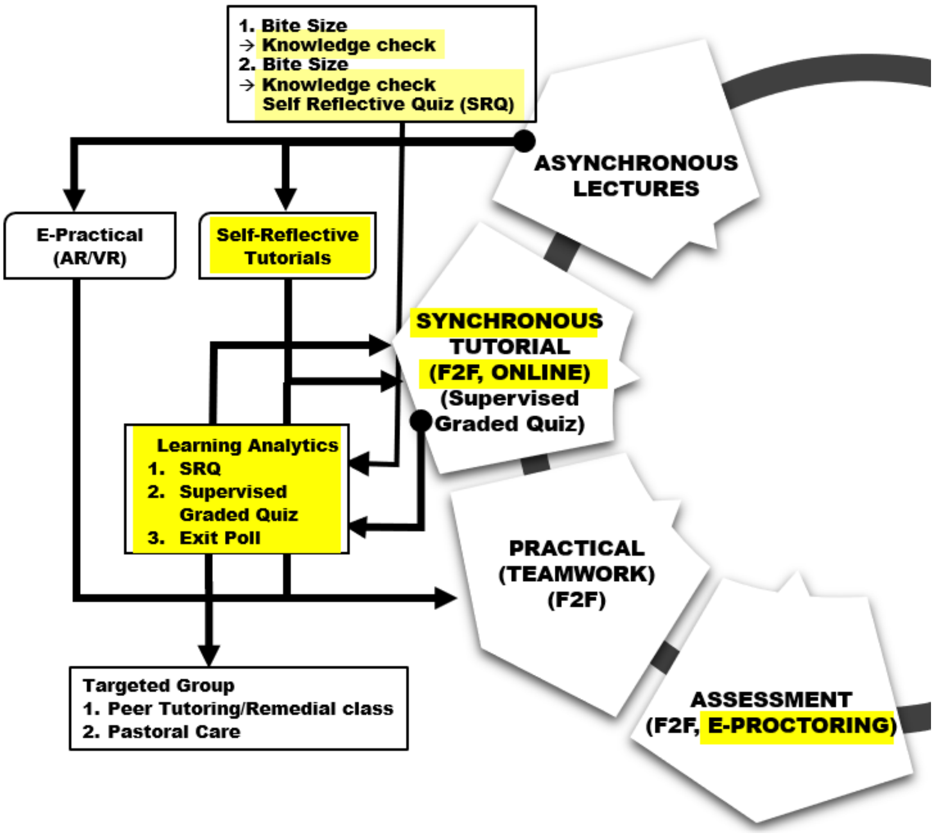

Figure 1. SEEE's School-wide Approach to Support Learning Engagement of Students

It is crucial that for such a large school, a consistent school-wide implementation on the expected teaching and learning practices, and also of assessments, in times of rapid changes such as during the pandemic, is in place. This is to ensure that both staff and students could be better eased, and cope with the new demands of the changed learning environment. Prior to that, all students were already doing flipped learning of at least one module per semester for all year of studies. The pandemic accelerated the switch, with all remaining modules previously delivered as face-to-face lectures, replaced by asynchronous lectures instead.

This paper seeks to determine at the school-level, whether the strategies were deployed effectively to engage students prior, during and at the end of the synchronous lessons. The School forged ahead to stage remote e-proctored online assessments for the mid-semester test in June 2020 during campus closure. Students' views on their learning and experience with the first-ever implementation of remote e-proctored online assessments were sought, and an analysis on the impact of the academic achievement of the students were also carried out.

Diagnostic Assessment as Part of Structured Teaching and Learning (T&L) Approach

With the school-wide approach for teaching and learning described, co-ordinated efforts were in place to ensure that baseline requirements on the quality of teaching and learning were met. With the above school pedagogic approach, diagnostic and formative assessments are even more important to provide real-time learning data to help students concretise the learning, and make connections across the different lessons and make learning progress in this holistic learning approach. This is aligned to CDIO Standard 11: Learning Assessment, which states that "assessment of learning serves to measure the extent to which students achieve intended learning outcomes within their respective courses" especially in "concepts and competencies … described in Standards 2, 3 and 7". Diagnostic assessment contributes to the variety of learning assessment methods to derive learning data that can inform how students are engaged in active (and self-directed) learning and examine the learning progress so as to apply learning design interventions and provide feedback for learning (CDIO Standard 8).

Remote E-Proctored Online Assessments as Part of Summative Assessments

Assessments are conducted to ensure the quality of the curriculum design and delivery (Standard 11). Without any precedent to guide on staging summative assessments in the previous HBL exercises, the School in June 2020 mounted school-wide remote e-proctored online assessments, a possible first on such a large scale in campus. This could not possibly replicate perfectly the usual conditions under the strict in-person, closed-book, written assessments conducted on campus. Measures were taken to ensure minimal compromise on the necessary academic integrity and rigour. More than 100 staff, 2400 full-time and 500 part-time students, and over 100 modules were involved for the mid-semester test (MST) conducted. For the following semester, half of the year 3 cohort, who were previously on their internship in industry in Semester 1, also sat for similar remote e-proctored mid-semester tests. More than 400 full-time Year 3 students and 31 modules were involved. This was aimed to achieve some degree of equity, which is defined as based on the equal treatment for all (National Research Council, 2012), on two aspects. Firstly, in terms of the student learning experience in the form of e-proctored online MSTs. Secondly, as these were deliberately conducted open book, this ensured the whole Year 3 cohort would be assessed on online assessments, with fairly similar academic challenge.

LITERATURE REVIEW

Diagnostic Assessment in Flipped Learning

In many flipped learning models, assessment (for learning) plays a critical role in learning progression. Following the self-paced learning of the asynchronous learning contents, the first stage in the synchronous lessons, F2F or online, would be to guide the students to assess their understanding of prior learning, examine misconceptions and clarify their learning, before engaging in activities for deeper learning and progressing to other performance tasks. Typical assessment activities for such sessions would include quizzes, summaries, discussion forums and reflections, videos, and peer feedback to these assessment artefacts.

Such activities are critical to help learners make connections with concepts previously learnt online and prepare them for further learning, as well as to emphasise to learners, the importance of active engagement and participation in synchronous learning activities. Results and observations from such diagnostic assessments would provide quantitative and qualitative data to the lecturers/facilitators and enable them to target learning interventions to different students, as well as build self-regulation, learning confidence and efficacy, learner motivation and control, by means of giving and receiving more immediate feedback about their learning (Hostt et al., 2020; Roach, 2014; Shyr & Chen, 2017; Treagust, 2006; Triantafyllou, 2015).

Online Assessments – E-proctoring and Design

Maintaining academic integrity is both key and a challenge when implementing any assessments, conducted online or otherwise. A definition offered on academic integrity is *'the expectation that teachers, students, researchers and all members of the academic community act with honesty, trust, fairness, respect and responsibility" (TEQSA).* Supervision is thus critical, typically in-person, and with students on campus, being overseen by invigilators or proctors. In the absence of such supervision, assessments rely on an honour system that expects students to uphold that they have attempted honestly, without the help of others or through unfair means.

For online assessments, educational institutions may resort to commercial online electronic or e-proctoring tools which may also be AI-enabled to analyse students' movements and their surroundings. Factors that deter such use may include cost, possible technical challenges and close monitoring, which are necessarily intrusive (Milone, Cortese, Balestrieri, & Pittenger, 2017). Such intrusion has been argued as possibly giving rise to test anxiety that may affect exam performance, although this effect is not well known (Woldeab & Brothen, 2019).

The workgroup for Singapore's five polytechnics and the Institute of Education (ITE) suggests that e-proctoring or remote invigilation as one that is "… *conducted remotely and online using Information and Communications technology (ICT). This includes single-camera views of students' faces, upper bodies and sufficient working/assessment area to ensure students do not receive unauthorised assistance during the duration of the E-Exam, E-Test, or Oral, Viva, or Performance Test*". This is also described as webcam-monitored exams using live proctors, termed web-based proctor and defined as "*one who utilizes a webcam for video surveillance to observe users and their environment during the online exam session."* (Hylton, Levy, & Dringus, 2015).

Video conferencing platforms, in addition to surveillance, also allow the assessment proceedings to be recorded. The set-up is relatively easy, affordable and is adaptable to most educational settings, thus eliminating the need for online proctoring providers (Tan, 2020). Another reason for deploying e-proctored online assessment is the need to authenticate students' identities, although this is somewhat a challenge (Hylton, Levy, & Dringus, 2015). However, in the School, as the staff perform this role, students accept and are accustomed to the practice as a necessary requirement in order to deter cheating by impersonation, and helps confidence in the integrity of the assessments.

To further deter cheating, features such as open-book, duration-limited, no back-tracking, randomised questions and answers, and the use of question banks (Budhai, 2020) (Weleschuk, Dyjur, & Kelly, 2019) (Shamo & Alford, 2021) are incorporated as part of the online assessments. Although students could refer to resources like books and the Internet, they need to declare the integrity of their attempts. Stern instructional warnings on the consequences of cheating were also included (Vasquez, Chiang, & Sarmiento-Barbieri, 2021). The use of a custom lockdown browser to prevent students from opening other applications or web pages was also considered but was not included in the initial implementation stages, given the overwhelming changes to be undertaken. However, the School has further fine-tuned the remote e-proctoring process to include the use of the lockdown browser as well.

SCHOOL-WIDE STRATEGIES – STAGING AND IMPLEMENTATION

Figure 2 shows the timeline of the key stages of the school-wide structured teaching and learning approach during the two-semester-long academic year. Throughout the semester, teaching staff during the synchronous lessons, discern student learning engagement of the flipped learning contents. This is by monitoring students' completion of the self-reflective quizzes before these lessons. Through students' attempts of the regular weekly bite-sized online quizzes, staff can further ascertain their understanding and learning as they progress through the weeks.

Classes are assigned one of their module lecturers as their personal tutors, who also look into the students' pastoral care and well-being. Through these interactions, personal tutors are thus able to check on their students' overall well-being to cope with the demands of a changed learning environment. During the term, the lecturers also receive training on the procedures of the remote e-proctored online assessments to prepare themselves as well as their students.

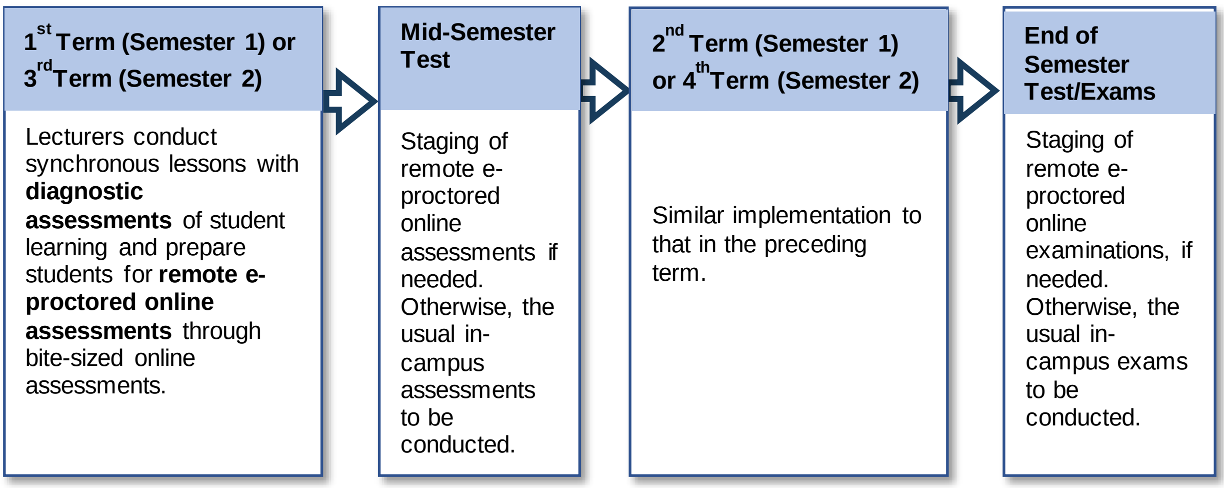

Figure 2. Timeline of Key Stages of Implementation

Diagnostic Assessment

To guide teaching staff for the long term, a structured teaching and learning approach is provided. This helps to establish the quality of effective learning as students move from asynchronous e-learning to synchronous online or F2F sessions. As previously mentioned, all asynchronous learning contents include appropriate knowledge checks that students are expected to complete before proceeding to the subsequent learning contents. This is further supplemented with self-reflective quizzes to enable teaching staff to know if students have learnt with understanding through being able to answer relevant questions correctly.

An in-class student response system (SRS), called ClassPoint, for diagnostic assessment purposes during synchronous lessons was also introduced. It allows teaching staff to include questions as part of the PowerPoint slides they typically deploy during such lessons, on the fly, if needed. This enables them to obtain their students' responses as part of the slides, without switching to other web-based student response platforms. Easy to use, with display of real-time live responses for performance drill-down (to individual students) as part of the slides, they can do in-situ performance analysis, immediate feedback and just-in-time learning interventions. The teaching staff can thus assess their students' prior learning, draw out their misconceptions and help them to clarify learning before deeper learning.

With the pilot run completed in semester 1 of the academic year 2020/21, the School streamlined the use of ClassPoint for diagnostic assessment for synchronous lessons. Enhancements and refinements to the facilitation approach were made and a structured process for the approach, applicable to all modules, help to guide staff. This was to enhance faculty competence in providing integrated and active learning experiences and learning assessment (CDIO Standard 10). For the following semester, close to 2700 students (full-time and part-time), for 88 modules facilitated by 112 staff were involved in the deployment.

The School aimed to achieve the following outcomes with the deployment:-

- To encourage staff to design effective and engaging synchronous lessons
- To prod staff and students along new ways of effective learning
- To promote diagnostic and formative assessment in day-to-day lessons
- To identify and support weaker students at a lesson level and provide early interventions
- To promote the use of real-time learning data for timely assessment for learning and learning interventions
- To ensure that students are prepared for and are engaged in deep learning before and during lessons

Figure 3 shows the structured teaching and learning approach for diagnostic assessment with ClassPoint for synchronous lessons to guide teaching staff. This is needed to ensure that staff who have not already previously conducted any flipped synchronous lessons are implementing consistent facilitation practices for all the students as part of their lessons.

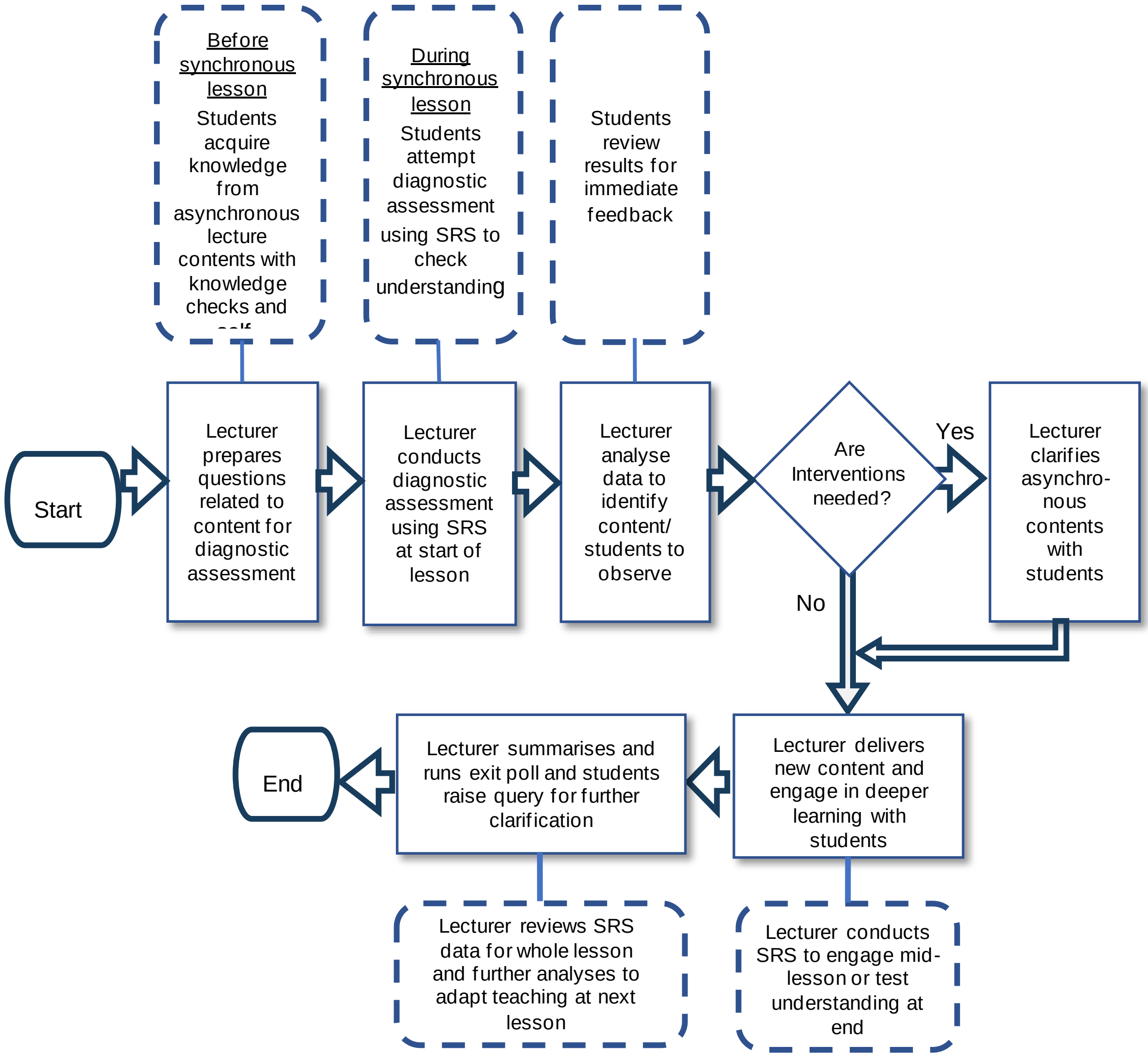

Figure 3. Structured Approach for Diagnostic Assessment for Synchronous Lessons

E-proctored Online Assessment

Figure 4 shows the set-up of the remote e-proctored online assessment. Students are expected to be at their homes. Each requires a laptop with camera, smartphone, reliable network access and a quiet conducive environment. Zoom is used as the virtual space.

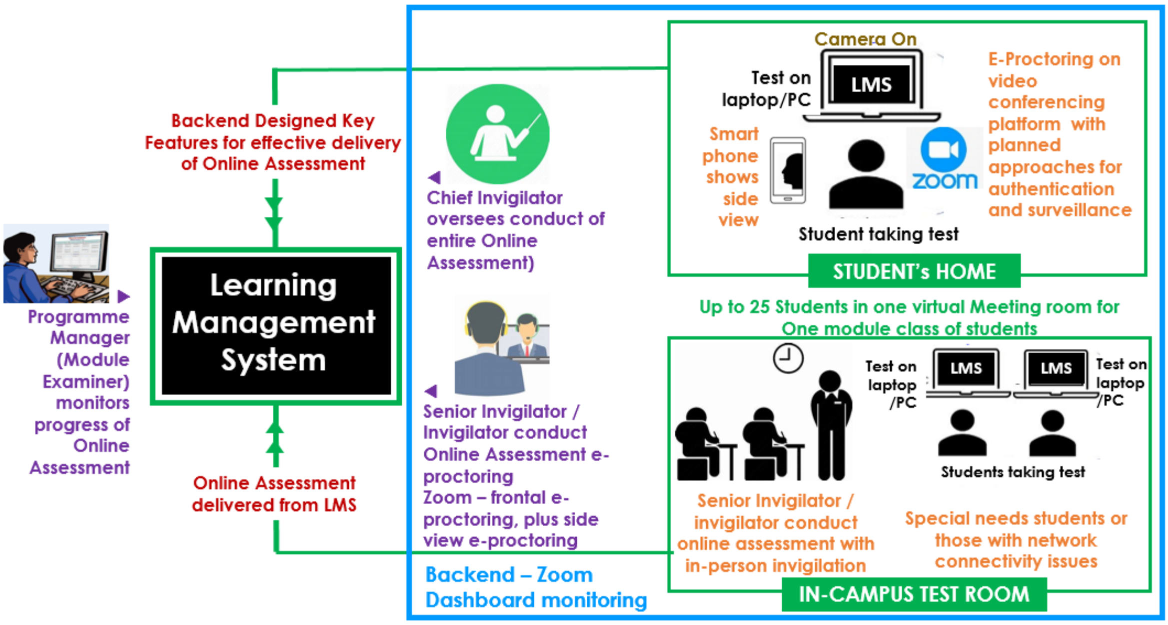

Figure 4. Overall System Set-up of the E-proctored Online Assessment

For the initial online assessments, personal tutors prepared their tutees. That entailed coaching them, looking into whether they had the necessary laptops, devices and smartphones and stable home Wi-Fi access. They also watched out for students with special educational needs, or those who could be uncomfortable with the demands of remote e-proctoring. As they also served as invigilators for their tutees, it was easier to verify students' identities and assure them, which helped to reduce student anxiety, thus smoothing the implementation.

Two staff; a senior invigilator and invigilator preside in the virtual meeting, with the former observing students' laptop camera views in the main meeting, and the latter presides over the smartphone views in the breakout room. This helps ensure that there will always be one invigilator if the other invigilator cannot do so, due to a drop in internet access or for other reasons. Each invigilator screen records the proceedings that can serve as reference for any possible incident follow up.

All IHL's aim to conduct fair and secure assessments of unquestionable academic integrity with a regiment of standard operating procedures (SOPs) and protocol for consistent implementation. Similarly, the students were issued guidelines as "must-reads" to prepare them to abide by the requirements for the e-proctored online assessments (Jeffries, et al., 2017). Common challenges associated with the use of e-proctored online assessments include the following: measures of redress for students when the technology fails and default steps students should take when the Internet fails. These measures were part of the standard announcement made by the senior invigilators before the start of the online assessments, and were similar to the polytechnic's expected SOPs before the start of any in-campus exams.

RESULTS AND DISCUSSIONS

For the conduct of synchronous lessons as part of the flipped learning, the survey aimed to determine the following:

- Staff implementation of the diagnostic assessment to improve student learning

- The frequency of SRS usage for the conduct of their synchronous lessons
- The extent of students' motivation to prepare prior to the synchronous lessons
- Students' views of the use of the SRS in the synchronous lessons

For the remote e-proctored online assessments, the survey aimed to find out students' views on these, vis a vis their learning engagement, and sought their views on what they like and dislike about the implementation.

Survey findings of Diagnostic Assessment in Flipped Learning

These surveys were conducted in early 2021. The implementation of the structured approach meant that staff would need to consciously and deliberately re-design their F2F and synchronous online lessons, creating space and time in each lesson for this, analyse and interpret learning data real-time, apply immediate learning interventions and observe the effects of the approach. The design considerations and staff sentiments on the structured approach, as well as students' learning experience and sentiments were surveyed.

It was found that the broad intents of the structured approach for diagnostic assessment to support flipped learning, after students have acquired knowledge through asynchronous lectures, were largely met. Staff reported that they have used the SRS as intended in all synchronous sessions which followed asynchronous lectures: 85.1% of F2F tutorials, 9.5% of synchronous online tutorials and 5.4% of practical. 65.5% of staff reported using the SRS at the start, and during the lesson, for diagnostic and formative assessment purposes. This is for them to assess students on prior learning of asynchronous contents and engage students during lessons and to assess deeper concepts taught/learnt.

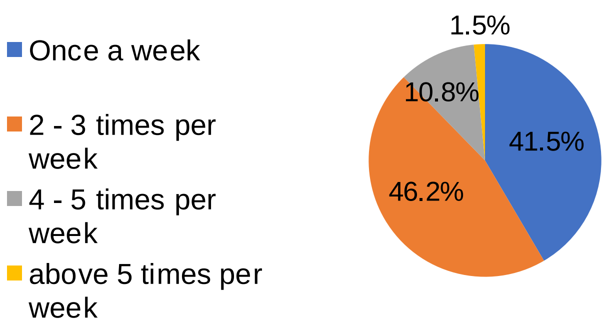

Figure 5. Frequency of ClassPoint Activities (per week)

It was observed that 87.7% of staff used the SRS one to three times a week. This corresponds with the use of SRS approach for the intended diagnostic assessment for tutorials minimally, and the occasional use of the approach for formative assessment purposes and other lesson types, i.e. practical, as shown in Figure 5.

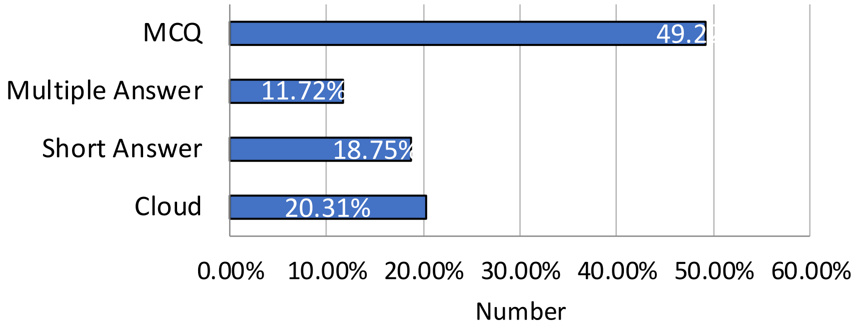

Figure 6. Types of ClassPoint Questions / Activity

As observed in Figure 6, staff explored the features of the SRS through the use of a variety of question types and activities to engage learners, ranging from objective questions like multiple-choice questions and multiple answer questions, which would facilitate quick compilation of live responses for real-time analysis of learning/performance data, to qualitative activities such as short answer questions and word cloud activities which would allow for deeper reflections and discussions.

The inference that staff were competent to adopt the structured approach efficiently was by means of examining time spent to design and conduct, and their sentiments on ease of use. The data was further analysed to determine staff's sentiments on various benefit statements. Responses (Fully Agree and Agree) to each of the benefit statement was compiled, ranked and normalized within each statement's using the % of responses as the base (Figure 7) to determine the extent of positive (Fully Agree & Agree) and negative Sentiments (Fully Disagree & Disagree) in each statement.

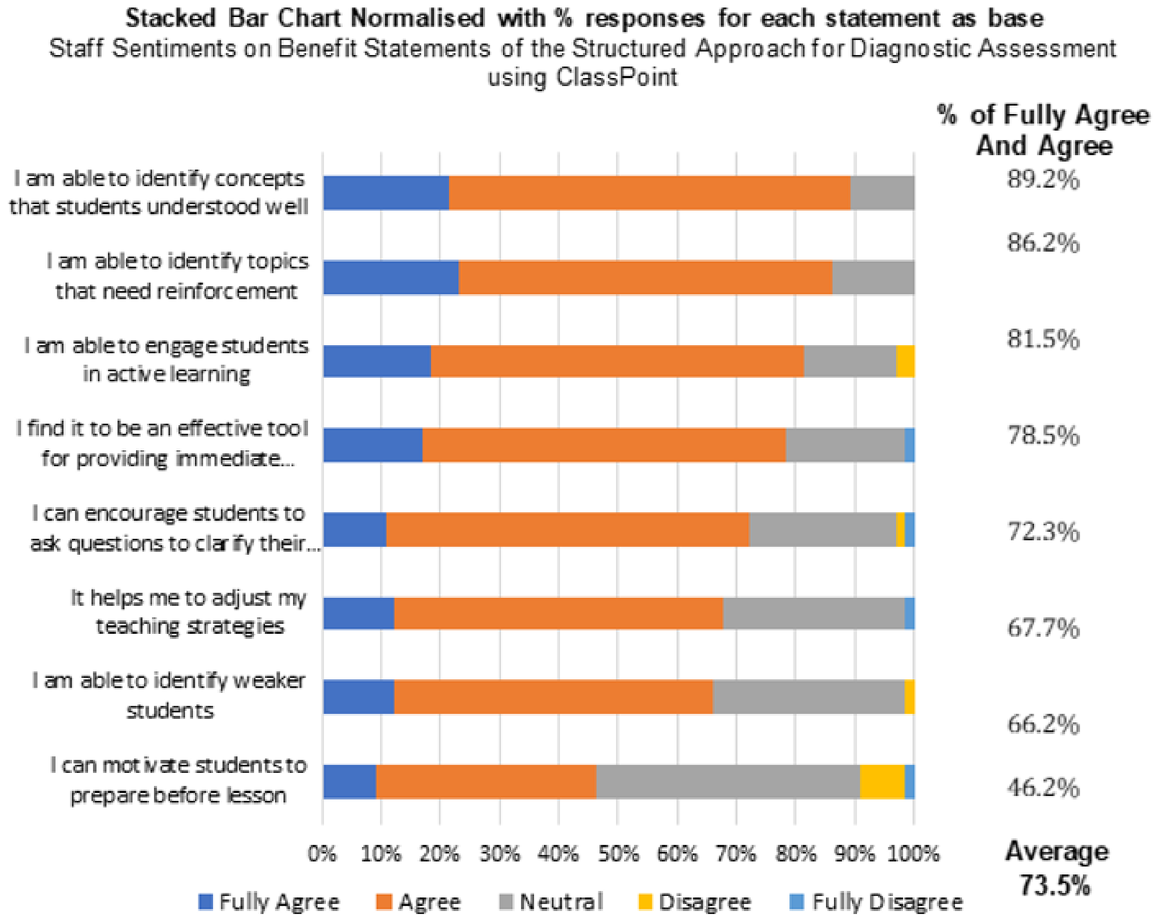

Figure 7. Staff Sentiments towards benefit statements

The top ranked benefits statements (sentiments of 75% and above) were aligned to the intended objectives of the structured approach for diagnostic assessment in tutorials (or practical) using an SRS that provided real-time learning data for adjusting learning interventions.

The students' sentiments towards the various benefit statements are compiled in Figure 8. The top two benefit statements with higher positive sentiments (Fully Agree & Agree) were aligned to the intended objectives of the deployment, which was to support student learning through diagnostic assessment. Namely, this is to check their understanding of pre-lesson learning and providing immediate/real-time feedback. It was observed that students most valued the ability to obtain immediate feedback on their learning using ClassPoint, with 77.3% of respondents providing positive sentiments (Figure 8). The overall percentage responses with positive sentiments for the benefit statements for students was an average of 65.6%, as compared to that of staff of 73.5%.

Discounting staff ambivalent "Neutral" responses, the lower ranked statements with higher negative sentiments (Disagree & Fully Disagree) were related to the theme of motivation, namely, motivating/encouraging students to prepare ahead of lesson and ask questions to clarify understanding. These were triangulated against findings from the student survey data, which revealed that motivation also ranked lower. Consistent with the observation from the staff survey data, the items on motivation to prepare ahead of lesson and raise queries, for students are at 57.1% and 51.6% respectively.

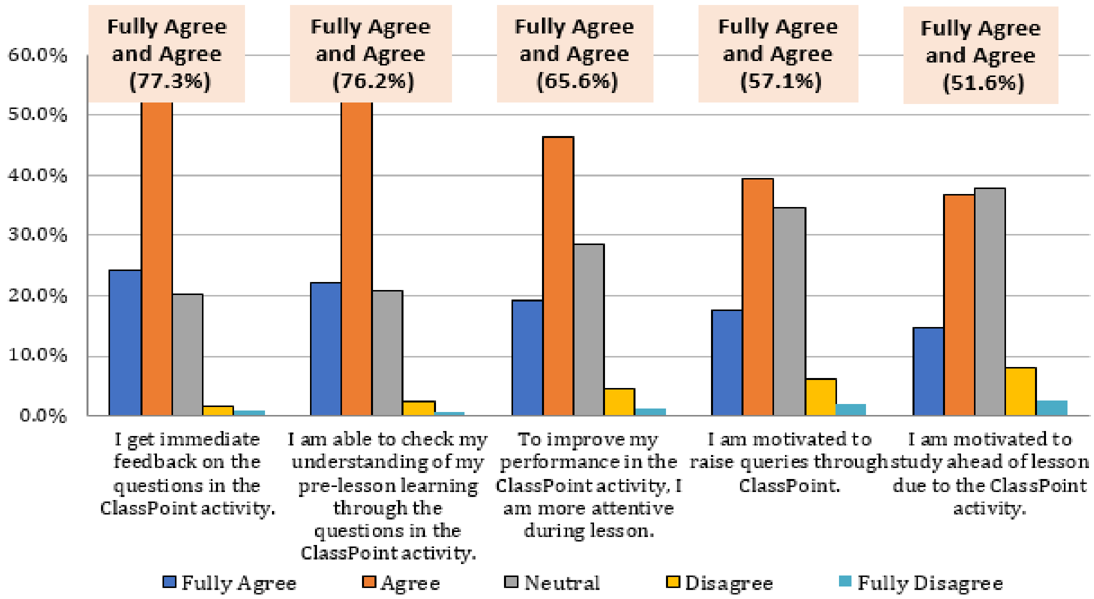

Figure 8. Students' Sentiments towards benefit statements - % Responses on Likert Scale

As this approach was still in the early stage of implementation against the background of tremendous changes occurring simultaneously, the results obtained were deemed remarkable. Still, on-going efforts are in place to help students to be more engaged to seek clarification in synchronous sessions, and to help students to understand the purpose of their learning and to be motivated to prepare ahead of such sessions.

For an approach to have pedagogical impact, it should be regular and pervasive. The School's teaching and learning team further studied if too much of an assessment load, whether diagnostic, formative or summative assessment, could be demanding cognitively on the students. To manage any negative sentiments, the team also explored if there was a "sweet spot" on the frequency of diagnostic assessment using ClassPoint against the sentiments towards the benefit statements.

Table 1. Students' Positive Sentiments on Benefits vs Frequency of ClassPoint Activity

Benefit statements against % of Positive Sentiments	**Once a week**	**2 - 5 times per week**	**6 - 10 times per week**	**Above 10 times per week**
Average (% of Positive Sentiments)	68.4%	68.9%	87.9%	86.1%

It was observed that students who have encountered ClassPoint 6 to 10 times per week selected more positive responses towards the various benefit statements (average of positive response - 87.9%). For 6 to 10 encounters with ClassPoint weekly, it was likely that ClassPoint was used not just for diagnostic assessments, but also for formative assessment and engagement for active learning.

Remote E-proctored Online Assessments

From the student survey in semester 1 of the academic year 2020/21 conducted to gauge students' views of the remote e-proctored online assessments (Figure 9), the majority of students strongly agree or agree that the online assessments engage them in their learning, and help them to know how well they have learnt (strongly agree from 26.3% to 28.7% and agree from 61.2% to 59.8%). On the statement that doing preparatory small-stakes online quizzes (termed as "cFA") prepare them for the online assessment (termed as "cMST"), the majority of the students agreed (strongly agree- 23.4% and 59.8% agree). The results suggest that the School has prepared the students well for the online assessments.

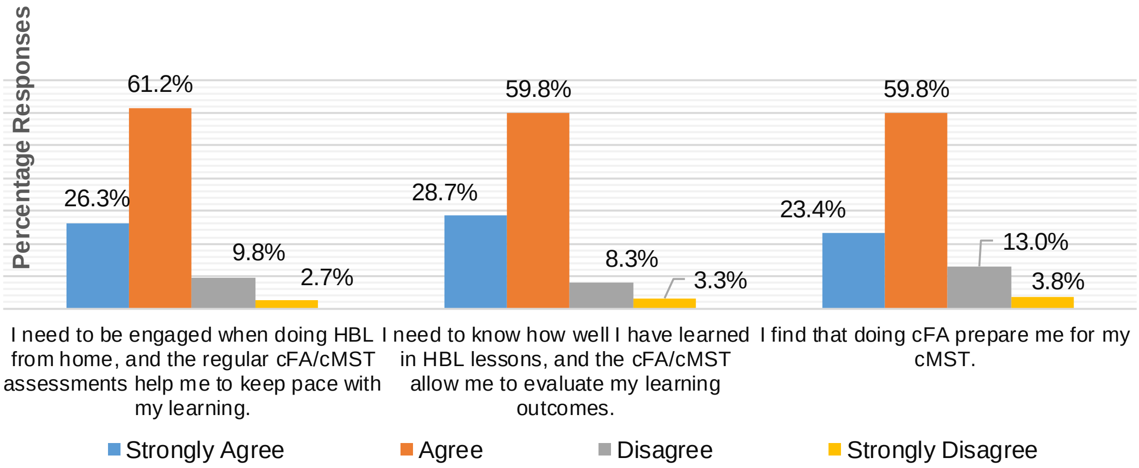

Figure 9. Students views of online assessments vis a vis their engagement in learning, learning outcome evaluation and online assessment preparation

The survey also included three open-ended questions on what students like or dislike about the online assessments, and what could have been done better for the online assessment to help their home-based learning. The five favourable factors ranked by students from the highest to the lowest were: open-book online assessment, convenience, helpful in learning engagement, motivation to study and the experience was not stressful. The results were as expected. For instance, students appreciated the open-book feature as they were able to refer and look up for information. Being at home was convenient without the need to be in campus for the online assessment. They were motivated to learn as they needed to prepare for the online assessment.

Students cited lack of time, no backtracking of questions, the need to upload images of their hand-written solutions, stress and connectivity issues as their top five dislikes. As expected, lack of time was a top grudge for students for all assessments. The need for no backtracking was perhaps not fully appreciated by students. This feature was incorporated so that there was a degree of authenticity of student assessment, as it tested the student's ability to apply learnt knowledge at that point in time. The upload requirements similarly were needed to provide solutions to questions which were based on higher order thinking skills, which could not be adequately assessed perhaps through multiple-choice questions alone. As expected, the responses received for the third open-ended question were mostly suggestions to address what were the top-ranked dislikes, such as asking for more time, to allow for backtracking and to not have uploads of images of solutions.
Overall, it could be summarised that students had positive views of the online assessments and appreciated how these helped them to be engaged and also to gauge their learning. This

also pointed how the School was able to stage the remote e-proctored online assessments and prepare the students for a different form off assessments.

Students' Overall Academic Performance – Observations and Comparison

A key concern that the School has, possibly shared by other IHL's as well, is whether the overall academic performance of students are affected by the switch to full flipped learning for all modules previously conducted through face-to-face lectures. Measures were put in place to guide staff to help students in their self-directed learning through knowledge checks and self-reflective quizzes, while teaching staff facilitated students' learning during synchronous sessions. The entire school had experienced the remote e-proctored online assessments conducted in place of the usual mid-semester test for the academic year of 2020/21.

The School noted that despite these changes, the overall academic performance passing rates of the students do not show any significant variations, before the full switch to flipped learning, and after the switch to full flipped learning, coupled with the implementation of the remote e-proctored online assessments. This suggests negligible impact on the students' academic performances, attributed to the well-executed implementation of the school-wide teaching and learning strategies.

CONCLUSION

Key stages of the structured teaching and learning approach to support the fully flipped learning environment and remote e-proctored online assessments were drawn up. The school-wide strategies for the re-design of teaching and learning practices, from the incorporation of knowledge checks in the asynchronous learning contents, to students' attempts of self-reflective quizzes and tutorials and the use of an in-class student response system to further help student learning, has been deployed by the School to facilitate student learning through diagnostic assessment. The benefits of deploying the student response system for diagnostic assessment - giving staff and students real-time performance data analysis and immediate feedback, helping to check understanding to determine areas learnt well, areas needing reinforcement and to adjust learning interventions, are generally positively received.

The School was able to mount large-scale remote e-proctored online assessments for both semesters of the academic year 2020/21. The set up was designed to replicate to some extent, similar requirements and roles to those of tests conducted in-person on-campus that the staff and students were already familiar with. However, this also required innovative re-thinking for the transformation of the usual assessment procedures and processes to ensure both staff and students were prepared adequately for a different form of assessment. The experience garnered from staging two rounds of remote e-proctored online assessments on a large scale put the School in good stead should there be a need to implement similar assessments at a short notice in future. Going forward, further work will be required should the e-proctored online assessments continue, given the migration to a new learning management system in April 2022.

In the initial stages of the capricious climate of the pandemic, the overarching driving goal was ensuring that the learning engagement of students was not compromised, however the tide might turn under such unprecedented conditions. All the necessary effort and work invested by the School to ensure this has paid off. With the benefit of hindsight, the School is confident that both staff and students are prepared for the challenges in the new norm in the teaching and learning landscape. Overall, the School has been able to deploy school-wide strategies for delivery of its engineering diploma courses that engage students in their learning.

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BIOGRAPHICAL INFORMATION

Ser Khoon Toh: is the Director, SEEE, SP. Under his leadership, the School continues to be a strong advocator and practitioner for CDIO, Design Thinking and FabLab-based curriculum for the Engineering diploma programmes. His current focus is on nurturing and preparing learners to be self-directed and work-life and world-ready. In the area of teaching innovation, the emphasis is on Edutech use and applying learning analytics for engineering education.

Chow Leong Chia: is a Deputy Director at SEEE, SP. His current portfolio is in Course Management and Student Development. He oversees the planning, development and implementation of full-time courses and continuing education & training (CET) courses in his school. He has a strong interest in conducting action research to enhances students' learning and strengthen staff pedagogical competence. He also plans programmes to nurture students and develop them to become self-directed learners.

Safura Anwar: has been teaching in Singapore Polytechnic since 1986. After serving in various portfolios, she presently leads a team of highly experienced and dedicated staff in SEEE's Teaching Innovation Unit who share a common passion to work with colleagues and students alike, so that they become better self-directed learners in all aspects in their own capacities.

Andy Ngai: is an Academic Mentor at SEEE, SP and has been with SP since 1998. His key area of focus is on the use of Edutech tools for effective and engaging teaching and learning. Interested in programming and applying data (learning) analytics to help colleagues to better design learning interventions and to support students requiring more help, he also encourages students in evaluating their own learning process and become better self-directed learners.

Hua Joo Tan: joined SP in 1991, serving in various portfolios such as Academic Resource & Development Manager, Course Manager and Head of Teaching & Learning (T&L) Unit. His interest is in T&L matters, particularly in nurturing and developing students to become independent learners. He is also passionate about using Edutech tools in his teaching to help the students in their learning.

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PASSION AND CHOICES IN ENGINEERING EDUCATION THROUGH MULTIPLE PATHWAYS

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ABSTRACT

Students with diverse academic abilities, interest and inclination are studying engineering courses. CDIO Standard 2 defines learning outcomes codified in CDIO Syllabus 2.0 (CDIO 2020) to train competent graduate engineers. Effective training requires curriculum that integrates different components defined in CDIO Standards. A linear "one-size-fits-all" approach where all students go through same curriculum throughout entire course of study is likened them travelling on a single-lane in a tunnel with one entrance and exit. Such learning does not meet aspirations of some students. This paper describes how the School of Electrical and Electronic Engineering of Singapore Polytechnic (SEEE) embarked on the design of curriculum with multiple pathways that give students choices to pursue learning that matches their interests and abilities. The innovative curriculum stretches students' limits to learn beyond traditional lecture and tutorial, extends learning outside the confine of laboratory and campus, and raises learning beyond the standard curriculum. Students take modules in their chosen pathway in lieu of standard modules. All pathways have the same objective to nurture competent graduates by the end of the 3-year study. In essence, engineering education is enhanced and students are stretched to their maximum potential to become competent, versatile and self-directed engineers ready for 21st century workforce.

KEYWORDS

Learning Outcome, Multiple Pathways, Passion, Choice, Agile, Collaboration, Experiential, Integrated Learning, CDIO Standards: 1, 2, 3, 6, 7

BACKGROUND

Singapore Polytechnic is a government-funded tertiary institution with 10 academic Schools. SEEE admits full-time students who are from 17 to 20 years old to do a 3-year course in one of the four Diplomas, in Aerospace Electronics, Computer Engineering, Electrical and Electronic Engineering, and Engineering with Business. Our mission is to prepare learners to be life, work and world ready. Our vision is to develop students to be inspired learners who are purposeful, motivated and self-directed ("SP Mission & Vision", 2021).

SEEE's full-time enrolment is around 800 each year and comprises of students with very different abilities and entry qualifications. Majority gain admission with the General Cambridge Examination (GCE) Ordinary Level ('O') Certificate based on "ELR2B2" aggregate score of grades in **E**nglish **L**anguage, two **R**elevant subjects and two **B**est subjects. The subject grade ranges from 1 to 9 with a smaller number better than a larger one. The ELR2B2 score ranges widely from 5 to 26 points for our students. Other qualifications like General Cambridge Examination (GCE) Normal Level ('N') Certificate, and the National Industrial Technical

Certificate (NITEC) and Higher National Industrial Technical Certificate (HNITEC) which are awarded by Singapore's Institute of Technical Education (ITE), as well as foreign qualifications attained by international students are also considered for admission. Such diverse students' abilities call for a curriculum that offers multiple pathways where students could choose a programme that best matches their learning needs.

SP EDUCATION MODEL

The SP Education Model is depicted in Figure 1. Underpinning our education is the curriculum for applied and professional training. SP's course curriculum comprises of three components, namely Domain, Common Core and Choice. Domain consists of modules directly relate to the discipline of study. For example, a domain module in Diploma in Aerospace Electronics is Aircraft Communication & Navigation. Common Core modules are those pertaining to cross-industry and cross-domain human and digital skills and are taken by all SP students from all courses. The Choice space offers students the opportunities to take modules which are aligned to their interest and learning needs. It is for this purpose that the framework of multiple pathways is conceived where each pathway has a unique curriculum specially curated to match the different learners' passions and abilities.

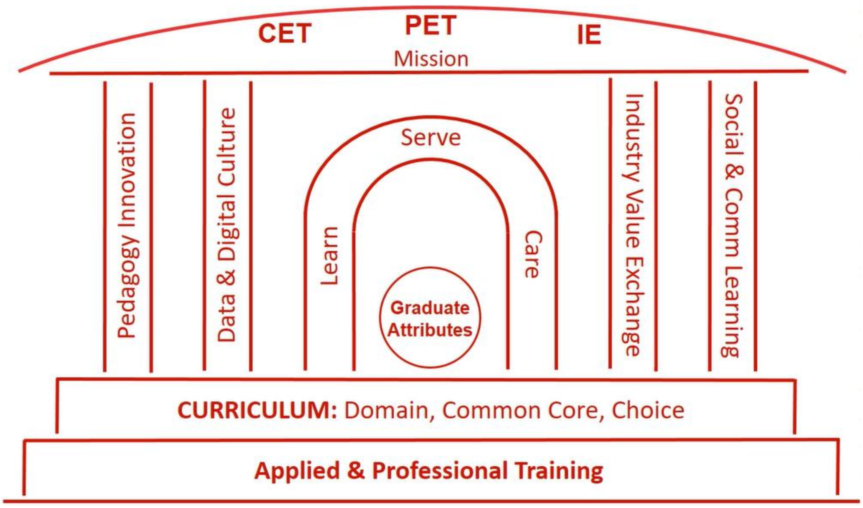


Figure 1. SP Education Model

CURRICULUM DESIGN FOR MULTIPLE PATHWAYS – PROVIDING CHOICES

There are problems in adopting a linear "one-size-fits-all" curriculum where all students in the same course take the same set of modules throughout the 3 years of study. These students have very diverse academic abilities, motivation and aspiration with the high ability ones potentially feel deprived from challenges if they do the standard structured curriculum (Reis and Renzulli, 2010) while academically weak students would find it difficult to cope. There is a need to motivate students to master learning tasks and achieve goals through differentiated and targeted approaches (Tomlinson 2014).

Today's education allows collaboration by different stakeholders to create multiple pathways to deliver learning. A framework to conceive and design curriculum with multiple pathways that enhance experience and meet aspiration of Gen Z students who often seek more personalised and experiential learning (Schwieger and Ladwig, 2018) is needed. In particular, learning does not only take place in campus, but rather, students could acquire skills and knowledge from a variety of platforms and sites (Marsh 2009). The School has developed an innovative framework called ***ACE*** (which stands for ***A***gile, ***C***ollaborative and ***E***xperiential) for designing multiple pathways. Each pathway is constructed within the Choice space of a specific diploma course. Figure 2 shows the main course curriculum with five available pathways.

Each pathway is curated with ***agility*** in term of course construct and contents. Students in their chosen pathway do not always follow the same sequence or contents taken by the majority of students in the same course. Learning in each pathway is specially conceived and curated to ensure academic rigour is maintained and students' workload is comparable to those doing the standard curriculum. CDIO Standard 2 is applied to align curriculum and learning outcomes with institution's vision and mission, and course's aims. Students are equipped with the required knowledge and skills to be competent engineers by the end of the course regardless of which pathways they are in. Flexibility is key if students are to be given choices of different learning approaches that best meet their learning needs, abilities and passions.

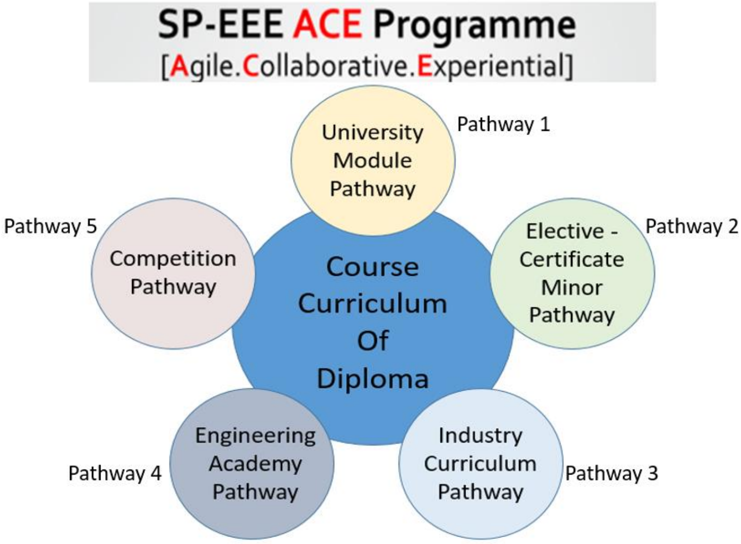


Figure 2. SEEE ACE Framework for Multiple Pathways

Pathways are curated ***collaboratively*** with partners from the industry, universities and relevant organisations that offers learning of engineering skills. Learning is not solely delivered by academic staff as partners' capabilities and resources are tapped to equip students with relevant skills and knowledge contextualised to the platform in which learning takes place.

Finally, unlike in traditional lecture, tutorial and laboratory lessons, students learn and explore new knowledge and skills in highly varied and ***experiential*** environments. Some get to experience university life by reading university-level modules with classmates who are a few years their senior. Others take up year-long attachment to research agencies or organisations to explore emerging technologies such as Robotics, Cybersecurity, and Artificial Intelligence of Things in projects. Others are coached by experts in selected fields of engineering such as Industrial Control, IT Networks or Rapid Transit System to participate in competitions at national and international levels such as the World Skills Competition, which allow talented students to showcase not only their skills but also to develop resilience as they out-wit, out-perform and out-last competitors from countries all around the world.

Students are briefed on the different pathways at the beginning of their courses. Majority are placed in the "normal pathway" where they take modules in the standard structured curriculum. Suitably qualified students could apply to different pathways that interest them and meet their personal goal and aspiration. Selection of students is carried out through a rigorous process.

SEEE aims to develop students to be inspired learners who are equipped with strong competences and imbued with values such as self-directedness, intrinsic motivation, growth mind-set, and versatility. SEEE recognises both the hidden and revealed potentials of the students and its commitment to nurture them is etched in the School's motto which states "Nurturing Curious Minds, Producing Passionate Engineers – From Potential to Fulfilment". This contextualises the training to produce skilful and competent engineering graduates who are capable of conceiving, designing, implementing, and operating complex and sustainable products, processes, systems and services in modern team-based environment emphasized in CDIO Standard 1. Several pathways have been designed and integrated successfully into the curriculum. A fundamental principle is to have a flexible structure that supports integration of knowledge and skills with multi-disciplinary connections (CDIO Standard 3) so as to create meaningful learning experiences for students (CDIO Standard 7) according to their ability and aspiration. Interviews by Ellington (2006) showed high-performing students enjoyed challenges in academic studies. Pekrun (2006) emphasized the importance of balancing these challenges with ability to develop intrinsic motivation of each student. While academically capable students have choices of different pathways, SEEE is mindful of students at the other end of the ability spectrum. Hence, academically weak students are helped through peer tutoring and supplementary class to better manage learning and cope with stresses.

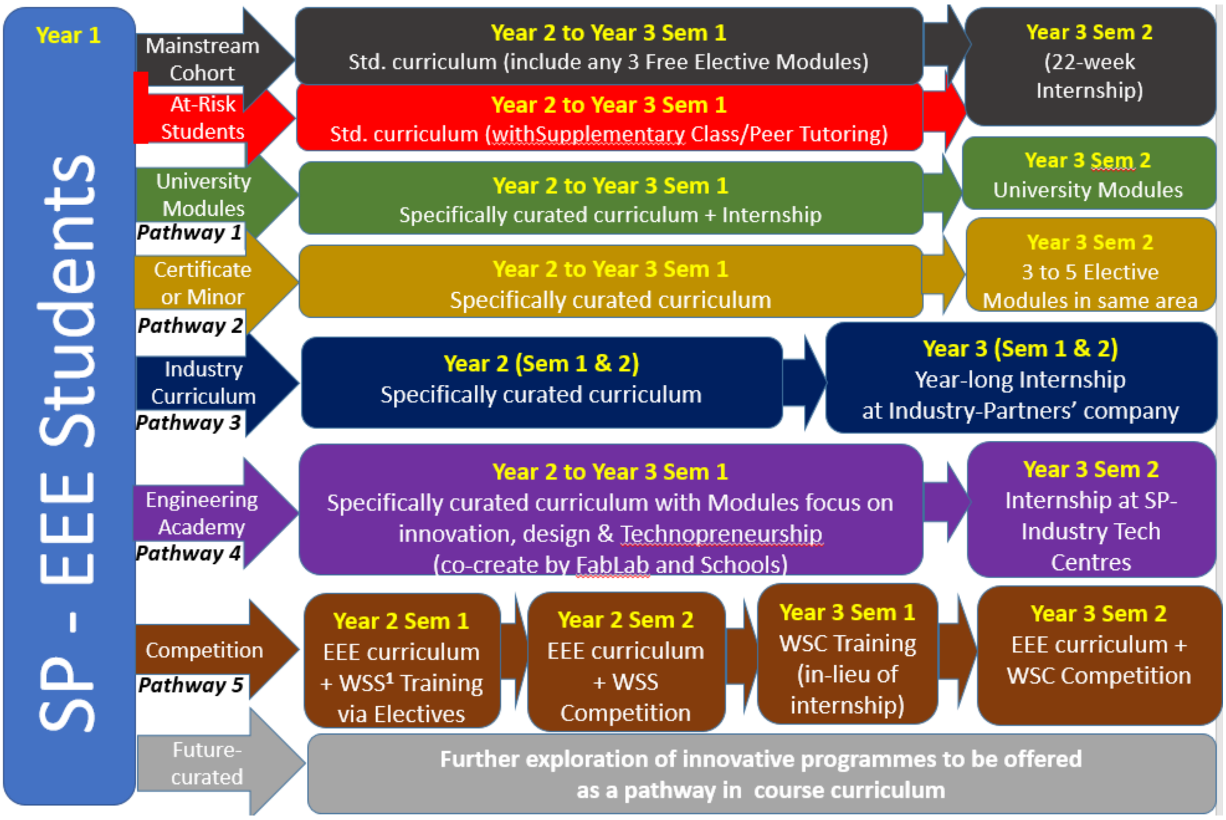


Figure 3. Innovative Design of Multiple Pathways in SEEE Courses

DESIGNING MULTIPLE PATHWAYS

Figure 3 gives a snapshot of students' possible journeys in their 3 years of study leading to a diploma qualification. Students could apply to a pathway subjected to meeting the criteria if its learning design matches their talents and passion.

UNIVERSITY-LEVEL MODULE PATHWAY

Rationale

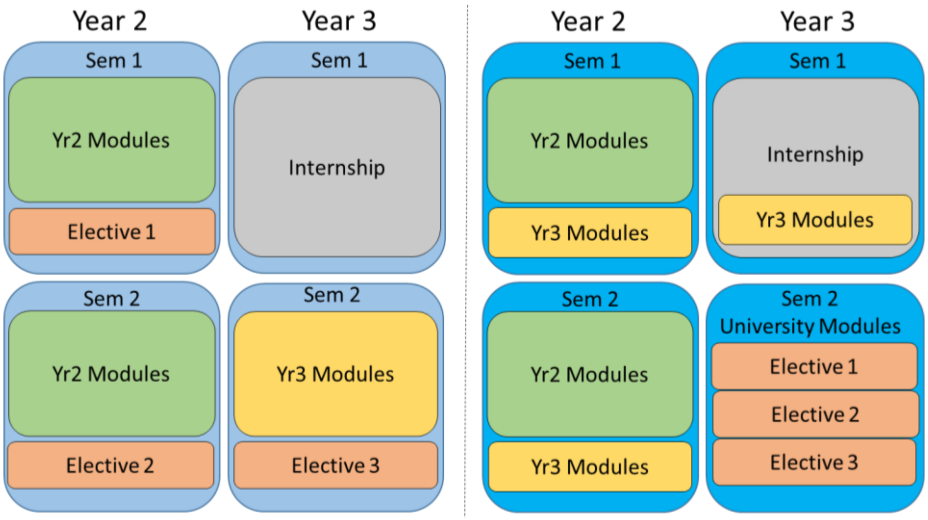
The impetus of this pathway stems from the understanding that many students aspire to further their study to obtain a degree after graduating with a diploma. Each year SEEE attracts a group of highly capable and motivated students who have attained very good GCE O-Level results. Many are "single-pointer" with ELR2B2 score of less than 10 and qualify to study at reputable colleges to take GCE 'A' (Advanced) Level before pursuing university education in many possible disciplines including medicine, law, architecture, business as well as engineering.

The University Pathway generated much excitement among prospective and current students. Many aim to get heads-up experience to enjoy university life while studying at SEEE. Partner universities are keen to offer high performing students a "preview" of their excellent academic programmes, engaging teaching and learning methodologies as well as state-of-the-art and modern facilities and campus. With insights gathered from stakeholders, SEEE commenced this initiative by jointly conceived and co-designed with National University of Singapore (NUS) and Singapore University of Technology and Design (SUTD) two separate pathways whereby selected students could read university modules during their diploma courses at the respective universities.

This University Module Pathway therefore serves to give students a unique learning experience and heads-up in having university education when they are still pursuing the diploma qualification. The innovative arrangement allows students to earn university module credits which potentially reduce the duration and cost of their university education later.

Implementing University Module Pathway – Examples of SP-NUS CP and SP-SUTD PP

In the Elective Framework, students are required to take 3 to 5 Elective modules from a basket of modules. The original course construct of a typical diploma is shown in Figure 4a. Students normally take one Elective module per semester from Year 2 onwards.



(a) Original Construct (b) Restructured Construct

Figure 4. Designing Couse Construct to incorporate University Module Pathway

The University Module Pathway uses the Elective space to create “curriculum time” within the diploma’s construct. Figure 4b shows the pathway design by re-sequencing the modules resulting in having the university modules taken in the final semester in Year 3 and in lieu of SP’s Elective modules. A basket of the University’s Year 1 modules which are rationalised and aligned to the objectives of the diploma courses are carefully identified and incorporated in the pathway and count towards the SP’s requirements for graduation in the diploma course. Students earn module credits for relevant degree programmes at respective universities. Students with outstanding results may be offered conditional admission by the university.

Deliberation on the different standard of a university module vis-à-vis a diploma-level module resulted in the implementation of grade translation to accord diploma students an upgrade equivalent to one grade point from the actual grade attained by students for their university modules taken in this pathway. Two University Module Pathways, namely SP-NUS Collaboration Programme (SP-NUS CP) and SP-SUTD Pathway Programme (SP-SUTD PP) are now on offer. Selection criteria based on academic performance and attributes which students possess are set by the respective universities. Interviews are conducted jointly by university professors and SEEE lecturers. Figure 5 shows the journey map of each pathway.

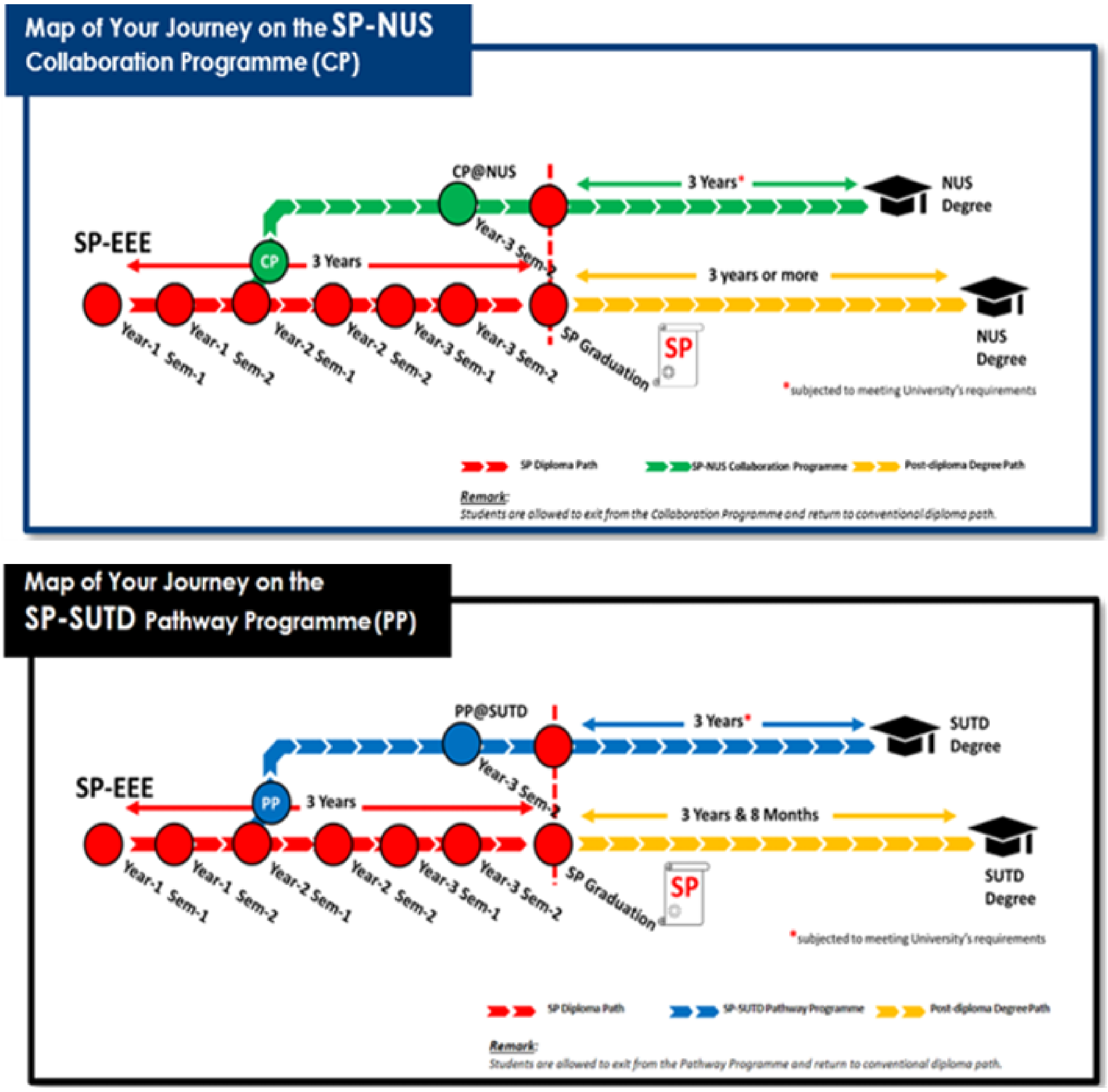


Figure 5. SP-NUS CP and SP-SUTD PP University Module Pathways

Performance of SP-NUS CP Candidates

Table 1. Academic Performance of SP-NUS CP and SP-SUTD PP Candidates

Programme	**Cohort**	**Range of ELR2B2 Of Candidates**	**Entrance Performance @ End of Year 1 (Candidates' average cGPA)**	**End of Programme Performance (Candidates' average cGPA)**
SP-NUS CP	1st	9 to17	3.923	3.926
	2nd	8 to 16	.863	Not available yet
SP-SUTD PP	1st	9 – 14	3.817	Not available yet

8 students from the pioneer cohort successfully completed the SP-NUS CP programme. Table 1 gives insights of the candidates' performance. It is worth noting that even as there is only one "single-pointer" among all the candidates with aggregate scores range from 9 to 17, these

students did very well in both their polytechnic modules and university modules. While GCE O-Level result is a typical indicator of an individual's academic ability, students in the SP-NUS CP programme show that passion coupled with well design programme with engaging learning contents and conducive environment could propel them to persevere and excel in their chosen pathway. The second cohort of SP-NUS CP students is also shown in Table 1.

Performance of SP-SUTD PP Candidates

The SP-SUTD PP was launched one year after the SP-NUS CP Programme. Table 1 shows the first cohort of SP-SUTD PP candidates' academic performance available up to the point.

Remark on University Module Pathways

SEEE Course Team has learned much from the experience in designing two University Module Pathways as CDIO standards are carefully incorporated, such as understanding the context, defining learning outcomes, ensuring integrated curriculum and integrated learning experience and others. Challenges are also abound which include alignment of the two different levels of learning and the administration of students in the pathways to ensure smooth progression from one stage to another. With early success shown by the pioneer cohort of students, the School works towards enhancing the pathway to benefit more students together with interested partner universities. This initiative has met the objectives which were set out in beginning.

ELECTIVES – CERTIFICATE AND MINOR PATHWAY

Rationale

The SP Elective Framework is designed to provide students with educational experiences aligned with SP's aspiration of developing self-directed, versatile and life-long learners. It allows students to set and achieve goals through self-exploration, shaping their own learning paths and pursuing their passions ("Elective Module", 2021). The Framework under the Choice space allows students to take 3 to 5 Elective modules which are outside of their courses' domain modules. Elective modules allow students to either broaden or deepen their knowledge and skills. Students who have completed 3 Elective modules, or 4 to 5 Elective modules in a related area of study will earn a Certificate or a Minor respectively, in addition to a Diploma. For example, Diploma in Aerospace Electronics students would normally acquire knowledge related to avionics and aerospace engineering. With the aerospace industry going through digital transformation, these students would do well to acquire additional skills in emerging technologies such as 5G, Cloud, and Artificial Intelligence which are not covered in the course, by taking relevant Electives under the Certificate or Minor Pathway.

Implementing Certificate & Minor Pathway – Examples of Minor in 5G & Artificial Intelligence of Things (AIoT)

The emergence of digital transformation and smart technologies has great impacts on industry and business. Advancements in 5G communication network, Machine Learning (ML), Artificial Intelligence (AI) and Internet of Things (IoT) lead to greater adoption that bring about productivity gain for the economy. Graduates equipped with such relevant digital skills will be well sought after by employers. A series of Elective modules covering these emerging technologies are curated. Under the Elective Framework, students who opt to take at least 4 related modules will be awarded the Minor in 5G & AIoT. The knowledge gained in the Minor would allow students to work on real-life project when they do Internship in subsequent semester. Such skills will enhance their employability and are relevant for further study.

INDUSTRY CURRICULUM PATHWAY

Rationale

SP graduates contribute significantly to the workforce to help drive economic and technological development in the nation. The School engages and collaborates with industry to ensure that curriculum is up-to-date and students are well-trained with industry-relevant skills. The Internship module requires students to be attached to a company for 22 weeks which is equivalent to one semester of curriculum time. This is an important way to expose students to the working environment and to undertake real-world projects.

The impetus of the Industry Curriculum Pathway is that some students thrive when exposed to real-life workplace environment. They get to develop their engineer's acumen by applying CDIO concepts when working on engineering systems, processes, and services in the company. In addition, they participate in solutioning project with the aim to help improve productivity, efficiency or solve engineering problems. They apply, solidify and improve their understanding of the knowledge acquired from modules learned in the course, thereby putting theories into practice with real-life contexts and enhancing their appreciation of the chosen course of study (Martin and Wilkerson's, 2006). The success of the internship gives rise to the Industry Curriculum Pathway with the internship attachment extends from 22 weeks to two semesters or one academic year long of valuable learning in the industry.

Implementing Industry Curriculum Pathway – Example of SP-GOVTECH PTP

The SP-GovTech Polytechnic Technology Programme (SP-GovTech PTP) is shown in Figure 6. The School started this initiative with the Government Technology Agency of Singapore (GovTech) which is responsible for the delivery of Singapore Government's digital services to the public and support the implementation of the country's Smart Nation initiative. This Industry Curriculum Pathway entails a year-long Internship attachment. Besides working on project, students on this pathway are required to "learn" in industry-specific modules which are jointly curated by GovTech and SEEE. These industry-specific modules are aligned to the learning objectives and course outcomes and hence are taken in lieu of modules in the standard curriculum. In addition, two Elective modules, namely Independent Study 2 and Independent Study 3 are curated from the technological contents and real-life learning which the students would acquire in the internship attachment.

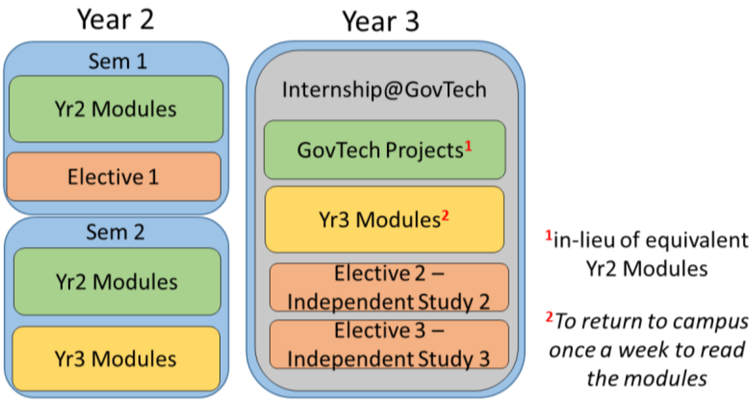


Figure 6. SEEE Course Construct incorporating Industry Curriculum Pathway

Performance of SP-GOVTECH PTP Candidates

The pioneer batch of 3 SP-GovTech PTP candidates started their full-year internship in March 2020. Table 2 shows the students' excellent academic results and their Internship grade. They managed the workload well and had enjoyed the unique learning offered by this pathway. One student remarked *"This year-long internship allowed me to work on the project from initiation to deployment, thus giving me great sense of satisfaction."*

Remark on the Industry Curriculum Pathway

Stepping out of the classroom to experience authentic industry experience definitely benefit the students. CDIO Standard 6 highlights the importance of having an environment and motivational drive that support the hands-on learning experience to apply the conceive-design-implement-operate concepts to work on products, processes, systems and services. This Industry Curriculum Pathway supports this learning experience with close partnership forged with industry partners. This initiative has met the objectives which were set out in the beginning.

Table 2. Academic performance of two batches of SP-GovTech PTP students

Batch	ELR2B2 of SP-GovTech PTP Students	Average cGPA	Internship Grade
1st	6 to 13	3.839	2 students with A grade 1 student with Distinction grade
2nd	6 to 9	3.848	Not available yet

ENGINEERING ACADEMY PATHWAY

The Engineering Academy (EA) pathway is designed to nurture engineering innovators who are self-directed, technically savvy, creative, resilient and have a growth mind-set. Students take specially curated prescribed modules that aim to deepen their engineering proficiency through in-depth training on maker-skills, engineering exploration and design, engineering solution realisation, trans-disciplinary innovation project and entrepreneurial skills. The academic profile of the EA students in cohorts 2019 and 2020 is shown in Table 3. As the EA pathway is best suited for students who enjoy hands-on learning and creating solution to every-day engineering problems, this pathway attracts students with wide-ranging academic profiles. Some graduates from the EA pathway had gone on to have their own start-ups.

Table 3. Academic profile of the EA students

Range of ELR2B2 of EA students from Cohort 2019 and 2020	Average cGPA of EA students	Range of cGPA of EA students
5 to 20	3.713	2.790 to 3.973

COMPETITION PATHWAY

The SP Elective space allows the Competition Pathway to be created which allows students to learn through the intensive training in specific domain as they prepare for competition. The learning is designed and integrated with other relevant modules and is considered as meeting the requirement for completion of SP Elective modules. Intensive trainings are conducted during the elective module time and internship period with assurance that students have acquired deep industry-specific skills and competences equitable to those acquired from modules in the standard curriculum. Such skills put students in good stead for both future employability and further study.

The School trains students for many national and international competitions. One such competition which requires high level of commitment, strong personal and interpersonal competences besides technical prowess is World Skills Competition. Exposure to such high intensity competition trains students to be technically-competent, as well as ability to handle stress at the highest level. Since 1994, SEEE students had constantly performed well in the competitions, winning a total of 28 Gold, 11 Silver, 12 Bronze and 10 Medallion in the World Skills Singapore (WSS) completion and 4 Gold, 1 Silver, 2 Bronze and 8 Medallion in World Skills (International) Competition (WSC).

PEER TUTOR CUM SUPPLEMENTARY CLASS FOR ACADEMICALLY WEAK STUDENTS

While the high ability and highly motivated students benefit from the different pathways, the academically weaker students always remain to be a concern for the School. They need help to cope with the rigorous training in engineering course. Supplementary classes for identified modules are conducted outside of the normal scheduled timetable to help students who are struggling in those modules. This programme is an integral part of the School's ecosystem in nurturing every students, including the academically weaker students to reach their potential. Students who repeat modules or pass marginally for pre-requisite modules would be placed in the supplementary class programme. The purpose is to strengthen students' understanding of fundamental knowledge and concepts to enable them to apply basic principles when they handle more advance-level modules subsequently. In addition, students facing difficulty in study would also have the Peer Tutor Scheme to find peer support. A student tutor is one who has done well in the module and he will be assigned to one or more academically weaker students. The student tutor will journey with the tutees by providing coaching in module content and imparts good study habits. Table 4 shows the statistics of students who passed their identified "weak" module upon attending the supplementary class or peer tutoring programme with passing rate of at least 80% and hitting a high of 92.5%. It is heartening to know that the Peer Tutoring and Supplementary Class scheme has helped many academically weak students.

Table 4. Statistics of students attending Supplementary or Peer Tutor Programme

Academic Year & Semester	No. of Students attending Supplementary Class	No. of Students passed Repeat modules	Percentage of Students passed Repeat modules
AY18 Sem2	31	28	90.32%
AY19 Sem1	43	37	86.05%
AY19 Sem2	25	20	80.00%
AY20 Sem1	75	69	92.00%
AY20 Sem2	88	78	86.64%
AY21 Sem1	40	37	92.50%

CONCLUSION

The creation of multiple pathways for students have provided them with choices and more control over their learning. These are keys to overcoming "boredom" with gifted students as shown in the interviews conducted by Kanevsky and Keighly (2003). As the current Gen Z students are known to thrive with challenges that connects with their personal interest, educators at all Institutes of Higher Learning need to create a more dynamic and flexible course structures and programmes that can constantly challenge the gifted and talented students (Moore, 2012), while ensuring the academically weaker ones are not neglected and left behind.

The challenge of each pathway is to maintain the attractiveness of the programme and the associated benefits to the students, in order for them to sign up and remain motivated throughout the pathway's journey.

All pathways described in this Paper have achieved the intended outcomes with validations and affirmations obtained from stakeholders such as employers, universities and governmental agencies. Students with wide range of abilities and passions, from the high potential ones to those academically weaker ones have all benefitted from the types of learning offered by the different pathways and programmes. For each cohort of students, approximately 75 to 80% of them undergo the standard curriculum, while 15 to 20% fulfil their aspirations by choosing one of those specially curated pathways, and 5% receive additional assistance in their study.

The School will continue to explore innovative ideas in designing new pathways that challenge education norms and bring the approaches to engineering education to greater level of diversity and collaboration.

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BIOGRAPHICAL INFORMATION

Toh Ser Khoon is the Director of the School of Electrical & Electronic Engineering. Under his leadership, the School continues to be a strong advocator and practitioner for CDIO, Design Thinking and Fab Lab curriculum. His current focus is on nurturing self-directed learners to be work, life and world ready. He is also interested in the use of educational technology and learning analytics for engineering education.

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A SCHOOL-WIDE ECOSYSTEM TOWARDS NURTURING STUDENTS TO BECOME SELF-DIRECTED LEARNERS

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ABSTRACT

Engineering education and training have evolved over the years due to the rapid pace of technological advancement and changes. It is imperative for the upskilling and upgrading of engineering knowledge to keep pace with changes in technology throughout one's working life to stay relevant. This requires one to possess the Self-directed Learning (SDL) mindset and skillset to constantly seek and acquire the necessary knowledge and skills independently as part of life-long learning. To meet this objective, the School of Electrical & Electronic Engineering (EEE), Singapore Polytechnic (SP) has fine-tuned the CDIO-based curricula for all its four diploma courses to strengthen the SDL elements for its 2400 full-time and 650 part-time students. Although the SDL project was launched about three years ago with differentiated learning, the implementation was accelerated due to the COIVD-19 pandemic. To further develop the SDL mindset through independent learning, multiple pathways were introduced in which the students were able to acquire skills and knowledge outside of the classroom environment. Strengthening the SDL elements resulted in the phasing out of the lecture component in a traditional classroom delivery and replaced by asynchronous e-learning. With the appropriate structure in place to support learning, the students are required to prepare for the lessons by self-learning before attending synchronous lessons to correct misconceptions or to seek clarifications from the self-learning. Students with different learning abilities are identified using learning analytics so that differentiated instructions can be conducted for optimised student learning. The findings from the four sets of students' self-assessment surveys on their self-directedness that were conducted for one cohort of students spanning from the time when they first joined the polytechnic to their graduation will be shared. This paper will also discuss on how well the students were received by the industry during their workplace internship in the final year.

KEYWORDS

Engineering education, self-directed learning, learning analytics, differentiated teaching, multiple pathways, CDIO Standards 6,7,8,11

INTRODUCTION

The school first embarked on the SDL project in 2019 and details can be found in the CDIO2020 paper titled "Using Learning Analytics in Moulding Students to Become Self-Directed Learners" (Toh S. K., Chia, Tan, & Safura, 2020). A second SDL paper titled "Adapting CDIO Framework to Cultivate Self-Directed Learning During COVID-19 Pandemic" was published in CDIO2021 (Toh S. , Chia, Tan, & Safura, 2021). The EEE-SDL Ecosystem has since evolved, and the final version is given in Figure 1. It can be divided into two major groups with one that focuses on learning in a formal structured setting comprising asynchronous lectures, synchronous tutorial, practical sessions, assessments, and the other group where learning takes place in a less formalized framework through multiple pathways and co-curricular activity (CCA). The structured learning framework focuses on learning needs, learning goals, learning resources, appropriate learning strategies; and evaluating learning outcomes that is largely based on research done by Knowles (1975). Differentiated learning to customize teaching and learning based on the learning abilities of the students is a feature of the framework as the school recognizes that every student is different and possesses varying degree of self-directedness as postulated by Brockett & Hiemstra (1991).

EEE-SDL ECOSYSTEM

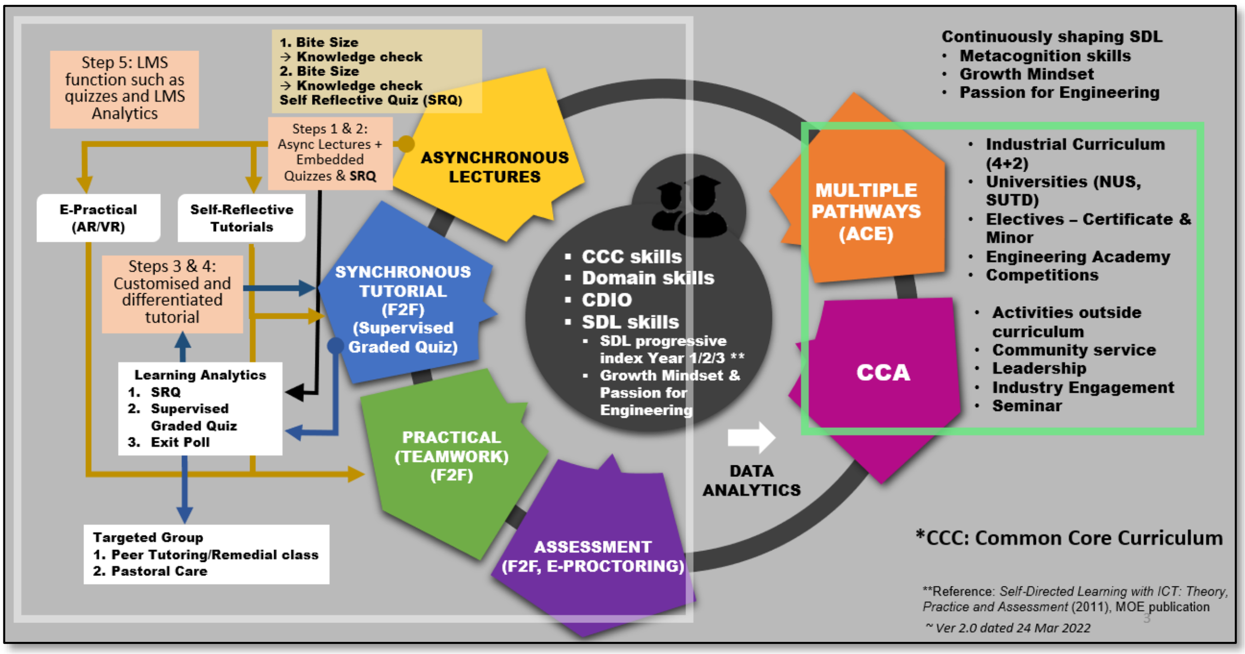

Figure 1. EEE-SDL Ecosystem

Curriculum delivery in the past comprised of three face-to-face components (lecture, tutorial, practical). New topics were taught during lectures to a large cohort of students – about 40 in media classrooms or more than 100 in lecture theatres. Tutorial lessons were scheduled immediately after lectures in smaller groups of 20 for better interaction and engagement between the lecturer and students to clarify doubts and reinforce understanding of the topics taught. The practical lessons were designed to strengthen the understanding by applying the theorical knowledge learned during the lecture and tutorial lessons.

Despite the constant exhortation to the students to prepare for the lectures by reviewing the materials beforehand, many of the students did not see a need to do so as they knew that they could cope with the lectures delivered by competent professionals. Although this approach of learning has been effective and sufficient in the past to prepare the students for a relatively stable and long working career, this is insufficient in today's working environment due to the rapid technological advances and changes. For the students to be work-ready, life-ready, and world-ready after graduation, they must become independent and self-directed learners in both their mindset and skillset.

ASYNCHRONOUS LECTURES

Face-to-face lectures were phased out and replaced by asynchronous lectures to develop the SDL mindset and skillset in the students. However, this could not be implemented overnight since the essential support structure must be in place to ensure that the necessary assistances are available when needed. The school thus adopted a two-pronged approach to address the short-term and long-term needs in the transformation to asynchronous lectures.

Online Learning materials

PowerPoint slides developed for classroom teaching are normally a summary of the main points that required the presence of a lecturer to provide the necessary explanation and illustration. This was supplemented using textbooks for further reading by the students. With the conversion to asynchronous lectures, contents of the PowerPoint slides were modified with two objectives in mind: -

1. Bite-sized PowerPoint slides with detailed explanation
   In the short-term solution to building up the necessary support structure, the contents of all slides were now expanded to include detailed explanation for the students. Whereas in the past where a lecturer was required to fill in the gaps, these were now covered by illustrations to promote self-learning and easy understanding. The deck of slides for a topic was segmentized into 10-minute bite-size length to make them less daunting and overwhelming to learn independently.

2. Knowledge Check (KC) With Narration
   The long-term solution called for narration to be incorporated in the slides and inclusion of KC at the end of each bite-sized segment. These were mainly in the form of MCQ quizzes to test the students' understanding before they could proceed to the next segment. If incorrect answers were given, they would have to review the lesson materials again.

At this juncture, the two above objectives were met for all the modules in the school, and this numbered more than one hundred. Apart from PowerPoint, other applications like Articulate Rise and iSpring were used to develop new online learning materials. Regardless of the type of application used, these new online materials were developed based on the "bite-sized with knowledge check" rule.

The asynchronous lecture process is given in Figure 2 below.

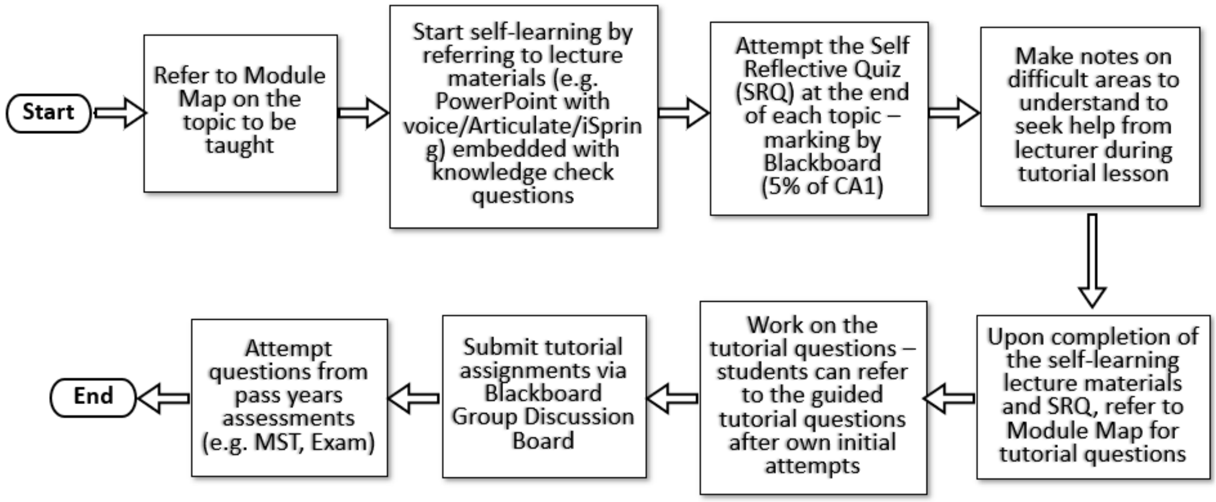

Figure 2. Asynchronous Lecture Process

In areas where the students find it difficult to understand, they are advised and encouraged to make notes and to raise these issues during the face-to-face or online synchronous tutorial lessons.

After completing a topic, the students are required to take a Self-Reflective Quiz (SRQ) that is graded. Grading based on the number of questions correctly answered is necessary as otherwise many students were be less inclined to review the online learning materials on their own. The final score for the SRQ component in the module assessment is calculated based on the average of the seven best scores.

Self-Reflective Tutorials

After completing a set of SRQ, the students will next attempt tutorial questions for the topic on their own. If they face any challenges in solving the questions, they can refer to a set of "Guided-Solutions" posted on the Learning Management System (LMS). This provides guidelines on how best to approach the questions to solve them without giving them the actual solutions.

The ability to solve the problems given in the tutorial questions can boost the students' confidence and encouraged them to attempt past years' Mid-Semester Test (MST) or Examination questions.

SYNCHRONOUS TUTORIAL LESSONS

The synchronous tutorial can either be conducted face-to-face or online in smaller class size of about 20 students. Although the focus of these tutorial lessons is to address any issue that the students faced during their asynchronous self-learning, another aim is to be able to customise the teaching to benefit students of different learning abilities by leveraging on the use of learning analytics. Pilot runs to fulfil the latter objective was implemented for one module comprising 40 classes during two semesters.

Three different approaches in the conduct of the tutorial lessons to meet the objectives outlined above were implemented in the past, and these are discussed below.

Short Period Tutorial

This approach is for 1½ to 2-hour long tutorial lessons and by far the most prevalent since many tutorial lessons are time-tabled for this duration. A list of prepared MCQ quizzes covering the whole topic is presented to the students during a lesson and the lecturers conduct just-in-time mini-lectures in areas where many of the students are unable to provide the correct answers. To implement this, a PowerPoint add-in called "ClassPoint" - similar to applications like "Socrates" or "Kahoot" - is used to provide the necessary interface. Since ClassPoint shares a common platform with Microsoft PowerPoint application, conducting the lesson by integrating the MCQ quizzes with the PowerPoint slides resulted in a seamless and less disruptive flow during delivery. Supervised weekly graded quizzes (WGQs) are also conducted to evaluate the students' learning during each lesson and the results contributed to the final grading of a module.

Long Period Tutorial

Modules with allocated tutorial time of more than 2 hours enable the lecturer to implement a more creative approach during the lesson. A typical class of 20 students is divided into 4 groups comprising students with different learning abilities. Four different questions are assigned to each group and members work together as a team to determine the solution. The role of the team leader, being the brightest in a group, is to ensure all members can understand and able to explain the solution. If need be, the lecturer will brief the leader in advance on the approach to tackle the question if the group makes little progress after some time. Time is set aside during the lesson for the presentation of the solution by the weakest student in a group. In this approach, the students not only learn how to apply the theories into practice through collaboration with their classmates but also strengthened their soft skills in the areas of teamwork, communication, and presentation.

Pilot Run Using Learning Analytics

This approach is largely like the "Short Period Tutorial" approach but with a small variation. The process in the implementation of this "Real-time Student Feedback" is given in Figure 3 below. Exit polls are conducted 30 minutes before the end of a lesson. Results from the SRQ, WGQs and exit polls are collected during a lesson and processed using learning analytics to identify the students' learning ability as well as finding out the areas that they require further assistance. The process of uploading and crunching the data and outputting the results is speeded up using Robotic Process Automation (RPA). Based on the results obtained during a lesson, the lecturers can identify students of different learning abilities. Questions of varying difficulty levels are then assigned to the students according to their learning abilities. This approach helps to engage the whole class during a lesson without neglecting the needs of the higher-ability students who are given more challenging questions to attempt. About 15 minutes towards the end of a lesson, the lecturer re-visits areas of the topic where the students have not fully understood to provide further clarification. (Mark & Chong, 2021)

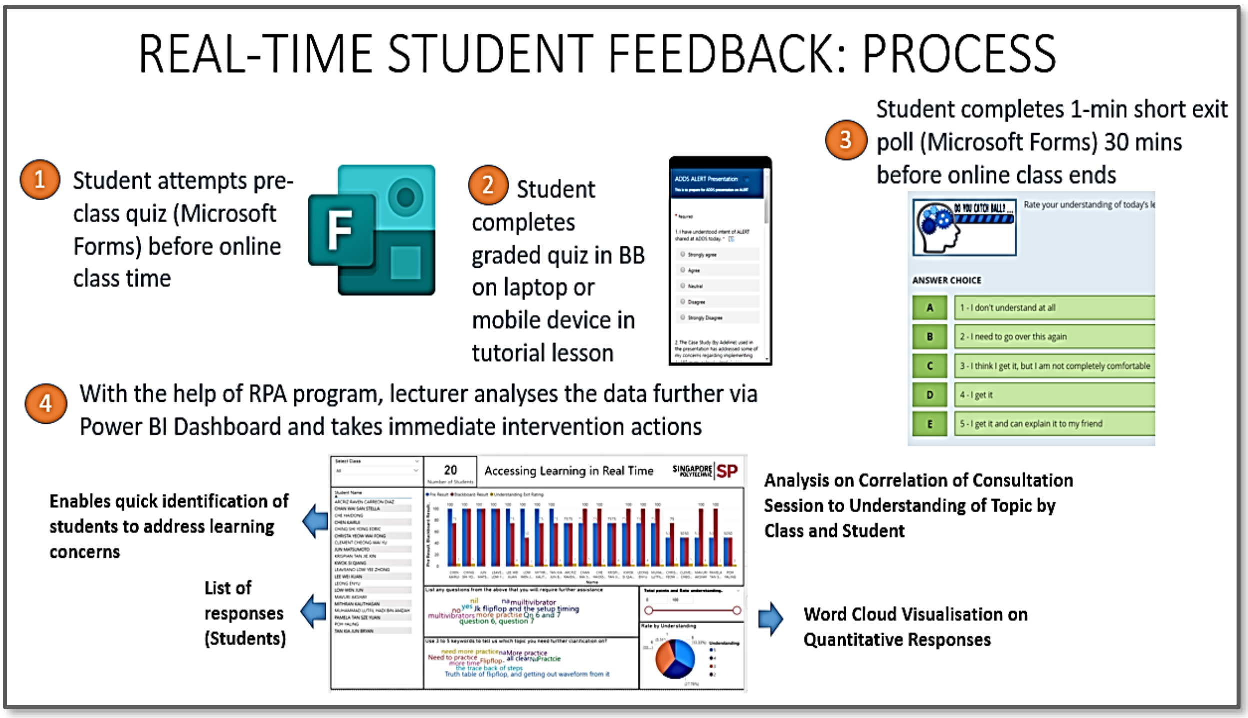

Figure 3. Real-Time Students' Feedback Process

Peer-learning and Supplementary Lessons

Prior to entering the polytechnic, student learning takes place in classrooms with teachers adopting the "sage-on-the-stage" approach. Students are used to having the teachers feeding them the necessary information in their learning. When faced with the need to change their learning style, it is understandable that some of them will find it difficult to cope. Safety nets are thus in place for students who needed more help in their learning, and these are in the form of a peer-tutoring network and supplementary lessons. In the former, senior students who had earlier taken and done well in the modules are roped in to help the weaker ones while additional lessons called "Supplementary Lessons" are conducted for these students by specially selected lecturers who are known to be more caring and dedicated.

LAB PRACTICAL LESSONS

A good engineer needs to be able to apply, create, troubleshoot, and ultimately make things work. As the students in the school are trained to become engineering professionals, practical lessons are therefore essential in their trainings. A typical two-hour practical lesson in the past could be broken down into three parts – first 30 minutes for the lecturer to give a briefing on the objective, theoretical background to support the experiment and the expected results. The next 60 to 90 minutes would be used by the students to conduct the experiment while the remaining time was for the lecturer to discuss the results obtained and finally to summarise the whole practical lesson. The practical lessons were conducted in pair of two for a class of about 20 to 22 students.

Videos on practical lessons were developed amidst the COVID-19 pandemic when a lock down was imposed. These videos highlighted the objective, circuit set-up and procedures to obtaining the desired results for the students to have an overall picture on what the practical session was all about. (Boon-Seng, et al., 2021)

When the students were able to return to the campus, the total number of students attending a practical session was reduced by half to between 10 to 11 students for each practical session in line with COVID-19 safe distancing measures. As the students were now required to view the practical videos before attending the practical sessions, the total time required for a typical experiment was reduced. This reduction in time allowed the experiment to be expanded to cover more areas in a practical session. Conducting a practical session for half the class had its advantage as unlike in previous case when students worked in pairs, the weaker students could no longer rely totally on their partner to carry out the whole experiment as they were now required to conduct the practical session on their own. More importantly, by having to review the practical videos before joining a practical session, the student takes a pro-active approach in their learning, and this progressively can lead to developing an SDL mindset.

ASSESSMENTS

Two types of summative assessments are in place for examinable modules, where one is scheduled during mid-semester and the other at the end of the semester. During the early days of the pandemic, the school rolled out a plan to ensure assessments could continue to take place even under the extreme situation of a lockdown when the students had to stay at home. This was in the form of an online e-proctored assessment that was developed in-house with compatible rigour and academic quality vis-a-vis in-person assessments where candidates are in the same site and supervised by invigilators who monitor them during the test. Even when the students were allowed to return to campus to take their assessments, one module was selected to undergo online e-proctored assessment to maintain the readiness of the school's ability to response to any future lockdown.

MULTIPLE PATHWAYS

All students take three years to complete a diploma course in the Singapore Polytechnic with a 6-month semester-long internship programme where the students are attached out to the industry in their final year. The school also recognises that students have different preferences and aspirations based on their passions and interests. In this regard, the school offers multiple pathways to the more capable ones to complete their diploma course of study by acquiring the necessary knowledge and skills through different platforms and experiences in order to stretch their potentials. Summaries of the multiple pathways are given below.

Industrial Curriculum Pathway (4+2)

A typical three-year diploma course of study takes six semesters (each lasting six months) to complete with the final semester taken up by the internship program and is denoted as 5+1. The school is always scanning the horizon in search for established and well-respected organisations that can provide relevant real-life industrial training to its students and when such organisations are found, only the exceptional students who are capable of coping with the project and work demands are selected. This is a year-long programme consisting of two semesters (4+2) with the modules to be taken in one semester being replaced by the relevant project and work experiences in the organisations. Students' involvement in industry projects and work attachments are curated to meet module learning objectives with the added benefit of gaining industry-based professional experience.

University – Level Modules Pathway

The National University of Singapore (NUS) and the Singapore University of Technology & Design (SUTD) are two of the more prestigious universities in Singapore where the admission criteria are stringent. The students joining this pathway takes three modules offered by the universities in their campuses and these modules replace three of the electives in the polytechnic that the students are required to take as part of their course of study. When students on this pathway joined the two universities after graduation, they are exempted from having to take the same modules again and this can help to shorten the time required for them to graduate.

Electives – Certificate & Minor Pathway

These are part of the Singapore Polytechnic's elective framework that provides all its students with learning opportunities to set and achieve learning goals through self-exploration, shaping own learning paths and pursuing their passions. The learning experiences help them in their development as self-directed, versatile, lifelong learners.

While a certificate is awarded if a student completes three electives that are related to their course of study, the student receives a minor if they choose electives that has no link to their courses. The minor provides a choice for the students individually to pursue an additional discipline beyond their domain core to enhance their portfolio for future employability and studies. Students' knowledge, and competency in this second selected domain will be deepened to complement their domain core and attributes such as creativity and innovativeness can be demonstrated in their resulting portfolios.

Engineering Academy Pathway

The Engineering Academy (EA) Programme was conceived to challenge the selected students to be engineering innovators where they will learn to create workable solutions to solve real world problems. They will learn how to figure out the right questions to ask, take charge of their own learning and work through uncertainty. This is to be accomplished by collaborating with peers from other engineering diplomas, learning about Design and Business, acquiring prototype skills, and working closely with industry and university partners.

Competitions Pathway

In general, competitions help the students to expand on their portfolios, develop new skills or deepen existing skills, and for the school to benchmark the standards of its students against both local and overseas institutions. These competitions ranged from domestic to regional and international such as World Solar Car Challenge 2019, WorldSkills Competitions, Robocup Asia-Pacific 2019, 14th International Standards Olympiad 2019, Greenpower UK Challenge 2019, National Smart Nation Competition 2020, Virtual Robocup Asia-Pacific 2020, Robocup World 2021, International Standards Olympiad (2019, 2020 and 2021), World Skills Singapore 2021, Robocup Asia-Pacific 2021.

CO-CURRICULAR ACTIVITIES (CCA)

Activities outside curriculum

The polytechnic and school organize many events outside of the students' coursework throughout the year to provide the opportunities for the students to develop their leadership, interpersonal, teamwork, and organisation skills. Some examples are the Freshmen Orientation Programme (FOP), Graduation Ceremony, Open House for potential new students, Educational and Career Guidance Day as well as EEE Alumni Day. During these events, students are recruited to serve as ambassadors and tasked to organise some of them.

Another area where the students can contribute is in the Peer Tutoring Scheme. These students are usually the exceptional and brighter ones who will promote good study habits to the weaker students and coach them to work towards better academic performance.

Community Service

One of the school's missions is for its students to become socially responsible citizens who are compassionate to genuinely care and have respect for other people especially the under privileged and senior citizens. In this regard, students are required to serve the community in each semester by planning and organizing two-hour interactive activities for residents in welfare homes and community centres. During these sessions, students engage the residents by socializing and interacting through food, games and providing listening ears especially to the senior citizens.

Leadership

Students who exhibit leadership qualities are nominated to attend the SP-Leadership Programme where they will be trained on fundamental knowledge and skills on personal leadership for personal effectiveness, team leadership for leading teams and working with others and servant leadership for developing others. The aim is to stretch the potentials of these student leaders to take on challenges at higher levels as part of their development progression.

Industry Engagements & Seminars

Over the course of their studies in the polytechnic, the students are given many opportunities to attend various talks, seminars, workshops, and technical conferences by professionals from the different industries under the auspices of the Educational Career & Guidance (ECG) module. Through these events, the students can gather industry insights and understand the types of skills required in the different industries.

SURVEY ON SDL INDEX MEASURING PROGRESSION IN SELF-DIRECTEDNESS

The self-assessment survey to measure the self-directedness of the students at different milestones in their studies consists of four surveys. The first survey is targeted at new students before the start of their courses while the other three are conducted at the end of their first, second and final year of study. Each survey is made up of 14 statements (see Table 1) on a 7-point Likert scale. The set of statements can be divided into three groups, the first two groups relating to intrinsic and extrinsic motivations respectively, and the remaining ten on SDL readiness that were adapted from the work by Tan, Divaharan, Tan and Cheah (2011).

Table 1. Students' Self-assessment Statements for SDL

Statements S1-S2 Intrinsic Motivation	
S1	I prefer learning materials that really challenge me so I can learn new things.
S2	I prefer learning materials that arouse my curiosity, even if it is difficult to learn
Statements S3-S4 Extrinsic Motivation	
S3	I want to do well in my studies because it is important to show my ability to others.
S4	Getting a good grade is the most satisfying thing for me.
Statements S5-S14 Dimensions of Self-directedness	
S5	I set learning targets for myself.
S6	I normally ask questions when I am not sure about my learning.
S7	I always look for more information to help me understand better.
S8	I always make a list of what I need to do for my learning.
S9	I usually complete my assigned tasks on time.
S10	I often try to understand where I go wrong in my learning.
S11	I try different ways to solve problems on my own at all times.
S12	I have a habit of applying what I learned to other topics or areas.
S13	I always seek out what is required of me beyond the syllabus of my module.
S14	If I try hard enough, I will understand the learning materials.

One cohort of students who joined the polytechnic as new students in the 2019/2020 academic year has completed the four surveys. The results are given in two different plots – one focussing on motivation trend (Figure 4) while the other on their self-directedness (Figure 5).

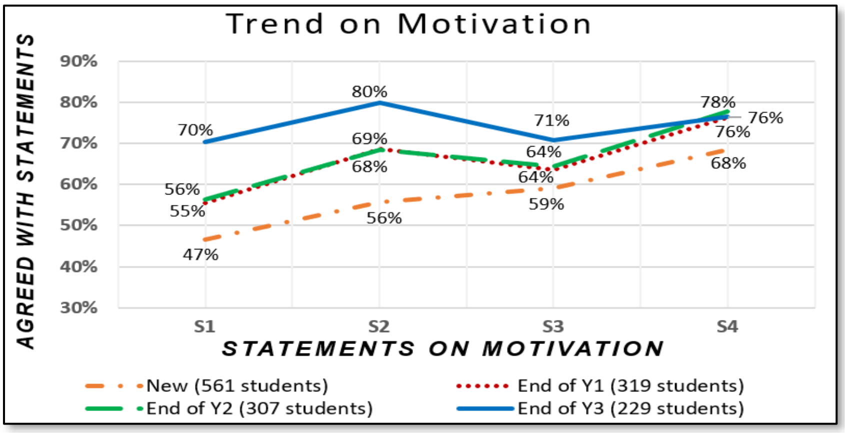

Figure 4: Students' self-assessment indicating heightened motivation.

For the first two intrinsic motivation statements (i.e., S1 and S2) based on the plot given in Figure 4, it is evident that the students have shown positive and significant improvements. For example, from the time that the students joined the polytechnic to the end of their 3-year courses, there has been an increase in 23% of students who relish learning materials that challenge them to learn new things. Likewise, an improvement of 24% over the same period for S2 means that the students are motivated enough to want to learn out of curiosity regardless of the difficulty level. It is thus heartening to note that more students are now more intrinsically motivated when it comes to acquiring new knowledge and skills after completing their courses in the polytechnic.

Results on extrinsic motivation also registered improvements albeit not as significant as the earlier ones. The percentages for S3 and S4 have increased from 12% and 8% respectively. These measures centred on the students' personal satisfaction in showing their ability to others and in getting good grades.

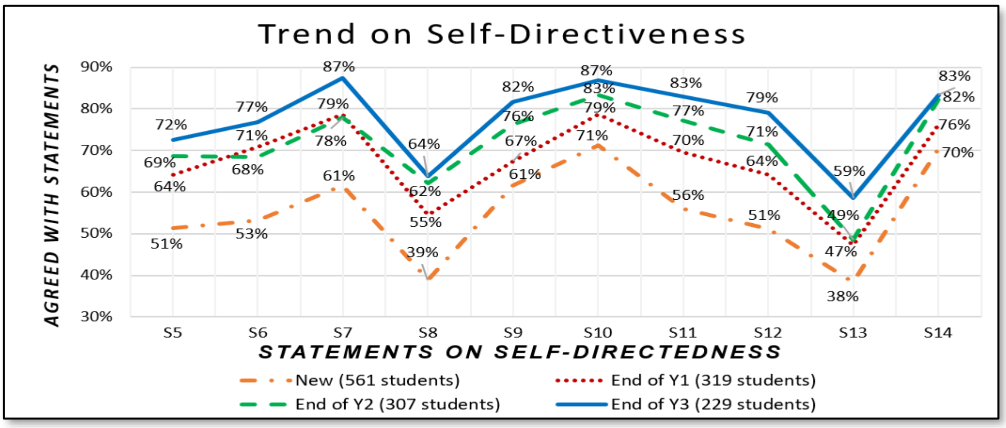

Figure 5. Students' self-assessment indicating heightened self-directedness

Evaluating the dimensions of self-directedness in the students were based on the statements from S5 to S14. From the results obtained in Figure 5 above, it is comforting to note that the students have benefitted from the three years in the polytechnic as can be seen from the overall trend lines as eight of the ten statements (i.e., S5, S6, S7, S8, S9, S11, S12, S13) registered more than 20% improvement while the remaining two (i.e., S10, S14) were well above 10%. The highest percentage of 28% for S12 demonstrates that more students have developed the good habit of applying what they have learned to other topics or areas. More students are now prepared to try different ways to always solve problems on their own as shown by the 27% improvement for S11. S7 also sees a marked improvement of 26% and this relates to the students always looking for more information to help them understand better.

STUDENTS' GENERAL PERFORMANCE DURING INTERNSHIP

Internships in the relevant industry are valuable experiences for both the students and the hosting organisation as the former can benefit from the work experiences while the latter gets to evaluate in depth a potential future employee (Martin and Wilkerson's, 2006). The majority of the third-year cohort in the school are attached out for a six-month internship in the industry during their final semester. Surveys are conducted with the hosting organisations to gather feedback on the students' performances at the end of the internship. Over six semesters from AY2019-20 S1 to AY2021-22S2, the average number of organisations who responded to the surveys was 208. Two pertinent questions posed in the surveys were on whether the hosting organisations were keen to take in more interns in the future and whether the interns have done well to be considered for long term employment in their organisations after graduation. Based on the results from the surveys given in Figure 6, the hosting organisations were satisfied with the performance of their interns as more than 93% expressed their interest in accepting more interns in the future while at least 74% were willing to offer them employment after their graduation.

Interns are paid an allowance by the hosting organisations during their internship and guidelines are set on the minimum amount to be paid. If the hosting organisations had experienced positive and significant contributions from past interns and were confident of the quality of future interns, they were encouraged to pay a higher allowance. On this note, it is heart-warming to note that the number of organisations who were willing to pay higher allowances to the interns had increased progressively from 51% to 57% over the past three semesters.

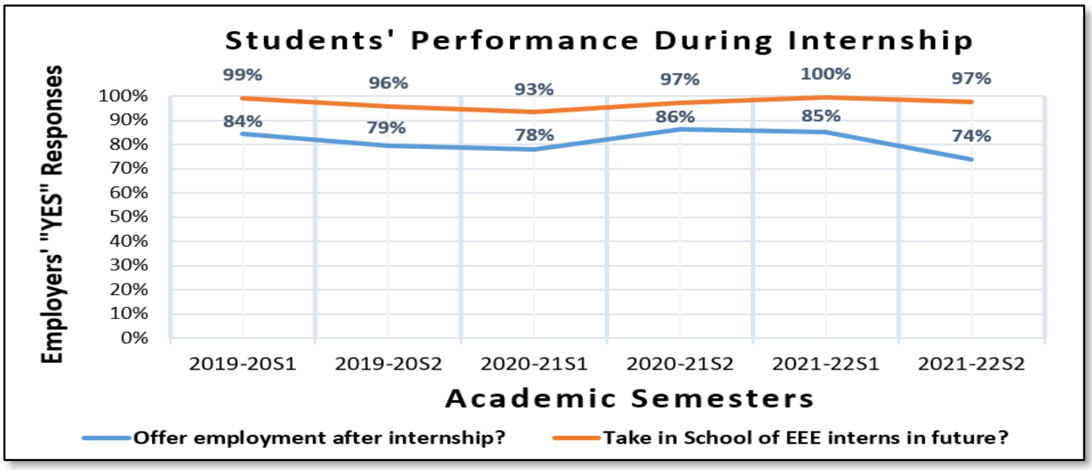

Figure 6. Results of Survey on the Performance of the Students During Internship

CONCLUSION

The acid test in any polytechnic course is how well its graduates are accepted by the industry since the students are educated and trained to fulfill the industry's needs and demands. Based on the contributions of the interns in the industry, hosting organisations were generally happy and satisfied with the interns' performances as evident from the fact that many of them were prepared to offer employments to their interns after graduation, willing to take in more interns in the future and paying the interns above the recommended minimum guidelines. This positive and encouraging responses from the hosting organisations is a testament of the new EEE-SDL ecosystem's capability in producing graduates who can perform and excel in the work environment.

Over the last three years, ten of the School's top graduates had won prestigious national-level scholarships which was a feat that was never achieved in the past before the EEE-SDL ecosystem was established. The other impactful outcome was in the peer tutoring scheme and pastoral care network which have helped more than 80% and 74% respectively of the at-risk students to progress successfully to the next stage of their courses.

The findings of the students' self-assessment surveys measuring the progression in self-directedness have also affirmed that the whole-school approach in the cultivation of SDL is progressing well on the right track. During the COVID-19 pandemic lockdown from April to June 2020 when Home-based Learning was enforced, and the subsequent measures introduced in the classroom for safe-distancing after the lockdown was lifted, the students were able to cope relatively well based on the comparison of their performances in the summative assessments with preceding semesters. As this can be considered as the second acid test for the EEE-SDL ecosystem, the school is heartened that the inculcation of the SDL mindset and skillset has contributed to the students' ability to face challenges and cope with uncertainties in their learning journeys.

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BIOGRAPHICAL INFORMATION

Toh Ser Khoon is the Director, School of Electrical & Electronic Engineering, Singapore Polytechnic. Under his leadership, the School continues to be a strong advocator and practitioner for CDIO, Design Thinking and FabLab-based curriculum for the Engineering diploma programmes. His current focus is on nurturing and preparing learners to be self-directed and work-life and world-ready. In the area of teaching innovation, the emphasis will be on the use of educational technology and the application of learning analytics for engineering education.

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INTERNATIONAL PROFESSIONAL SKILLS: INTERDISCIPLINARY PROJECT WORK

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ABSTRACT

Higher education should provide learning situations that prepare students for a future profession and make them world-ready. This paper reports insights from an international interdisciplinary collaborative project aiming to create learning experiences that are close to a professional situation. The collaboration setup simulates a setting of a digital agency with a development team in Sweden and a marketing team in Australia working together to solve a task. The collaborative project has been active since 2017, completing its fifth iteration in 2021. Post-course survey results show that the students felt that a real situation was created with a high level of collaboration and commitment, internationalization, well selected digital collaborative tools, and that an interdisciplinary community of practice was created among the students.

KEYWORDS

Internationalization, collaboration, professional experiences, Standards: 1, 3, 4, 5, 7, 8, 10

INTRODUCTION

The fast-paced technological development has drastically influenced and affected society for a long time. At the center of this development is the art of engineering. Since engineering is the “application of science, mathematics, economics and social science which can manifest into creations” (Kumar, 2018), engineering itself is also affected by research and practice within many different areas. Hence, engineering innovations that create value happens in the cross-section between scientific discoveries, technological development, and societal changes. This development has had a profound impact not only on the professional role as an engineer, but also on engineering education throughout the world. Rapid technological changes, which are common within engineering, create a high uncertainty among students of future career paths. Consequently, interdisciplinary skills and being able to work with professionals from other disciplines have become increasingly important over a long period of time (Ertas, Maxwell, Rainey, & Tanik, 2003). This is especially true for even more interdisciplinary areas such as, e.g., interaction technology where today's students are facing complex contemporary problems (Churchill, Bowser, & Preece, 2013). Professional skills such as communication, teamwork, and understanding external and societal context are all desired by the industry (Mechefske, Wyss, Surgenor, & Kubrick, 2005). Therefore, it is important that students in higher education move beyond the pure disciplinary subject and are given opportunities to develop their skills in relevant societal and business-related contexts (Cardozo et al., 2002).

During the last 20 years, the CDIO Initiative has been focusing on bridging the gap between engineering education and the industry's vision for their new employees' skills. According to the CDIO, engineering education should focus on real-world demands in the complete value system and all skills needed to successfully execute the engineering profession - Conceive, Design, Implement and Operate (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Hence, the CDIO approach is largely based on the idea that students should, during their time at the university, face reality-alike contexts and face situations that facilitate learning of professional skills which are very important to prepare students for their future profession. Simulating these settings can increase students' motivation and enhances the learning (DuHadway & Dreyfus, 2017; Mejtoft, 2015). For participating engineering students, interdisciplinary collaboration has a positive impact on, e.g., communication, and provides a solid foundation for future engineering units (Hirsch et al., 2001). Even though the CDIO thinking is designed to give students experiences that are needed for a professional career, collaboration and context are frequently addressed within the CDIO Syllabus 2.0 (Crawley, Malmqvist, Lucas, & Brodeur, 2011), e.g., Teamwork (3.1) and External, societal, and environmental context (4.1). Consequently, project-based learning has become more frequent in engineering education, due to its ability to address both these generic skills as well as developing the students' disciplinary skills within the same setting (Mills & Treagust, 2003).

Globalization with interaction and integration between countries, business, and, foremost, people have accelerated with the development of applications for real-time communication. Globalization and the use of technological innovation in society have made clear that engineering is a profession with global impact. From a work perspective, most students will face situations when working together with international customers and colleagues, either on-site or online. Creating diversified teams with collaborators from other cultures becomes more important to reach specific markets and to understand these users' needs. This development has gradually increased the importance of having international segments during students' education to prepare students for these types of situations (Borri, Guberti, & Melsa, 2007; Guillotin, 2018).

The CDIO emphasizes in the Optional Standard 4: Internationalization and Student Mobility, that education should have "curricula which prepare engineers for a global environment and exposes them to a *rich* [emphasis added] set of international experiences and contexts during their studies" (CDIO Initiative, n.d.). This is truly done mostly by exchange studies or other activities where students spend time abroad and submerge in the international context. However, there is a need to give students who cannot, or do not want, to spend time abroad the opportunity to participate in different kinds of authentic international experiences. During the last two years, this has become increasingly important due to the global pandemic and closed borders, which has affected students' internationalization and mobility negatively.

Since the Covid-19 global pandemic hit the world in 2020, there have been many good practices regarding the possibilities of emergency remote work and collaboration over distance for professionals. Consequently, there has also been a vivid discussion about remote work and more flexible solutions for employees in a post-pandemic world. Even though many still prefer to work on site, there is a huge increase in the number of employees that desire a more flexible solution to their work situation (Alexander, Smet, Langstaff, & Ravid, 2021). In combination with globalization, there is an increasing need for engineers to work in an international hybrid environment for firms to utilize human resources in the best possible way and, thus, create competitive organizational capabilities. According to Berkey (2010), combining international experience with exposure to interdisciplinary situations and collaborative learning creates high quality learning experiences. Furthermore, from a university perspective, students feel that focusing on solving real-world problems in a collaborative and international context increases the perceived quality of their education (Damnjanovic & Novcic, 2011; Srikanthan & Dalrymple, 2002).

This paper discusses how hybrid collaboration in an international interdisciplinary setting as part of the curriculum can create professional situations that prepare students for future challenges. The paper presents results and learnings from the latest iteration of a long-term international interdisciplinary collaborative project. The aim of the project has been to expose students to a range of "real" situations to strengthen their professional skills. This paper extends preliminary results presented at the CDIO Conference in 2020 (Mejtoft, Cripps, Berglund, & Blöcker, 2020) by focusing on creating simulated settings close to what students will face professionally.

During all five iterations of the joint project (2017-2021), surveys have been conducted among the students, both at the beginning and the end of the collaboration. These surveys have been focused mainly on the setup of the collaboration and have been separated from the ordinary course evaluations. Furthermore, discussions with students and group interviews have been conducted during the different iterations. This paper is mainly based on the latest iteration between the two post-graduate units *Advanced quality project work in interaction technology* at Umeå University and *New product development* at Edith Cowan University. The results are based on documentation from entry and exit surveys as well as group interviews and discussions with the students, carried out between August 2021 and January 2022.

COLLABORATION SETUP

This paper presents results from an interdisciplinary project in an international setting between two universities: Edith Cowan University (ECU) in Perth, Australia, and Umeå University (UmU) in Umeå, Sweden. The collaboration is set up between a marketing unit at ECU and an engineering unit at UmU. The idea of the collaboration (Figure 1) is simple, and structured as a potential collaboration between a marketing team (ECU) and a software/UX development team (UmU), located at two different offices of a fictional digital agency. This is close to a real situation where firms often have different competences located in different parts of the world, depending on what and for whom a product is developed. Together, the teams are developing a solution for a wicked problem (Churchman, 1967; Rittel & Webber, 1973), given to them by a hypothetical customer, i.e., the teachers. The problem definition is intentionally kept broad to give the students the opportunity to shape the project, but also to reflect the common real-world situation that rarely all required information for a project is available. Hence, this is close to real

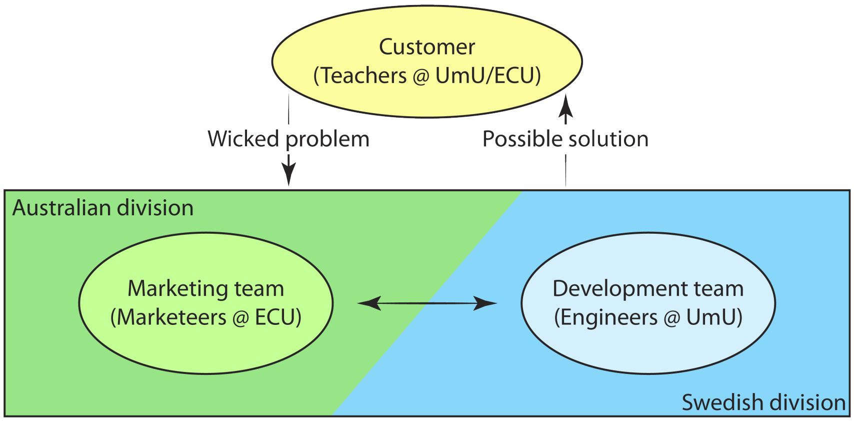

Figure 1. Collaboration setup where the marketing team at ECU and the development team at UmU form a fictional digital agency, and the teachers are their customer.

situations that the students might face when seeking a professional career after graduation.

The collaborative project was first initiated in 2017 and has been active ever since. During fall 2021, the fifth iteration was completed. Three different engineering units at Umeå University have been active in the collaboration over the years: *Prototyping for mobile applications* (fall semester, 7.5 ECTS, 50% pace), *Social Media Technology* (spring semester, 7.5 ECTS, 50% pace), and *Advanced Quality Project Work in Interaction Technology* (fall semester, 15 ECTS, full-time). These engineering units are similar in structure with project work that makes up about half of the first two units while the last unit is based entirely on project work. Regarding the marketing counterpart at ECU, two different units have been involved in the collaboration – *Current issues in marketing* and *New product development*. Regarding these two units, the latter is a better fit for the collaboration because it has a clearer focus on product development. The latest iteration of the project has been between the two post-graduate units *Advanced quality project work in interaction technology* and *New product development*. A major difference to previous iterations is that the engineering students were working full-time with the specific unit during (almost) the full length of the collaboration and the development work.

During each iteration, different wicked-like problems have been presented to the students for them to solve. During 2021, the following question was proposed to the students: "How can technology be used to support isolated elderly in Australia during the pandemic?". Students' learning connected to the CDIO approach and has been framed within the ideas of Design Thinking (Brown, 2008; Gibbons, 2016; Hasso Plattner Institute of Design, 2010). This framework was used as a common ground for the students' collaboration and development (Figure 2). The combination of using design thinking to implement CDIO skills in project-based learning has been discussed by, e.g., Isa, Mustaffa, Preece, and Lee (2019). The motivation for how the project work was structured was to facilitate inter-disciplinary exchange of best practices, as one goal of the collaboration was to make the students teach each other about how they approach problems within their respective discipline while leaving the problem specifics open to let the students determine them. Hence, the idea was to facilitate a community of practice (Lave & Wenger, 1991) among the students from the two disciplines.

The tasks for the two project teams were defined according to the structure of the design

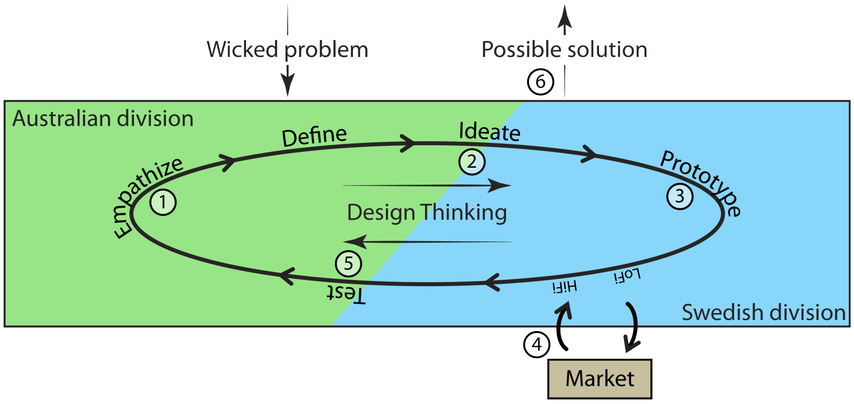

Figure 2. Illustration of the phases in the design thinking approach, together with how they have been divided in the context of the collaboration between ECU and UmU.

thinking approach (Figure 2). However, while the two student cohorts worked collaboratively, each had assessments required by their own institutions. The joint project was part of electable project-based courses and not a capstone project or part of the students' final thesis work.

First (see Figure 2), the marketing team at ECU conducted desktop market research, corresponding to the empathize and define phases (cf., conceive stage), into the needs of the potential customers which the new product development unit is focused on. In the most recent iteration of the project, the focus was on the needs of socially isolated elderly in Australia. As the ECU semester commences before the semester at UmU, the first assessment was done before the joint work started. As part of the market research, the ECU students developed customer personas for the potential market. The findings from the market research and customer personas were then shared with the UmU students, both electronically and as part of a joint session at the start of the UmU semester. To facilitate the collaboration the Swedish students had been asked to jump-start their semester to get some common knowledge before the work by the ECU students started. Second, in a teacher-facilitated ideation session (cf., design stage), the marketing and engineering teams worked jointly towards specifying an idea based on the insights from the market analysis. During this session the two teams, jointly, identified and discussed the problems to be solved as well as the gaps in the market in relation to meeting the needs of isolated elderly. The ideation session utilized the online real-time collaboration tool Mural. Both the engineering and the marketing teams gained insights into the respective other discipline through discussions where the marketing team explained the identified real-world needs, and the engineering team highlighted possibilities and limitations regarding practical feasibility within the time frame of the project. Third, from the information provided in the collaborative sessions and through the collaborative platform (Microsoft Teams), the project entered the prototyping phase (cf., design stage). The prototype phase was sub-divided into two milestones, i.e., a low-fidelity (LoFi) prototype phase using a parallel prototyping approach, and a high-fidelity (HiFi) prototype, for four reasons: (i) to keep as many ideas as possible in the first stage, (ii) to help with time management and provide a tangible product as a basis for discussion in the middle of the prototype work, (iii) to let the teams adjust the product with regards to the initial market analysis, and (iv) to provide a version to the marketing team as a basis for their subsequent work. During the LoFi phase, the engineering students created two LoFi prototypes in parallel which they presented and discussed during a virtual collaboration session. The UmU students integrated this feedback into the LoFi prototype, producing a single refined version. Forth, based on the "final" LoFi prototype, the ECU students used a new software called SpaceDraft to communicate their assessment of the product market fit of the proposed LoFi prototype. The feedback from this software was used by the engineering students and incorporated into the final HiFi prototype. Fifth, the HiFi version of the prototype was tested by the ECU students with customers in the target market (cf., design/implement stages). This gave results that are important for further development of the prototype and, consequently, for potential future launch of the product. Sixth, the students in the marketing team individually created 90-second pitches for funding from the hypothetical organization to take their product based on the HiFi prototype to market (cf., Leadership and Entrepreneurship in the extended CDIO Syllabus). These pitches were presented to their customer, i.e., the teachers and evaluated by their fellow ECU students as well as the UmU students. Importantly, the design thinking phases are not executed in a strictly linear fashion but provide feedback to each other and can be re-iterated several times. For example, prototype results can lead to a better understanding of the customer's requirements, which affects ideation outcomes and feeds into a revision of the prototype. During the progression of the course, the students were encouraged to stay in touch and to share and discuss their progress, however, no formal requirements were defined regarding the form and frequency. Design processes in general and, in this case, the Design Thinking process have a good fit into the CDIO Syllabus 2.0. Consequently, this collaboration has a focus on conceive (4.3) and design (4.4) with some focus on implementing and testing of the prototype (4.4) along with Leading engineering endeavors (4.7) and Engineering entrepreneurship (4.8).

RESULTS FROM THE COLLABORATION

This paper presents results from an international interdisciplinary collaborative project which has recently completed its fifth iteration. Even though every iteration so far has been successful in terms of satisfied and motivated students, there have been different aspects that needed more attention and have been gradually developed further to create a good learning experience for the students and, at the same time, fulfil learning outcomes of the courses involved in the collaboration. Over the six iterations there have been many challenges which have been addressed in e.g., Mejtoft et al. (2020) and Mejtoft, Cripps, and Blöcker (2021). The biggest challenges over the years are presented in Table 1. The most recent iteration has been focused on creating a learning environment that is close to a real-life professional situation (cf. the setup described above). When asked if they were willing to participate in a similar collaborative project in the future, 63% of the students said that they were "extremely likely to participate" with the rest saying that they were "likely to participate".

The students believed that the learning environment created through the collaborative project was different from a traditional academic learning environment – *"Getting tossed together with people from a different study discipline [. . .] that is always interesting. Working with a development project side-by-side with marketing students feels very close to a real work situation where several competences are involved"*. Furthermore, the students felt a higher motivation – *"I believe that it's easier to become more laid back when just taking a course at the university with [ordinary] assignments compared to when doing a collaboration with an external firm or, as in this case, with students on the other side of the world. I feel that something happens to the motivation and the commitment when more [external] parts are involved."*.

Table 1. Challenges addressed in previous iterations (Mejtoft et al., 2020, 2021).

Introduction	It is hard to give sufficient information and knowledge about the other student cohort.
Interactions	Even though possibilities for interaction were created, both the number of interactions and the quality of the interactions were lacking.
Collaboration	Expanded and deepened collaboration between the groups were requested by the students.
Timing	Timing of semesters between the different countries and real-time timings for meetings are problematic.
Digital tools	Different online platforms between the two universities and different digital skills between the two student cohorts created challenges.

One of the major differences, as experienced by the students, that created a professional situation was that they did not need to know about all the work that was done in the project - *"One difference is that we actually delivered by handing over results [between the two groups]. They did the marketing research. They gave us the information that we analyzed and used for developing the product. The situation when material is handed over is very much like a real work situation [. . .] It's a different type of collaboration, when we collaborate within the class it is more like 'you have this area of responsibility within the project [but we still work together]'. But in this case, we have nothing to do with the other things at all."*.

Overall, a professional situation was simulated by (1) a high level of collaboration and commitment, (2) internationalization, (3) digital collaborative tools, and (4) creating an interdisciplinary community of practice.

High level of collaboration

Post-course surveys from previous iterations have indicated that the students wanted a higher level of interaction and integration between their courses. As a test to see the effects of increased interaction, the latest iteration of the collaboration had the highest level of virtual collaboration so far, in class as well as in the students' own time. Both student cohorts were smaller than in previous iterations, which led to higher levels of interaction and a setup where all students worked on the same project and prototype throughout the course. Several of the online meetings, which were held at lunchtime Swedish time/Thursday evenings Western Australian time, continued past the scheduled end because the students formed personal bonds during the time working with each other. This was the first time in the collaboration where the students actively collaborated in real-time outside of the set class times, not only working together but creating a sense of collegiality. Students commented on the benefits of a high level of interaction and collegiality as: *"You get to know each other and their backgrounds and also their style of approach towards a given task"*, and *"[We were] learning about different styles of communication, commitment to complete tasks"*. The collaboration was commented as: *"One of the best things was when we had meetings in a smaller group, like when we had meetings with [a single ECU team]. That's when we thought that we had the best interaction, because we talked to each other . . . This was when I believed that we got the most out of it [the collaboration]"*.

Communication becomes more important for the students when communicating beyond within their own cohort or with their local teachers. Working with people they did not know beforehand, and whom they did not meet in person, made the situation more real, which had impact on the attitude among the students – *"We always have the attitude that we want to be professional and do a good job. But, even more so in this situation. This was the attitude from both sides in the collaboration"* and *"We had higher demands [on ourselves] because there were more 'strangers' involved"*. This was also shown when students pointed out inappropriate comments from other students that they did not feel were professional.

Internationalization

Working with teams in other countries is common when working with development work, especially within engineering. The present setup created an international setting involving different cultures, time-zones, and languages. According to the results of the survey, all but one student found it easy to work with international students in another area of study. English language proficiency was not an issue in communication among the students, however it was commented that it was a little bit difficult to understand each other, particularly as the Swedish students were working with the ECU students who were both Australian and international students from countries as diverse as China, South America, and South Asia. One major obstacle for working with students overseas were the time zone differences (7 hours between Perth and Umeå), as it *"has taken some doing to schedule availability over several different time zones"*.

Digital collaborative tools

Regarding digital tools to collaborate between the two cohorts, Microsoft Teams and Zoom were used. Learning how to use these tools was regarded as a valuable professional skill, and the tools have become preferred environments for students compared to platforms used at previous iterations (e.g., Slack). For collaboration within their cohorts, students used, e.g., WhatsApp and Facebook Messenger. As part of the joint course sessions, the students used real-time collaborative tools, such as Mural, to develop the concept in real-time. All the students found the real-time collaboration useful, with the majority considering it to be very useful. Mural created a virtual place where the students focused on their task together, facilitated lively discussions, and choosing between proposed ideas through anonymous voting allowed the students to feel comfortable when taking a stand. The students commented on the digital platforms as: *"A great tool that I use in the workplace too"*, and *"I think it was a great platform for the collaboration, it was easy to get in contact with everyone at once or one specific student"*.

Interdisciplinary community of practice

When starting the development work, both student cohorts were lacking in-depth information about the other students, their background, and experience. However, this created an interdisciplinary community of practice where the students had to support each other to create a common learning in the intersection between engineering and marketing. The students commented on this as: *"Having to explain basics and other thing within our area is something I'm not used to but is very informative"*, *"We had to explain our process in an understandable way to students who are not as familiar with the area of our study. In return we got some insights regarding their field of study."*, and *"[A] clash of thoughts which can sometimes lead to a different approach."*. This situation where students have to explain things that they are not used to, and when collaborating and working across disciplines gives, according to one of the students *"different perspectives and knowledge transferring"*.

CONCLUSIONS

Our idea of an international interdisciplinary collaborative setup to create world-ready students was established and tested and refined repeatedly before the global pandemic accelerated the creation of online learning and online working environments. We believe that the range of skills gained by the students when participating in this collaboration has grown during the last couple of years and will be even more valuable in industry in the future. Even though many valuable skills have been gained by the students in terms of disciplinary and interdisciplinary knowledge, one student commented on one of the main outcomes: *"In my experience collaboration is a valuable skill that is appreciated in the workplace"*.

Throughout the five iterations of the collaboration, the level of online interaction between the students at ECU at UmU has continually increased. Initially, the collaboration was driven by the teaching staff, however, it was the students in the most recent iteration who repeatedly requested to meet to discuss and refine their project. The collaborative meetings continued past the end of the semester.

As teachers on the courses, it is extremely encouraging to know that the students appreciate the efforts made to create this learning situation. Even though there have been frustrations and problems, the students commented on the collaboration as: *"It was a fantastic unit, I enjoyed it"*, *"I looked forward to those Thursdays"*, and *"It's fun!"*.

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Engineering Students' Engagement in a Hybrid Learning Mode: Comparative Study

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ABSTRACT

After almost two years since the COVID-19 pandemic hit the world, higher education institutions are adopting transitional strategies towards returning to normal campus life while respecting the health and safety regulations.

An example of such strategies is the hybrid teaching model where only half of the students attend their classes physically on campus while the other half attend their classes simultaneously but online, and their attendance alternates every week. A major challenge imposed by this strategy is the complexity of students' engagement as instructors are exposed simultaneously to two different teaching styles. In this paper, the effectiveness of an Audience Response System in terms of boosting the students' engagement in a hybrid learning environment is investigated. The collected data is analyzed at various stages and comparative conclusions are drawn about the Audience Response System's effectiveness over the interaction of online and on-campus students. Furthermore, an anonymous detailed survey is conducted to verify the students' satisfaction level and to link its results with the conclusions obtained from analyzing the data of the Audience Response System.

KEYWORDS

Audience response system, Active learning, Student-centered approach, Hybrid learning, CDIO Standard: 8.

INTRODUCTION

According to the World Health Organization, the COVID-19 pandemic is still threatening the lives of human beings with a concerning level of infection spread around the world. At the same time, over the past two years, the pandemic created an accumulation of socioeconomical problems which require immediate attention (Liguori & Winkler 2020). As such, our corrective actions towards remedying these problems should be implemented with a high level of caution. For instance, higher education institutions are adopting transitional strategies toward returning to normal campus life while maintaining the online teaching methodologies they invested in during the pandemic.

At the Australian College of Kuwait (ACK), a hybrid teaching model is adopted in Fall 2021 to ensure a smooth transition from online to face-to-face teaching while maintaining the health measures imposed by the ministry of health in the state of Kuwait. In this model, the students are divided in two groups, whereas the first group of students attends their classes physically on campus, the other group attends their classes simultaneously but through online streaming and the attendance method alternates every week.

Although this practice guarantees the requirements of local health authorities, it imposes some pedagogic challenges as it applies simultaneously two completely different teaching styles, face-to-face and online. For instance, it has been argued that students have an attention span of around 20 minutes in a normal class (Mayer et al., 2009) which becomes much less in an online streaming class because of the lack of face-to-face interaction, continuous distractions, and gazing at a screen for a long time. This will cause the student's mind to scatter while grasping the course material and lose the track of studying and following up with course content. Online students as well are less to speak and participate by opening their mics because of some surrounding noise and weak internet connections. This may also lead instructors to unintentionally give more attention to students attending and interacting physically on campus and ignore online students. As a result, unless active learning is assured for both groups of students, applying a hybrid teaching methodology may result in undesired unfairness and unequal learning opportunities.

In alignment with CDIO standard 8 which is related to "teaching and learning based on active experiential learning methods", innovative active student-centered learning approaches are inevitable in this situation to ensure the simultaneous engagement and involvement of both online and on campus students while addressing their various needs and learning styles. This requires a multi-modal learner-support technology that can operate in a range of time and place settings.

As assessments are one of the most efficient ways to grab the attention of students, (Brent & Felder, 2012) suggested an active learning approach called "Thinking-Aloud Pair Problem Solving or TAPPS" which allows the in-class lectures to be divided into chunks where the students will be exposed to short practices and exercises in the middle of the lecture distributed within the slides. The Audience Response System (ARS) emerged later as an efficient tool to facilitate this kind of active learning approach inside the class. It was used as a clicker (Bergtrom, 2006; Mayer et al., 2009; Niyadurupola, 2016), electronic voting system (Harris & Zeng, 2010; Kennedy & Cutts, 2005), or personal response system (Hinde & Hunt, 2006). It was also used to enhance student satisfaction, learning outcomes, engagement, and levels of confidence (Farhat et al., 2021). An ARS is a simple-to-use online interactive software enabling formative in class assessment with instant feedback. Its online nature makes it ideal for hybrid teaching scenarios as both the on-campus and online students can use it simultaneously.

Although the usage of Audience Response Systems as a powerful tool to implement active learning strategies was thoroughly studied in the literature, its effectiveness in keeping a balance and equal opportunities between online and in-class students who are simultaneously attending a hybrid online/face-to-face class is still not addressed. Therefore, in this paper, the efficiency of the Audience Response System is investigated in terms of boosting the students' engagement and learning in a simultaneous hybrid learning environment and comparative conclusions are drawn about the interaction of online and on-campus students.

IMPLEMENTATION

In this study, I-Vote application is selected as the ARS software and is implemented in four Engineering Diploma courses at the School of Engineering at ACK: Electrical Circuit Analysis I, Electromagnetism Fundamentals, Instrumentation and measurements, and Analog Electronics. I-vote is installed on the instructors' personal computers or tablets as an add-on to Microsoft Power-Point presentations and is used through the web or the pre-installed application on tablets or any other mobile device from the student side. I-Vote app is used in this study, in the same way it was implemented previously at ACK by (Farhat et al., 2021). The main aim is now increasing the instructor-student interaction simultaneously for both online and on-campus students in an equal manner in a hybrid teaching context in contrast to the pure face-to-face context it was initially implemented in by (Farhat et al., 2021).

At the beginning of the class, the instructor shares the session ID with the students through the instruction page which allows them to access the questions predefined by the instructor and respond to them online one by one when prompted (e.g. Figure 1). To differentiate online from on campus students, the students are also required to specify their attendance mode. One question is posted by the instructor at a time (e.g., multiple choices, true/false and calculation). After a predefined time, the students' responses were posted on the board which is accessible physically to on campus students and though streaming for online students, both groups also receive feedback on their devices. The anonymous feature in i-vote is enabled and students are allowed to save all their activities for future study. Using the i-vote ARS this way would motivate in-class shy students to participate and share their thoughts (Farhat et al., 2021) and is expected to increase the attention span of online students as they will be frequently exposed to pop up questions. Moreover, the instructor benefits from an in-class rough estimation of students' understanding without the need to waste the lecture time in addressing the questions individually neither for online nor for face-to-face students. On the contrary, and depending on the results, he/she would invest more time in beneficial discussions and ideas sharing (Hinde & Hunt, 2006). Having the responses displayed anonymously on their screens would also assure students who answered incorrectly that they are not the only ones and would hence encourage them to be more active in these discussions.

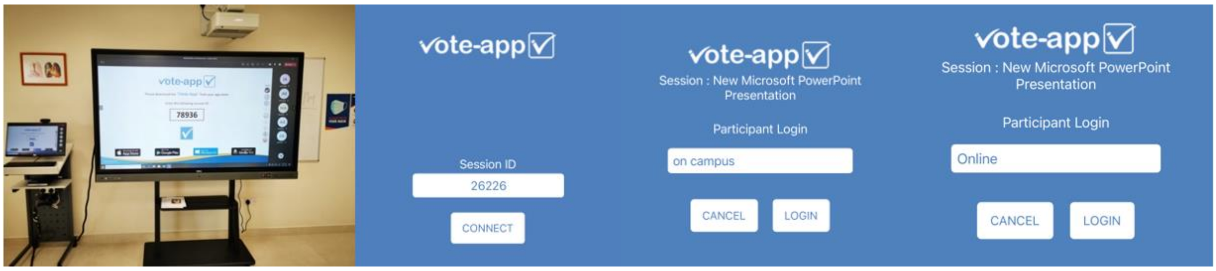


Figure 1. ARS instruction page includes session ID.

Pedagogically speaking, a combined teaching method was implemented in classrooms: some passive transmission of knowledge followed by individual work, then discussions. All classes were following the operational flowchart depicted in Figure 2.a. The lecture material was shared with students ahead of the session. A diagnostic assessment and pre-class preparation were conducted before the teaching session to tailor the teaching activities to students' requirements and use the instructional time in an optimal way. This has shown to be very helpful and motivating the students for more pre-class preparation. The session started traditionally, as the teacher explained some concepts for around 15 minutes, then moved on to ARS questions.

As indicated in Figure 2.b, students had to think individually, then discuss in peers their findings and opinions, communicate, justify their point of view, co-operate with each other, learn, and help each other to clarify any concerns arising from the presented questions. When in doubt, peer discussions moved to classroom discussions to seek the instructor's help and advice. The shift from traditional teaching after 15 minutes of lecture to active teaching strategies is underlined by the evidence that student attention wanes after about 15 to 20 minutes in a traditional classroom environment.

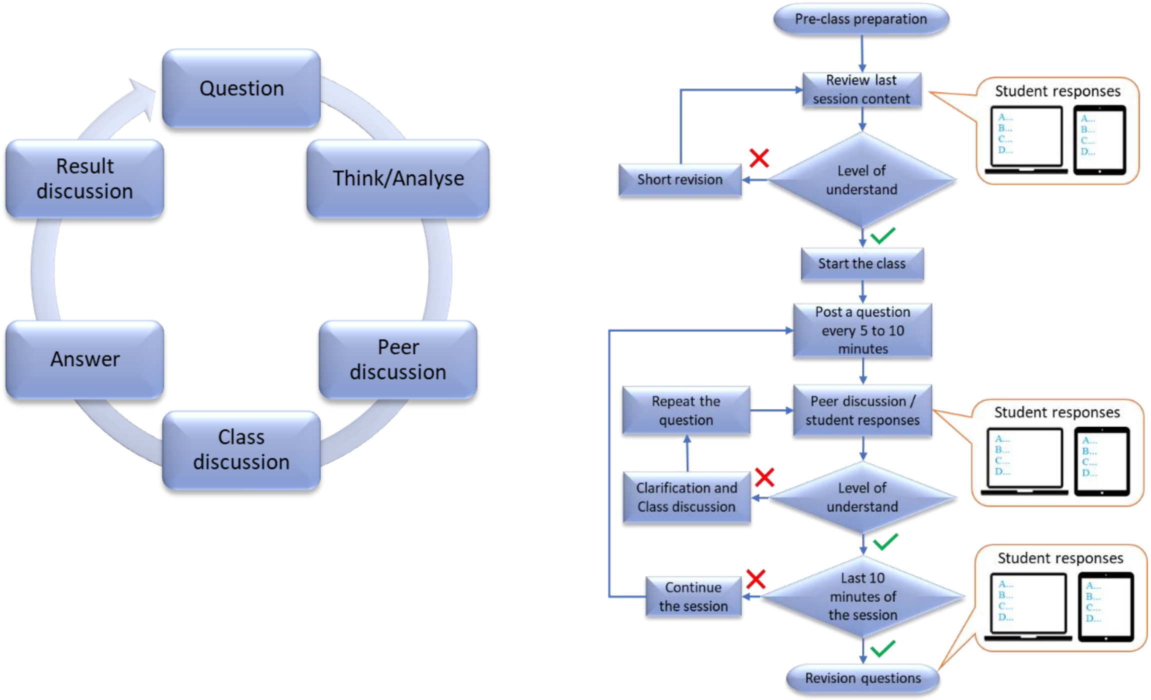


Figure 2. (a)The response sequence for most ARS questions. (b) Operational flowchart of ARS in active learning environment.

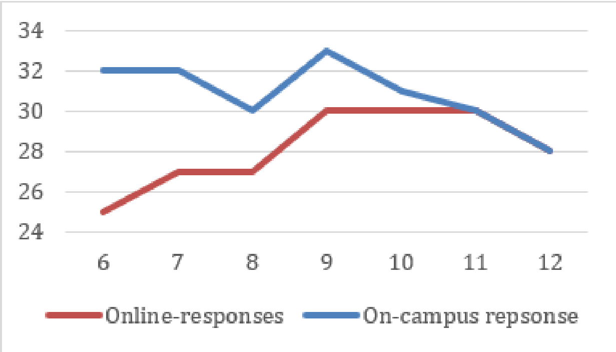
RESULTS AND DISCUSSION

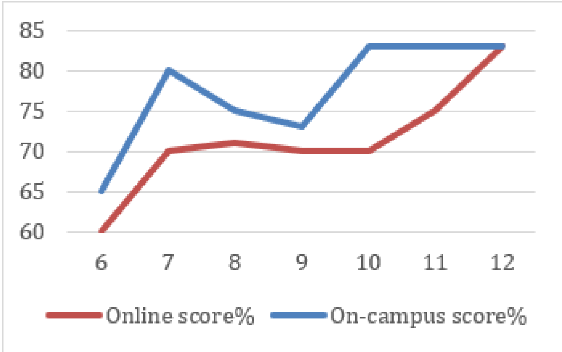
The effectiveness of the ARS in enhancing active learning in hybrid mode was evaluated in two phases. First through several meetings conducted between the involved instructors to share their experiences, analyse the ARS results and remarks on the most successful method of using the ARS. Second phase is by conducting an anonymous survey to examine the student satisfaction level with the new teaching style, and to assess different elements that were involved to enhance active learning.

ARS Analysis

As mentioned earlier, the ARS i-vote system is implemented in four different courses which involve a total of 90 students. The ARS data was collected, merged, and analyzed on weekly basis. Every week's data includes: the number of attendees whether online or on-campus, namely "attendees", the number of attendees who answered all the ARS questions during the classes, namely "responses", and the average percentage of correct answers of these participants, namely "scores". The implementation of the ARS i-vote system and the collection of data started in the 6th week of study and endured for 7 weeks until week 12. Figures 3.a and 3.b present the obtained results for online and on-campus students.

In regards to Figure 3.a to Figure 3.b, one may obtain several conclusions. At first, at the beginning of the ARS implementation, the online students' responses were relatively less than their on-campus counterpart as students were still not used to the formative assessment approach, whereas towards the end of the semester, the response rates of online and on-campus students became almost equivalent. The same pattern may be observed on the scores achieved by online and on-campus students which started to stabilize after almost four weeks of implementing the ARS system. These results suggest that, at the beginning of the ARS implementation, on campus students were more attentive and engaged then online students. After the transitional period of almost four weeks, i.e. after each group had been exposed twice to the ARS system in its online and on-campus form, the engagement and scores of both group of students became almost the same. This is clear evidence of the effectiveness of the ARS system in creating equal learning opportunities in a hybrid learning mode. The survey results presented in the next section further support this conclusion.





(a) (b)

Figure 3. (a) ARS analysis of students' responses. (b) ARS analysis for students' score.

Survey

To further support the conclusions derived from the ARS data analysis, a survey was conducted over all the students who took part of this study. The first part of the survey was for demographic data collection, followed by several questions related to ARS technology in general, student's satisfaction and engagement, hybrid learning, formative assessment, and the overall instructor performance. The survey ends with two open-ended questions asking the students to express their thoughts about ARS effectiveness in both on-campus and online situations.

The survey was created on Microsoft Forms to simplify data collection. The students responded within a scale ranging from strongly disagree, disagree, neutral, agree to strongly agree.

The summarised aims of the survey were sent to the students via the official communication platforms of ACK. The students were notified that the collected data is anonymous, not including any personal or sensitive data, the privacy of their responses is protected, their participation is voluntary, the survey is not part of any assessment, and that they cannot withdraw from the survey once submitted.

Sixty students from the four courses responded to the survey. Almost half of the participants shared their feedback on the last two questions covering their thought of using I-Vote app either on-campus or on-line.

Figure 5 illustrates the respondents' demographics. There is a good variation of ages, but males count was higher than females' as more males join engineering programs than females here in Kuwait which is also a common pattern in many other countries. Also, there is a good variation in GPA and the academic level.

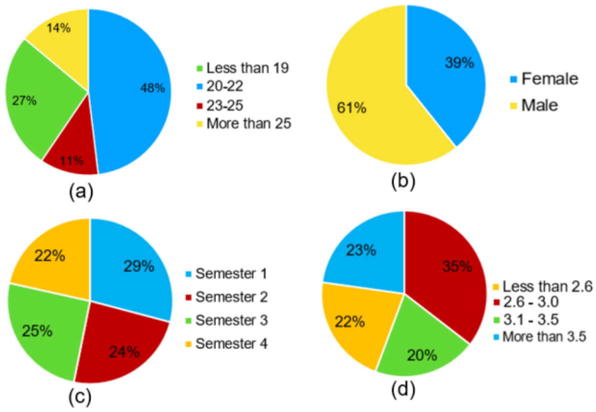


Figure 5. Demographic results (a) Age (b) Gender (C) Academic level (d) GPA

Figure 6 reflects the students' feedback and satisfaction level on implementing ARS in their classes using their mobile phones. Most students agreed that ARS helped them in general to be more interactive, engaged, and attentive, and they do not consider it is as a waste of time. While most of the students as well did not face any technical issues, a considerable amount stated that they did during the classes and that might be related to network connection stability.

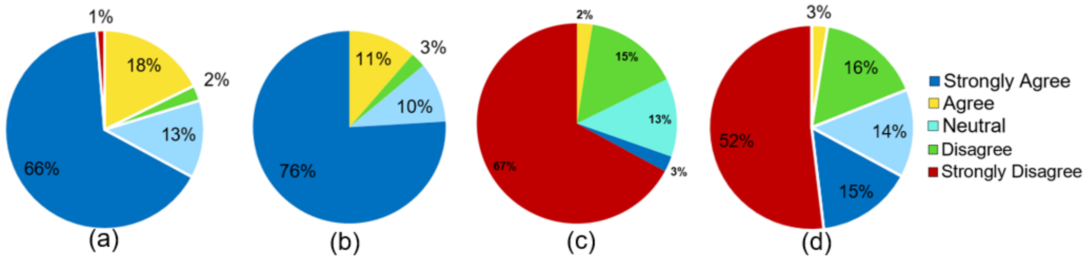


Figure 6. Using ARS in classes (a) ARS increased my interaction in class (b) ARS helped me to be more active, engaged, & attentive during the class (C) ARS wasted too much time (d) I faced technical problems when using ARS

Figure 7 illustrates the students' feedback and satisfaction level on the hybrid learning model and implementing ARS to enhance their engagement, attention and improve their hybrid learning experience. Most students agreed that they are more distracted while they are attending their classes online unlike on campus classes where they are more attentive and active. A significant number of responses confirmed that ARS helped the students to be more active and attentive during their online classes and helped them understanding the material.

Samples of students' responses to the first open ended question "How far did using ARS was helpful during your On-Campus lectures?"

- "Helped me be active and focus"
- "Using ARS was so helpful for me to understand the course clearly on campus and improved my learning skills, also it was helpful to get the idea of how the exam would be"
- "On campus is much easier to focus and learn better"

- “It was very useful to me as I was able to discover where my weaknesses were and learn from my mistakes. Participation during the semester at the university was more useful so that it is fixed in my memory.”

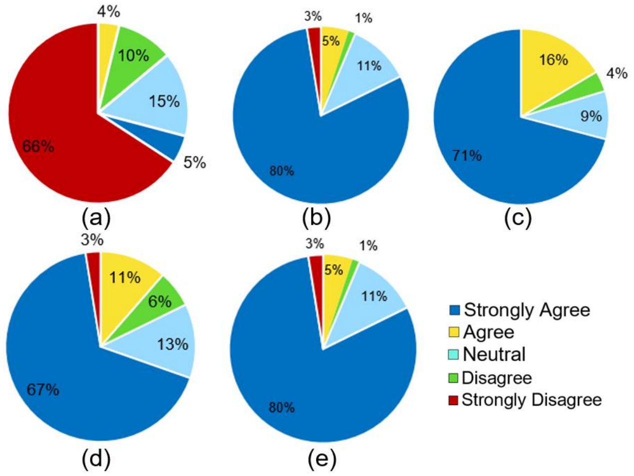


Figure 7 ARS in Hybrid Learning a) I pay more attention when I study online b) I pay more attention when I study on campus c) The hybrid learning process gets better when my instructor uses ARS technology d) ARS helped me to pay more attention when I am attending the class online e) ARS helped me to pay more attention when I am attending the class on campus.

Samples of students’ responses to the second open ended question “How far using ARS was helpful during your Online lectures?”

- “Online we usually get distracted easily but with ARS we don’t”
- “It made me pay more attention to the lecture since attending lectures online you can easily get distracted”
- “It was helpful because it makes me pay more attention to the class”
- “Helped me to focus and interact.”
- “It same as on-campus but I vote app is a little bit laggy so I suffer when I switch between teams and I vote specially when I use single device for both”

CONCLUSION

The use of technology in classroom activities facilitates interactivity whether is it used to acquire information or as a formative assessment tool. The wide availability of smart devices nowadays makes this possible anytime anywhere as they support a wide range of tools and applications that can be integrated into the classroom for different courses at all levels. Students can now engage with their learning process through the technology sitting in their own pockets.

In this paper, an ARS system has been applied in a hybrid learning model at ACK in Fall 2021 semester with the aim of enhancing students’ in-class participation and engagement equally whether they were attending their classes online or on-campus. A noticeable difference in the engagement and attention levels between online and on-campus students was observed by the instructors and concluded from the ARS data analysis at the beginning of the study for a transitional period of almost four weeks. However, the results later converged to an almost balanced participation and success scores of both online and on-campus students which is a clear proof that ARS is an effective way to enhance and maintain equal students' engagement in a hybrid learning context.

The student survey results presented in this paper further support this conclusion. It shows that ARS-based activities enabled a beneficial collaborative learning style. Engineering students positively accepted the ARS as it enhanced their engagement and participation in answering questions as well as their involvement in peers and classroom discussions. They also acknowledged that the anonymous environment of this type of activity is more encouraging to their participation in the learning process.

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BIOGRAPHICAL INFORMATION

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International accreditation and CDIO optional standards achievement levels at UCSC

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ABSTRACT

In this article, we describe the self-evaluation processes undergone by the UCSC School of Engineering's undergraduate programs under the CDIO standards since 2013 and show how this continuous improvement process drives the School of Engineering in 2021 to collect information related to the CDIO optional standards proposed and approved by the CDIO council in November 2019. In 2019, the School of Engineering, considering its advances and achievements, its participation in the CDIO network and the experience obtained in previous accreditation processes, decides to seek an international accreditation. Currently, we have just finished our self-assessment process to achieve international accreditation under the Washington Accord. Thus, taking advantage of the coherence between the graduate attributes defined by the agreement and our students' competencies developed considering the CDIO optional standards, The School of Engineering has collected data to assess itself and thus incorporate its short-term required training requirements. Among the main findings of our self-assessment, the programs with the highest achievement levels in Sustainable development are Electrical Engineering and Civil Engineering; in the first case, it can be explained by this competence being part of the graduate attribute profile; in the other case, by the nature of the discipline. All programs develop the Simulation-based mathematics optional standard to at least level 2, while the Geological and Electrical Engineering programs achieve level 4. Entrepreneurship and internationalization (optional standards 3 and 4) are being addressed at the institutional level by the CreoeInnovo UCSC program and through a slightly more recent UCSC Internationalization initiative launched in 2020. This work also presents an improvement plan for those programs needing improvement such as Computer Science. Implementation starts March 2022, to achieve at least level 3 in 5 years' time. We think that the optional standards should become mandatory in the short term to meet future engineers training requirements.

KEYWORDS

Standards: 1-12, optional standards, accreditation criteria, program evaluation.

FRAMEWORK

The CDIO framework includes the 12 CDIO standards and the CDIO Syllabus. The CDIO Standards correspond to best practices or principles that guide the continuous improvement of study programs, and its pillars are program philosophy, curriculum development, design-implement experiences and workspaces, methods of teaching and learning, faculty development, and assessment and evaluation (Crawley et al., 2007). At the same time, the CDIO Syllabus provides a list of professional, personal and interpersonal skills and CDIO skills for development during the training itinerary (Crawley et al., 2011). These documents have undergone improvements to reflect recommendations and new trends until a set of 4 optional standards was proposed in 2020: Sustainable development, Simulation-based mathematics, Engineering entrepreneurship, Internationalization & mobility. Currently, we are working with the Syllabus 3.0 update.

Optional standards

Malmqvist et al. (2017) noted that, as engineering education best practices and the engineering context are continually evolving, the CDIO approach must also evolve. Furthermore, they argued that the CDIO framework could be made more flexible and open by introducing an additional category of standards, called “optional CDIO standards”, to be added to the original twelve standards, now called “core CDIO standards”. Since then, several proposals for optional CDIO standards have been submitted (Malmqvist et al., 2019; Malmqvist, Edström & Rosén, 2020), and the CDIO Council has decided on a process to select the proposals and work with them for possible inclusion in the CDIO framework. Thus, in 2020, 4 optional standards are incorporated 2020 (Malmqvist et al., 2020):

Sustainable development: A program that identifies the ability to contribute to a sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address sustainability challenges.

Simulation-based mathematics: Engineering programs for which the mathematics curriculum is infused with programming, numerical practiced and simulation from the start

Engineering entrepreneurship: Engineering programs that actively prepare graduates for creating technology-based business ventures, to produce economic and other values for society.

Internationalization & mobility: Programs and organizational commitment which exposes students to foreign cultures, and promotes and enables transportability of curriculum, portability of qualifications, joint awards, transparent recognition and international mobility.

Washington Accord

The Washington Accord (WA), signed in 1989, is a multi-lateral agreement between bodies responsible for accreditation or recognition of tertiary-level engineering qualifications within their jurisdictions who have chosen to work collectively to assist the mobility of professional engineers. Accord signatories are committed to the development and recognition of good practices in engineering education, and their activities aim to assist growing globalization of mutual recognition of engineering qualifications. The Washington Accord is specifically focused on academic programmes dealing with the practice of engineering at the professional level (International Engineering Alliance, 2022).

Continuous program improvement at the School of Engineering

In a culture of continuous program improvement, the School of Engineering of the UCSC has voluntarily submitted its programs to multiple national accreditation processes, as shown in Figure 1. As can be seen in this figure, the Industrial Engineering, Civil Engineering and Computer Science programs have each undergone three national accreditation processes, each time increasing their accreditation periods. It is worth noting that the Chilean accreditation system assigns accreditation periods from 2 to 6 years. Currently, all five programs of the School of Engineering are working toward their accreditation under Washington Accord criteria.

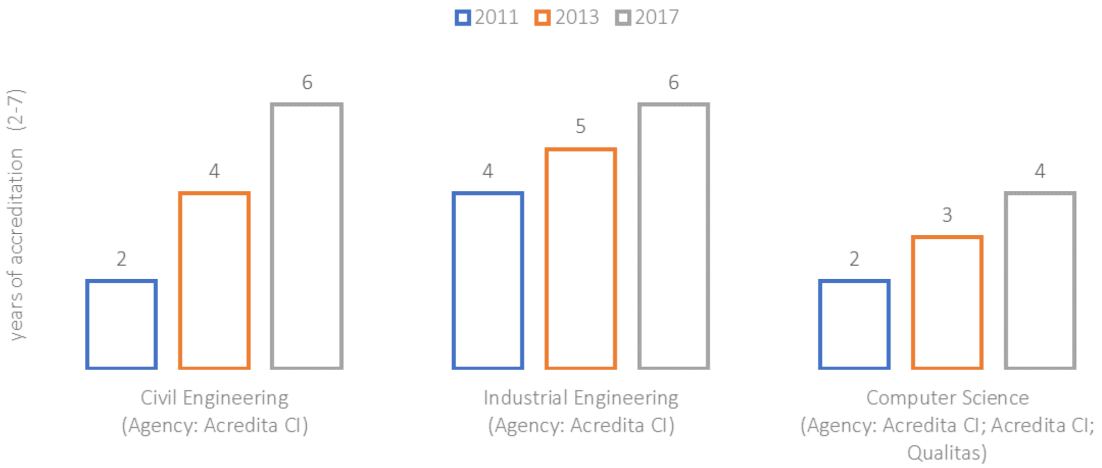

Figure 1. Increase in national accreditation periods

The School of Engineering has also been interested in self-assessing CDIO standards compliance. A preliminary global evaluation was done in 2013, which included only the Civil Engineering, Computer Science, and Industrial Engineering programs (Martínez *et al.*, 2013). Figure 2 presents these results.

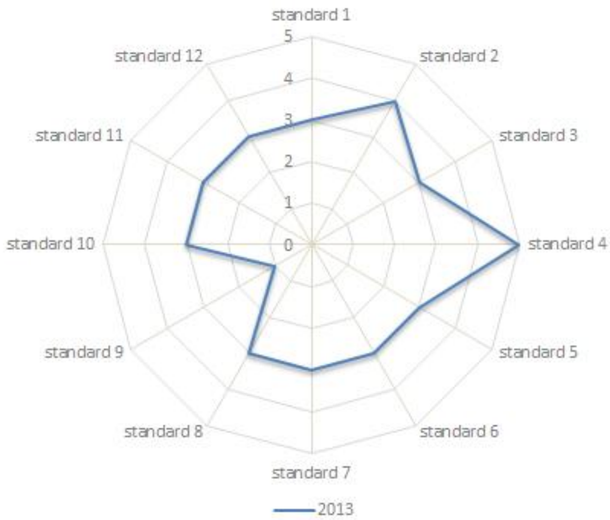

Figure 2. CDIO Global self-assessment, School of Engineering, 3 programs. (2013)

As Figure 2 shows, at that time the programs' high point was the existence of an introductory course giving students a framework for engineering practice in system building and introducing essential personal and interpersonal skills (standard 4). At the same time, the main weakness was the low level of faculty knowledge about the CDIO Initiative. To address this situation, we organized a CDIO workshop with the goal of disseminating the CDIO framework among all faculty involving in teaching engineering students, such as mathematics, physics, and part-time lecturers. As a result of this workshop, we recognized the need for a faculty competence development plan in personal, interpersonal, product, process and system building skills (standard 9). Given that the CDIO-based curricular reform had started just two years before, the levels of standards such as Design-Implement Experiences (standard 5), Integrated Curriculum (standard 3), were as expected. This self-assessment was repeated in 2015, achieving an improvement only in standard 9 (Muñoz *et al.*, 2020). Also, the Geological Engineering and Electrical Engineering programs were added in this exercise, which had begun accepting students in 2011 and 2013, respectively. Results for these programs showed that they had great room for improvement, which was largely addressed in their official curricular reforms of 2018.

Workspace improvement was addressed by building the 2,500 m^2 San José Obrero building, which includes a Structure and Geotechnics laboratory, a Hydraulics and the Environment laboratory, offices, and co-work rooms, thus promoting not only standard 6 but also standard 8. This was financed through a government-funded University Strengthening project (FIA USC 1308) and by using University funds. Standard 10 was initially strengthened by encouraging faculty to become certified through the Teacher Development Program offered by the Center for Innovation and Teaching Development of the UCSC. During the 2020 - 2021 pandemic, progress was made in aspects of disciplinary improvement (standard 9) and enhancement of faculty teaching competences by the issuance of 2 diplomas in innovation for university teaching through Laspau, an organization affiliated with Harvard University (standard 10). At the beginning of 2022, after completing the self-assessment process with a view to our international program accreditation under the criteria of the Washington accord (standard 12), we can show the progress that has been made in these years in Figure 3.

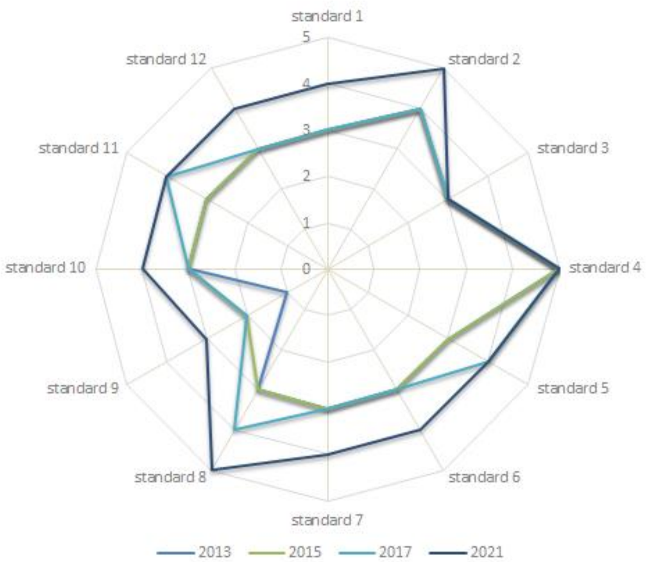

Figure 3. CDIO Global self-assessment, School of Engineering, 5 programs (2021).

Figure 3 shows a clear improvement over time in standards 2, 4, 8 and 12 related to learning outcomes, the consolidation of each program's introductory engineering course, the widespread use of active learning methodologies in both science and disciplinary courses, and an installed continuous improvement culture based on program systematic evaluations.

DATA GATHERING METHODS

In 2021, we carried out the optional standards self-assessment process for our 5 engineering programs. Data gathering was carried out using 2 strategies. The first strategy extracted relevant information from the programs' self-assessment reports for international accreditation under the Washington Accord. This strategy considers the coherence between the accreditation criteria and CDIO Syllabus skills as shown in Table 1, adapted from one presented in Muñoz *et al*. (2020), which was based on Lunev *et al*. (2013). The second mechanism was related to a survey given to the program heads and program committee members, given their in-depth knowledge of their respective programs.

Table 1. Coherence between national and international accreditation criteria and CDIO Syllabus skills (1/2)

Latin-America	Europe	Russia	Generic competencies in Latin-American, European and Russian surveys	ABET	CNA	WA graduate's attributes	CDIO syllabus
LA1	E19	R1	Ability for abstract thinking, analysis, and synthesis	x	X	WA1	2.3
LA17	E14	R2	Ability to work in a team	x	X	WA9	3.1
LA14	E7	R3	Capacity to generate new ideas (creativity)		X		2.4.3/4.2.2/4.2.6/ 4.2.7/4.3.1
LA15	E10	R4	Ability to identify, pose, and resolve problems	x	X	WA2 WA3	2.1.4/2.1.5
LA25	E22	R5	Ability to design and manage projects	x	X	WA3 WA11	4.4/4.5.6/4.6.1
LA2	E11	R6	Ability to apply knowledge in practical situations	x	X	WA1	2.1
LA7	E1	R7	Ability to communicate in a second language	x	X	WA10	3.3
LA8	E27	R8	Skills in the use of information and communications technologies	x	X	WA5	3.2.4
LA10	E2	R9	Capacity to learn and stay up-to-date with learning	x	X	WA12	2.4.6
LA6	E3	R10	Ability to communicate both orally and in the written form in the native language	x	X	WA10	3.2.3/3.2.6/3.2.7
LA24	E26	R11	Ability to work autonomously	x	X	WA9	2.4.1
LA16	E12	R12	Ability to make reasoned decisions	x	X	WA6	2.1
LA22	E25	R14	Appreciation of and respect for diversity and multiculturalism	x	X		2.5.2/2.5.6
LA5/LA21	E23	R15	Ability to act with social responsibility and civic awareness	x	X	WA6	2.4.1/2.4.2/2.5.1/ 2.5.2
LA26	E17	R16	Ability to act based on ethical reasoning	x	X	WA8	2.5
LA20	E28	R17	Commitment to the conservation of the environment	x	X	WA7	4.1.1./4.1.2/4.1.7/ 4.5.6/4.6.1/4.6.6
LA6	E18	R18	Ability to communicate with non-experts about one's field	x	X	WA9 WA10	3.2.1/3.2.7/3.2.8/ 3.2.9/3.2.10
LA3	E5	R19	Ability to plan and manage time	x	X	WA11	2.4
LA27	E30	R20	Ability to evaluate and maintain the quality of work produced	x		WA2	4.4.6/4.5.1/4.5.6/ 4.6.4/4.6.6
LA12	E4	R21	Ability to be critical and self-critical	x	X	WA2	2.4.4
LA11	E8	R22	Ability to search for, process, and analyse information from a variety of sources	x	X	WA4	2.2.2

Table 1. Coherence between national and international accreditation criteria and CDIO Syllabus skills (2/2)

Latin-America	Europe	Russia	Generic competencies in Latin-American, European and Russian surveys	ABET	CNA	WA graduate's attributes	CDIO syllabus
LA20/LA26	E24	R23	Commitment to safety	x	X		2.5.1/4.1
LA18	E21	R24	Interpersonal and interaction skills	x	X	WA9	3.2
LA9	E13	R25	Ability to undertake research at an appropriate level	x	x	WA4	2.2
LA4	E15	R26	Knowledge and understanding of the subject area and understanding of the profession	x	x	WA1	1
LA27	E30	R28	Ability to focus on quality			WA2 WA3 WA6	4.4.6/4.5.1/4.6.4/4.6.6
			Generic competencies only in the Russian survey				
LA12		R13	Ability for critical thinking		x	WA2	2.4
		R27	Ability to resolve conflicts and negotiate			WA9	3.2.7/3.2.8
		R29	Ability to focus on results				4.3.1/4.3.2/4.3.3/4.3.4
		R30	Ability to innovate		x		2.4.2/2.4.3/2.4.6
			Generic competencies only in the European survey				
LA13	E29		Ability to adapt to and act in new situations		x		2.4.2
LA19	E31		Ability to motivate people and move towards common goals			WA9	
LA23	E16		Ability to work in an international context		x	WA9	3.2.10/3.3.1
	E20		Spirit of enterprise, ability to take initiative		x		2.4.1/4.8
	E6		Ability to show awareness of equal opportunities and gender issues				2.5.5
			Computer Science competencies in the LA survey				
LA13	E12		Ability to adapt to technological changes		x	WA5	2.4.2/4.2.6

RESULTS

The results obtained after gathering and processing information are shown in Figure 4. Among the main findings, the Electrical Engineering and Civil Engineering programs have the highest achievement level for the Sustainable development standard. In the case of the first program, this is explained because this competence is part of the graduate attribute profile. Likewise, the nature of the Civil Engineering discipline explains its high achievement level. Simulation-based mathematics (optional standard 2) is present in all programs in at least 1 course (level 2), reaching level 4 in the Electrical Engineering and Geological Engineering programs. Entrepreneurship (optional standard 3) is being addressed at the institutional level by the CreoeInnovo UCSC program, an initiative that aims to strengthen and promote the development of innovation and entrepreneurship skills for all students at UCSC. A slightly more recent UCSC Internationalization initiative, launched in 2020, explains Internationalization (optional standard 4) reaching level 2 in almost all programs. This latest initiative allows students to take courses at any institution belonging to the G9[1][2] Network through the Virtual Student Mobility project. The G9 Network brings together nine non-state public universities of the Rector's Council. Thanks to this mobility project, any student will be able to study online a subject from another institution associated with the G9 during the first semester of 2022.

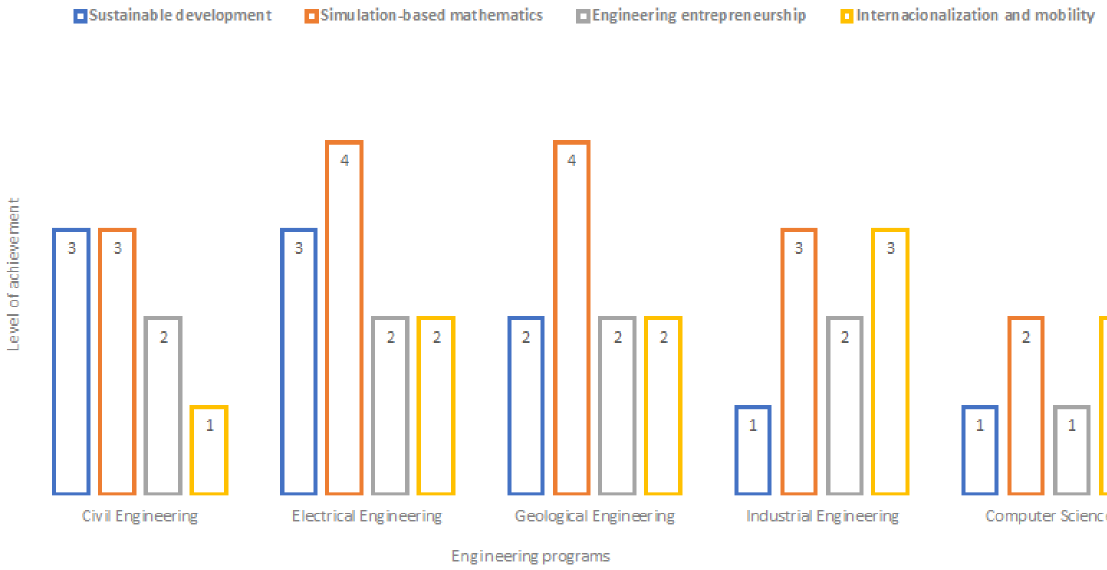

Figure 4. Optional standards achievement levels at the School of Engineering.

DISCUSSION AND PROPOSALS

We recognize that adopting the CDIO Initiative in 2011 has installed a culture of continuous improvement of our engineering programs that gives us a strong foundation for an international accreditation process. As a result, we have improved and systematized our data gathering processes.

Regarding the optional CDIO standards, our programs have not reached uniform achievement levels, being Computer Science the program with the lowest levels. However, all programs present standards at levels 2 or lower, as seen in Figure 4. It is recommended to focus our efforts on ensuring that all programs achieve at least level 3 in all four optional standards. This work should start by March 2022, to attain level 3 by the end of 2026. It is recommended to incorporate the proposed actions into the current improvement plans to ensure financing. If this is not possible, these standards should be made explicit in the actions currently planned for the coming years. It is recommended to leave the plans for standards 3 and 4 in institutional hands, actively participating in the actions and initiatives available to achieve progress. Table 2 presents some actions from our improvement plan, common to all engineering programs for the 2022-2024 period

[1] https://internacionalizacion.ucsc.cl/

[2] The G9 Network of Non-State Public Universities brings together universities belonging to the Chilean Universities Rector's Council (CRUCh). Eight of them are regional universities, from the north, center and south of the country. These institutions have a long tradition and history of proven public service. The G9 institutions are committed to Chile and its development, are diverse and inclusive and are national and international benchmarks in various matters, leading the agenda for regional development.

Table 2. Improvement plan 2022-2024 (elements common to all engineering programs).

Action	Goal	Period	Responsible	Linked to institutional strategic plan or program improvement plan
Foster sustainable development aspects in real-world projects developed during the program (optional standard 1)	At least 2 experiences per program incorporating sustainable development (one at a basic level and one an advanced level, leveraging current design-implement experiences)	From 2022 to the end of accreditation period	Program head / Faculty	Yes
Foster enrollment in entrepreneurship courses (optional standard 3)	At least 10% of all program students	Starting 2022	Program head	No
Active participation in the UCSC internationalization program linked to the USC 20102 project (optional standard 4)	At least 1 international student experience per year	Starting 2022	Department head and Institutional Relations Director	Yes

Additionally, in 2020, UCSC declared its commitment to the Sustainable Development Goals and stated a model that contributes to these goals through its teaching, research, development, innovation, entrepreneurship, cooperation, and outreach, thus assuring that UCSC has a commitment to supporting initiatives in that direction.

CONCLUSIONS

Adopting the CDIO Initiative in 2011 has proven to be a strong strategy for installing a culture of continuous improvement in the School of Engineering. Both the 12 Core Standards and the 4 Optional Standards have been helpful guidelines to prepare our programs for an international accreditation process.

Our optional standards self-assessment process has reinforced our commitment to work to achieve at least level 3 in all our engineering programs, especially in the Computer Science and Industrial Engineering programs. To that extent, our improvement plans propose that all programs include an annual interdisciplinary design-implement experience focusing on sustainability, electromobility, climate change, among others.

Starting the first semester of 2022, the institutional internationalization plan will allow us to address optional standard 4, either through the G9 Virtual Student Mobility project or by teaching courses in a second language.

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SURVIVING AND THRIVING IN FIRST YEAR - SUPPORTING STUDENT EXPERIENCE

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ABSTRACT

To support to students' transition into university, the authors developed the Engineering Attributes Program in 2019. The program includes a series of modules, such as The Mental Health Continuum, Exam Anxiety, Procrastination, Time Management, Academic Burnout, Motivation, and Diversity. Each module includes information delivered to first year students and a corresponding reflection grade. The delivery modes implemented over the three years of the program's delivery are summarized in this paper. The authors have reviewed student comments and have grouped them into themes, which are summarized in this paper. The authors will share their insights into the student experience, based on our interactions with students over the years, and our reading of their reflection assignments.

KEYWORDS
Mental Wellbeing, Reflections, First-Year, Standard 8

INTRODUCTION

At universities across Canada, student survey data indicate that students in first-year engineering face common challenges related to their mental wellbeing. Students report feeling overwhelmed by all they have to do (89.2%), feeling overwhelming anxiety (60.3%), feeling things are hopeless (52.6%) and feeling so depressed that it is hard to function (39.0%) [ACHA]. In engineering in particular, the workload in first-year is high and many students struggle in the transition to university life. Student surveys at our institution indicate that our engineering students are no exception to this trend – well over half the students report feeling overwhelmed, lonely, anxious and sad frequently throughout the academic year. While many students acknowledge that mental wellbeing supports are available on campus, small numbers of students choose to access those supports – only 5-10% of our students report having accessed any type of mental wellbeing support on campus.

At the University of Calgary, we implemented a first-year engineering wellness program (called The Engineering Attributes Program) in 2019 to provide students with concrete tools for wellness and learning strategies. The purpose of the program is not to replace professional mental wellbeing supports; rather, it is to normalize conversations around mental wellbeing, increase awareness of campus supports, foster a positive sense of belonging and community, and encourage students to develop a self-reflection practice. The curriculum for this program was developed in collaboration with students, a faculty member from the department of psychology and staff in the University of Calgary's Wellness Centre. The curriculum includes topics such as The Mental Health Continuum, Exam Anxiety, Procrastination, Time Management, Academic Burnout, Motivation, and Diversity.

The program includes student reflection assignments, which provide very rich data for understanding the student experience. Throughout the three years of running the program, our first-year engineering courses have had very different delivery modalities; starting with a “traditional” lecture delivery in year one (2019/2020), moving to remote learning in year two (2020/2019), and finally a blended delivery with a focus on studio-based in-person active learning (CDIO Standard 8) in year three (2021/2022). This new delivery method is discussed in the author’s companion paper “Implementing Active Learning in First Year Engineering – A Leadership Perspective” from this same conference proceedings.

BACKGROUND

The transition to university from high school is a time of significant change for students, and this can cause the emergence of significant anxiety and depression (Merriam & Baumgartner, 2020). During this time of transition, students can feel overwhelmed, isolated, and that can often lead to attrition of students (Schuh et al., 2010). Often, undergraduate students who feel they are not able to achieve their goals will list procrastination and poor time management as factors which led to their lack of achievement (Lavecchia et al., 2016).

Studies have shown that curriculum and programming which is targeted at improving student self-efficacy and self-esteem leads to increased retention and positive outcomes for students (Nordstrom et al., 2014). There is a direct correlation between GPA outcomes and student mental health and wellness, suggesting that early intervention with mental health programming could support student success for undergraduate students (Krumrei-Mancuso et al., 2013).

In engineering specifically, mental health and wellness research is a growing area of research that is still quite limited (Danowitz & Beddoes, 2020). A study at the University of British Columbia found that over 50% of students in engineering felt overwhelmed, exhausted or sad (Golsteyn & Nino, 2018). Additionally, 10% of students considered suicide within the last 12 months, which is an alarmingly high number of our students (Golsteyn & Nino, 2018). These numbers emphasize the importance of doing mental health and wellness programming to provide students with resources and tools to support them both academically and personally.

In the medical field in Canada, there is a call to create a national framework to support student wellness (Bourcier et al., 2021). It is important to remember when integrating mental wellness programming to not just rely on providing students with information, but to also analyze the system and chance systemic factors (such as too high of a workload) that are contributing to student stress and wellness. In engineering, the University of British Columbia has also implemented integrated programming and their results show the importance of interventions for reducing stress factors such as exam anxiety.

ENGINEERING ATTRIBUTES PROGRAM

The curriculum for this program was developed by the Engineering Attributes (EA) team. The EA team was comprised of academics, graduate and undergraduate students from the faculties of both engineering and psychology and the Engineering Academic Development Specialist (ADS). The EA team worked to compile the curriculum in consultation with staff in the University of Calgary's Wellness Centre. The curriculum is summarized in Table 1.

Table 1. Engineering Attribute Curriculum 2021/2022

Timing	Topic	Speaker/Facilitator
Wk 3 Fall	Academic Integrity	Associate Dean
Wk 4 Fall	Exam Anxiety	Engineering ADS
Wk 5 Fall	Mental Health Continuum & Wellness Wheel	Psychology Professor
Wk 6 Fall	Teamwork	Psychology Professor
Wk 7 Fall	Impostor Syndrome and Resiliency	Engineering ADS
Wk 8 Fall	Time Management and Procrastination	Undergraduate Student
Wk 9 Fall	Academic Burnout	Undergraduate Student
Wk 11 Fall	Teamwork #2	Psychology Professor
Wk 12 Fall	Diversity and Resilience	Assoc. Dean T&L
Wk 13 Fall	Review	Engineering graduate TA
Wk 2 Winter	Safety Mindset	External
Wk 4 Winter	Biases and Social Wellbeing	Undergraduate Student
Wk 6 Winter	Substance Use	Social Work Professor
Wk 10 Winter	Metacognition, Bloom's & Errorful Learning	Assoc. Dean T&L
Wk 12 Winter	Review and Emotions in Learning	Engineering Graduate TA

Students are expected to submit reflections related to the module for completion grades. As an example, in the "Imposter Syndrome and Resiliency" module, the Academic Development Specialist delivered a presentation defining and describing Impostor Syndrome, and shared practical strategies for cultivating more resilient thinking. The students' reflection assignment, as seen by the students in their online Learning Management System page is shown in Figure 1.

Oct 19 Imposter Syndrome & Resiliency
REFLECTION QUIZ
Quiz

Due Oct 21, 2021 1:00 PM Starts Oct 19, 2021 12:00 PM Ends Nov 2, 2021 5:00 PM

Disclaimer: The following questions ask about your resiliency, imposter syndrome, and possible cognitive distortions. Please review the material presented in the seminar to support your answers. Do not feel obligated to delve into deep personal stories on these topics if it doesn't feel safe for you right now. Your marks are completion based.

Reflect on a situation you may have fallen into imposter syndrome, a fixed-mindset, or cognitive distortion narrative.

1. CATCH IT: What thoughts, feelings, and emotions were you experiencing in this situation? Consider and summarize at least 3-4 different feelings and emotions.

2. CHALLENGE IT: What cognitive distortion do you think you may have fallen in to? How could you reframe or rephrase your internal narrative to a positive, growth-mindset oriented thought? Summarize in 2-3 sentences.

3. CHANGE IT: Consider your responses above, what resources or habits do you plan on leaning on to support you in this kind of situation, or when you fall into this kind of thinking? Summarize in 2-3 sentences.

Figure 1. Screen Capture of Reflection Assignment for Impostor Syndrome & Resiliency Module

In the three years of the program implementation, the delivery mode of first year has changed significantly, while the basic content of the Engineering Attributes program has remained largely consistent. Delivery methods are described in below.

First Implementation – Delivered via In-Person Class Visits

In the first year of the initiative (2019/2020), we delivered the material through conventional in-person lecture where the content was integrated into technical courses for most of the year, albeit the delivery transitioned to remote in March 2020. The course instructors for 5 of the ten first year courses agreed to take part in the program. For each of these 5 courses, instructors scheduled 3 class visits throughout the semester. In these class visits, a member of the Engineering Attributes team delivered a 15-minute module, which included information on a mental wellbeing or learning strategy topic, a short activity, and a personal reflection assignment. In each participating course, 3-5% of the course grade was assigned to Engineering Attributes reflections, which were graded on a completion basis.

Second Implementation – Delivered via Virtual Class Visits

In second year of the initiative (2020/2021), all the content was delivered remotely, due to the global pandemic restrictions. The course instructors for 4 of the ten first year courses agreed to take part in the program. For each of these 4 courses, instructors scheduled 3 class visits throughout the semester. In these class visits, a member of the Engineering Attributes team delivered a 15-minute module in the zoom-based classroom environment, which included information on a mental wellbeing or learning strategy topic, a short activity, and a personal reflection assignment. In each participating course, 3-5% of the course grade was assigned to Engineering Attributes reflections, which were graded on a completion basis. In this second iteration, a D2L course page was created specifically for the Engineering Attributes program. The modules were recorded and posted for the students to review as they wished.

Third Implementation – Delivered via Weekly Scheduled Seminar Hour

In the most recent year (2021/2022), the entire schedule of the first-year engineering student experience has been transformed with the transition to blended learning. The first year blended model is described in another of the author's papers in this conference proceeding. The Engineering Attributes content is now being delivered in weekly 50-minute seminars scheduled specifically for this purpose. The seminars were delivered in person, and live-streamed over zoom. They were recorded and posted for the students to review. Following the seminar, students were assigned personal reflection questions. In each engineering course, 3-5% of the course grade was assigned to Engineering Attributes reflections, which were graded on a completion basis.

RESULTS and DISCUSSION

Across all three implementations, students regularly provided feedback on the Engineering Attributes program, through formal survey questions as well as informally through email feedback and personal conversations. Across the three different implementations, we observed similar themes in the feedback and will summarize those in this section.

There are four main themes that emerged in the feedback, three of which were common each year, and one of which had slight variation depending on the implementation. The three common themes were: *students feel seen, students are receiving information,* and *students feel we are helping them succeed*. The fourth theme can be summarized as *students don't have time*, and how this one emerged varied across each year. In the analysis below, representative quotes are only provided for the first and second implementations, as research ethics has not yet been completed for the third implementation.

Students feel seen

Across all three years, we regularly heard appreciation from students because they felt seen and didn't feel alone due to the content being discussed in the engineering attributes program. Much of this feedback was informal through one-on-one conversations and emails from students sharing their appreciation. There were two main subthemes within this area: being seen by faculty and leadership, and not feeling alone.

Being seen by faculty: "Just the idea that you guys care"

It was common for students to come up to us after class and let us know that it's nice to see the faculty and leadership cares about their wellbeing. One student from the second implementation said in their reflections, "Just the idea that you guys care is enough for most of us. We do appreciate it and what you guys do." Students often shared their appreciation with us, and genuine thanks for showing that we care. In the first implementation, a student said, "Everything was very useful thank you for doing what you have done." Much of this sentiment comes because students want faculty and leadership to acknowledge the huge transition that they are going through and how this can be quite difficult. One student phrased it well, "I have found these presentations critical to my transition to university and would love to see more content presented." Simply reminding the students that we understand they are going through some things is helpful in helping them feel like we are treating them as human beings.

In the second and third implementation of the program, students regularly talked about how helpful it is to feel supported by their peers and feel as though others can relate to their experience. In these two implementations we had upper year students coming into the class to support the Engineering Attribute modules and we believe this made a huge difference. Additionally, in the second year when the program was entirely virtual and synchronous, students were more likely to share relatable feelings in the Zoom chat feature.

Many of the comments go beyond being able to relate to each other, but students often felt they were the only one struggling and it was very comforting to know that others were struggling in the same way and normalizing the feelings. One student said, “Talking to other people and making these things seem normal makes me less afraid when something like this does happen. Because I am not the only one.” Another student talked about how they were “feeling bad about [them]self” but during the Engineering Attributes they were able to “talk to the people in the class who were in the same boat as me” and that this “really helped and made [them] feel better.” Being able to normalize these feelings is an integral part of the program, one student even said, “I feel that one of the most helpful components that the program offer's is the normalizing of the feelings that most of us are feeling.”

In the first year of the program, it was less common to receive this feedback, which emphasizes the importance of the upper year students engaging in the module delivery. Some students even recommended this in the first year, suggesting, “Maybe even included personal stories from students or student-led aspects to make it more personable and less like a formal lecture” or that it would be helpful to learn “from upper year students and getting tips and tricks.”

Students are receiving information

When delivering a program, it can be difficult to know if the information resonates or is useful to students. From the feel on the program, we have found that all modules resonate with at least a portion of the students, and all students resonate with at least a portion of the modules. The goal is not to make every module applicable to everyone, for example, *exam anxiety* is not a topic we expect everyone to need support with. However, the concepts we teach can be applied widely and we have found that mostly everyone comes out with some useful information. We found two subthemes in this area, generally just that the information is useful, and specifically that the information on accessing additional resources and services is beneficial.

The information is useful: “Thank you for all the tips!”

Students will comment on specific modules that they found most helpful to them. For example, in the first implementation, students said “I found the stuff on wellness very helpful because balance is hard.” In the second implementation, students talked about how “the exam anxiety and de-escalation strategies were most helpful,” or how they “often use the "square breathing" technique and other grounding exercises we learned to get me through stressful times,” or that “the imposter syndrome/resilience seminar was by far the most helpful.” These are just a few examples, almost each module is specifically mentioned by one student as being the most impactful. Generally, the curriculum is designed to follow the flow of when students will need the information, which was acknowledged by this student, “I think that the topics are pretty spot on for what a first year engg student is going through so the material is super relevant”

The students also talk about how the information is application to their engineering career. In the first implementation, one student said, “Engineering Attribute Activities teaches us important applicable soft-skills that not only enhance our learning experience and academic career, but also apply to and will carry to our professional future in the foreseeable future." Although often the technical is valued about professional attributes in engineering, some students understood the importance: "This is awesome because these skills are equally as important as other things we are learning and will help us to be more well-rounded." Others appreciate the program because it has helped them to develop this understanding, one student staid the program "provides me with a new realization about the importance of mental health and how that affects others around me."

Access to resources on campus

Anecdotally we found that the Engineering Attributes program increased help seeking behavior. For example, the Engineering Academic Specialist whose role it is to support students in their academics, found before the Engineering Attributes program she only received emails asking for help *after* the first midterm. In the year of the first implementation, she had already schedule 10 appointments with students prior to the first midterm. That being said, in the first implementation we didn't have a structured resource list and often received feedback that this would be helpful. One student suggested, "Engineering Attributes should have more information on D2L a course shell maybe" and another said, "It could be good to have a list or explanation of all the resources in Schulich. As a student, I feel that I don't know where or when to access the Student Success Center, Academic Advisors, or other resources (I don't really know if there is any others)." This showed the importance of not just talking about the resources available during the modules, but also having multiple spots where students could find the list of resources.

In the second implementation, at the end of *every* module we included a slide with resources, as well as highlighting the specific ones relevant to the topic that week, and including resources on the D2L course shell. We received feedback from students which said, "I think that this is generally a good way to let people know about the resources available to them if their struggling" and "I also appreciate the knowledge of what resources are available for us," which shows that this was helpful.

Students feel we are helping them succeed

Beyond the engineering attributes program helping students to feel seen, and being useful to students, they truly feel that the program was designed to support them in their learning as best as possible. This emerged in two subthemes – they felt the reflections which followed each module were beneficial to their learning, and they appreciated the "free" grades.

Being forced to reflect each week - "Allows me to take time and think about myself"

In the first implementation of the program, we wanted to keep the homework to a minimum so we would often encourage students to quickly login and do the reflection quiz during class. This meant the reflections were often only a couple words and were very surface level. In the second implementation, since it was virtual, the reflection quizzes were due 48 hours after the presentation. Additionally, at the end of each question we included "summarize in 2-3 sentences". Although we knew this small change would lead to deeper reflections, we also expected students to have a stronger dislike of the reflections. Rather the opposite happened where we heard over and over again how much students appreciated the reflection. Here are just a few student quotes from the second implementation exemplifying this:

- “The most helpful part of this program is that it gives the students a chance to slow down and reflect. Sometimes we get busy and everything is moving so fast it is nice to stop for a moment relate with others on how the semester is going.”
- “I mostly write these for myself as its incentive to think about how I think more in depth than I usually do. Also it makes me think critically about how I deal with these problems.”
- “Seminars give me chance to reflect my learning process. It allows me to take time and think about myself and recognize my strengths and weaknesses.”
- “I really enjoy these reflective quizzes. Since they have a due date, it kind of forces me to reflect, which I think is very helpful going forward. It's nice to take a break on school and reflect on how I'm really doing regrading my mental health and my academics.”

Free grades - “the tiny GPA boost in my class”
Although it might be unusual to highlight students giving feedback that they appreciate the free grades, this exemplifies one of the values of the Engineering Attributes program. We want to provide students with useful information and value without added stress. For example, one student in the second implementation said “I like how we can get marks for our classes by answering these thought-provoking questions, and that the seminars really do help with my mental health, as well as teach me some life skills.” Another student in the first implementation said, “It's nice getting free marks during these seminars, while simultaneously learning studying strategies.” If a couple ‘free’ marks is all we need to get students to listen to mental health strategies and reflect on their academic wellbeing, then we would call this a success.

Students don’t have time
As with any program, there are always areas for improvement. Students often gave suggestions for improvement, but they often fell within a common underlying theme. Students struggled to have time to fit in self care when they were already feeling overwhelmed by all the other requirements on their time. Because each year the program was implemented slightly differently, this manifested uniquely in each year dependent on the implementation.

Implementation year 1: Bad timing
In this year, many students talked about how they felt when Engineering Attributes were in their classes they were missing out on other material. This student quote highlights it well: “The presentation during our ENGG 233 lab was not good timing as labs usually take the entire class to complete and everyone was hoping to finish early in order to go and review for our chem midterm later that day, as consequence not many people were truly listening to the talk and it added unnecessary stress to our day.” It is evident that this student prioritizes their ENGG 233 (computing for engineers) lab and their chem midterm above the Engineering Attribute materials. Another student gave a suggestion saying that instead of class or lab time, “seminars work better as it's a chunk of time allocated to that so it doesn't leave students feeling like they're wasting time or anything.” Again, the implication here is that Engineering Attributes are a ‘waste’ of time relative to other technical course material.

Implementation year 2: Stressful deadlines
Although many students talked about the learning value with the reflective quizzes, they also said that they felt the regular deadlines added stress to their already busy schedules. One

student said that the “reflection quizzes, sessions and projects take more time from studying or taking a break.” The higher value this student places on ‘studying’ relative to learning about Engineering Attributes is evident. Another student said the goal of the program was positive, but “attaching a grade and deadline to these quizzes - as minimal as they may be, might not be the best approach, as they could end up being just another source of stress on top of an already packed workload.” Other students talked about how the deadlines were “cumbersome” or difficult to “keep track of” or feeling “swamped.” Overall, these responses show that students feel their workload is too high and to resolve this, they would change the Engineering Attributes program as they view it as lower value than their other classes.

Implementation year 3: Sessions too long

In the third implementation, sessions were delivered by consistent weekly scheduled seminar hours. Across the feedback, we regularly saw comments from students who said that the sessions were too long. Again, these comments are often include the sentiment that there is other studying the students could be doing with their time. This seems to be consistent with the perception that students value their technical engineering content over the engineering attribute content. In addition, attendance was observed to be lowest in this format of content delivery.

CONCLUSIONS / RECOMMENDATIONS

The Engineering Attributes team has successfully implemented a program for First-Year engineering students to support them in their mental wellbeing and transition to the university environment. In general, the feedback about the program is that it enhances a feeling of support from the students, like the university environment “cares” about them. The students agree that the content delivered in this program is important and helpful to them as they navigate their first year on campus.

Ongoing challenges with the program are that the students still feel like it is difficult to make time for this content. Students acknowledge how important their humanity is, but they tend to prioritize technical content and grades in their courses and therefore find it challenging to prioritize their wellbeing.

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IMPLEMENTING ACTIVE LEARNING IN FIRST YEAR ENGINEERING – A LEADERSHIP PERSPECTIVE

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ABSTRACT

In Fall 2021, the delivery of first year engineering at the University of Calgary was changed to blended (or "flipped") delivery mode, with a focus on studio-based active learning experiences in the in-person component of every course (CDIO Standard 8). In this paper, we offer the leadership perspective on what was required to accomplish the complete overhaul of the first year delivery. Lessons learned from our first year are summarized. Recommendations for future iterations of the delivery method are described.

KEYWORDS

Active Learning, Blended Learning, First-Year, Leadership, Standard 8

BACKGROUND – WHY CHANGE OUR DELIVERY MODE?

The common first-year engineering curriculum is comprised of 10-technical courses: 5 engineering, 1 chemistry, 1 physics, 3 math. In the past (pre-pandemic), these courses were delivered in a fairly traditional manner. Each course included 3-4 hours per week of lecture time, 1-2 hours per week of tutorial and some courses have a 2-3 hour weekly or bi-weekly lab session. Prior to 2021, our first-year cohort consisted of approximately 800 students enrolled in 4 blocks of approximately 200 students. In Fall 2021, we expanded our first-year enrolment to 1000 students. With the conventional model, this would mean five separate instructors delivering the same lecture material to separate large classes. This presented continued challenges around ensuring consistent delivery of the material across lecture sections. In addition, with the large class sizes, students often report feeling quite anonymous and disconnected from their community.

The decision was made to change the delivery method in all ten courses to a blended delivery mode, with lecture content delivered via lecture videos, and all in-person time converted to active learning sessions. The benefits of flipped delivery has been discussed often in the past years (Lo and Hew, 2019). In our institution, there were several reasons why it was particularly appealing at this time.

Utilize Online Content

During the emergency switch to remote delivery during the pandemic (March 2020 onwards), instructors were forced to create online content. For many of us, this included creating lecture videos and developing our skills using online Learning Management Systems for communicating with students, managing a course, moderating discussion forums and holding assessments. Among instructors, there was a sentiment that it would be efficient if we could continue to use the online material that we developed during the pandemic. The advantages of continuing to deliver the lecture content remotely and asynchronously (eg. through lectures videos) include consistent access to lecture content for all students, access to lecture content if a student misses a class, students' ability to watch and rewatch at their own pace. In student surveys at our institutions in 2020 and 2021, students indicated high levels of satisfaction for lectures being delivered via pre-recorded videos.

Enhance In-Person Active Learning and Community Building

Delivering lecture content online created time and energy to convert the in-person class time to active learning. Active Learning comes in many shapes and sizes. In general, the goal is to engage the students in genuine experiential learning, where they are actively *doing* more than they are passively *listening*. This engagement results in deeper learning for the students (Jazayeri et. al. 2020, Cho et al. 2021). The courses were rescheduled from large lecture sections (>200) to ten blocks of 100 students. The course delivery was re-designed with the intention that the same active learning session would be delivered to each of the ten blocks of 100 students. With instructors, graduate teaching assistants and undergraduate learning assistants in the room to support learning, students would work on problems, projects, data analysis, class demos, etc. In the smaller classes, we assigned students to learning communities of 25 to encourage the students to make connections and develop study groups with their peers. Learning Communities have been observed to be a powerful mechanism to help students form bonds, develop a sense of belonging and build strong support networks as well as supporting student mental wellbeing (Ribera et al., 2017; Tinto, 2000; Harms et al. 2001).

Genuine Team Teaching and Teaching Mentorship

In this model, the teaching team is working more collaboratively to develop and deliver course material. In the conventional delivery of years past, the instructors worked in parallel, each preparing and delivering their own lecture material. In this new model, instructors worked together to develop active learning sessions, and all instructors delivered the same session. This reduces the wasted effort of having several instructors preparing the same material. For each course, we hired a mixture of experienced and inexperienced instructors, to foster an opportunity for teaching mentorship for our less experienced instructors. For example, in one first year course (ENGG 201: Behavior of Gases, Liquids and Solids), the teaching team consisted of experienced and new faculty members, Post-Docs from the department who were new to teaching and one Post-Doc who had no teaching experience. The most experienced faculty member was assigned the Lead Instructor/Course Coordinator role. The remainder of the team was responsible for developing and delivering the Active Learning Sessions, under the supervision and in collaboration with the Lead Instructor.

FIRST YEAR BLENDED LEARNING

In the Fall of 2021, the delivery mode of all 10 courses was updated to a blended delivery mode, with a focus on studio-based in-person experiential learning. First year enrolment is 1000 students, scheduled in 10 blocks of 100 students. The in-person class times are scheduled in studio-based learning rooms, instead of conventional lecture theatres. In the studio-based learning rooms, students can sit in table of 4 and teaching team can circulate through the room to engage with student teams.

Online Lecture Content
Each of the 10 technical courses delivers lecture content online through pre-recorded lecture videos, practice problems and short quizzes to test understanding. The online lecture content is available to students through an online learning management system, D2L. Students are expected to engage with 1h – 1.5h of lecture content per week per course. Sample problem solutions videos are posted for students to review. Practice problems are made available. To encourage students to stay current with the weekly lecture material, weekly online lecture quizzes are required to be completed for a small percentage of the course grades. The lecture quizzes tend to be short (one to five true/false or multiple choice questions) designed to test understanding of the lecture material.

In-Person Active Learning
The in-person content has been redesigned to be team-based experiential learning, including classroom demos, project and problem-based learning, hands-on learning, team-based worksheets, gamified learning and other active learning sessions (CDIO Standard 8).

Seminar Series
A weekly seminar series was created to support student wellbeing and professional skills topics. Seminars were scheduled for one hour every week and covered various mental wellbeing and learning strategies content. The seminar series is discussed further in the author's companion paper in this same conference series.

Extra Learning Supports
To support the students in their first year, many out of class supports are available. Learning Assistants are upper year engineering students who are hired and trained through the Engineering Student Centre. The learning assistants are scheduled and available daily to offer one-on-one tutoring for first year students. Upper year students are also hired to run Peer-Assistant Study Sessions to help large groups of students gain extra practice with the course material.

THE LEADERSHIP PERSPECTIVE

The authors of this paper are involved in the leadership team at the faculty. One author is the current Associate Dean, Teaching and Learning. In addition, she has experience teaching one of the first-year courses. The second author has acted in various leadership positions in the school and was brought into the project early on a the "First Year Academic Coordinator". He also has experience teaching one of the first year courses, and was instrumental in the development of the Integrated Learning Stream (Jazayeri et. al. 2020) in the Electrical Engineering program, on which this new first year program was modelled, in part. In the following section, we'll share our perspective of what went on "behind the scenes" to enable this significant change in delivery to successfully happen.

Learning Spaces

The spaces in which active learning are scheduled are important. In order to make this project work, we spent a great deal of time negotiating with The Registrar's Office. We secured 5 spaces for first year delivery. Each room had a capacity of 100 students. The summer was spent renovating the rooms. Instead of conventional lecture halls, the rooms were designed to host 25 tables of 4 students. This allows the students the space to work collaboratively. In the active learning sessions, there are still sections of instructor-led content. The technology in the room is designed to support this. The instructor can teach from a podium, which is fitted with a computer, a document camera, and hookups to connect to other devices (eg. personal lap-tops). From the podium, the instructor can project their work to screens which are set up on multiple walls of the room. This means students can see the screen, regardless of what direction they are facing.

The rooms were booked for the first-year classes all day. Five of the blocks were scheduled in active learning sessions in the morning, and the other five scheduled in the afternoon. The students were given access to the rooms over lunch break and in the evenings, to use as a collaborative workspace.

Staffing

In this academic year, additional funding was provided from the faculty for additional teaching assignments and graduate teaching assistants. For the engineering courses, we implemented a team model. This included one course coordinator and 5 Active Learning Instructors for each of the courses. The course coordinator was responsible for creating the online component of the course, managing communication with the students, coordinating the active learning sessions and setting assessments. The active learning instructors were responsible for designing and running the active learning sessions. In some cases, the active learning instructors were faculty members or experienced instructors. In each course, a few PhD Candidates or Post-Docs were hired as Active Learning Instructors, to support them in their career progression as part of a teaching team.

The faculty appointed a new teaching appointment of “First Year Academic Coordinator”. This position was given to an academic staff member with experience in active learning and team teaching. Their role was to coordinate the overall first-year experience. This included communication with students, running collaboration meetings with lead instructors of all first-year courses, and running the first-year seminar series.

In each active learning session, at least 4 teaching team members were assigned to support the students. This was typically the active learning instructor, two graduate teaching assistants and one undergraduate Learning Assistant. At our institution, students of all disciplines take part in an optional 12-16 month work placement in between their third and fourth year. Four full-time student internship positions, “Learning Assistants”, were created specifically for this first-year delivery method. The interns are scheduled to be in the active learning session for the engineering courses, to answer questions and give students feedback on their work.

In addition to the teaching team staffing, we assigned support staff to the first-year project. A Teaching and Learning Specialist was involved to help coordinate seminars, manage communication, support instructional team in other ways.

Collaboration

Non-Academic

There are many departments on campus involved with coordination of the first-year program. The planning of this significant change in delivery involved detailed consultation with the Registrar's Office, the Faculty of Science, the Student Advising Office, and student groups. The Registrar's office is responsible for scheduling and space allocation. The scheduling for this new delivery method does not conform to the standard schedule at our institution, so collaborative meetings were required to create a unique schedule for our active learning spaces and for the students. Because the first-year includes five courses taught by the faculty of science, their buy-in was critical to a successful delivery. Our Student Advising Office was a critical partner in this change. They are the first line of communication with incoming first years, and their help with communication and student engagement leading up to September was helpful. And finally, before and during this delivery change, we consulted regularly with our student reps to hear their opinions and ideas.

Academic

Within the ten courses in first year, there has not typically been much communication in the past, despite a widespread acknowledgment by instructors that more coordination would be helpful. We used this change as an opportunity to implement more communication and collaboration between course instructors. The lead instructors of each course met monthly or biweekly from May – April, both when planning courses and while delivering courses. These meetings were chaired by the First Year Academic Coordinator. Throughout these collaborative meetings, instructors were able to coordinate midterms schedules, so students did not have more than two midterms in one week. Instructors made some shared decisions about the overall layout of online course pages, to give students some consistency. When issues arose during the term, these regular meetings gave instructors more ability to create and enforce consistent course policies.

LESSONS AND RECOMMENDATIONS

Overall, our feedback from students and instructors is that the model works well. Students appreciate the active learning sessions, both as opportunities to learn in an engaging way and as a method to connect with their classmates. Instructors and TA's find the active learning sessions a rewarding way to connect with the students and enjoy seeing the "lights go on" when a student suddenly understands a concept. For future iterations, we have some recommendations based on our observations this year:

General Learner Orientation

The transition from high school to university is always a challenge for students, and that is no different in this learning modality. In future iterations of our first-year delivery, we intend to schedule the entire first week of class as a "learner orientation". In this week, we will deliver active learning sessions on topics such as: how to effectively engage with lecture videos, how to learn effectively in a team; how to create a schedule, as well as covering course-specific expectations for the term

Active Learning TA/LA Training

Our Teaching Assistants are a crucial aspect of the success of this program. Having a combination of graduate TA's and undergraduate LA's to support the active learning sessions is a model that works very well. However, for many of our TA's and LA's, the role of supporting active learning is new to them. In future years, we intend to develop a strong active learning training for the TA's and LA's to help them in developing the skills necessary to be effective in active learning spaces.

Coordinated Out of Class Supports

The students appreciate having spaces where they can go to ask their questions out of class, and we have many different programs and opportunities for them to do so (Instructor Office Hours, Learning Assistant tutoring hours, Peer-Assisted Study Sessions, etc). However, since those supports are delivered by different groups of people, their schedules can at times conflict. In future iterations, we intend to coordinate between the out of class supports to minimize time conflicts and increase students' awareness.

Seminar Series Engagement

While students appreciated the general material available to them in the seminar series, attendance and engagement was low. Our delivery method will be updated in future years to encourage engagement.

Instructor Face Time

A challenge with our current instructional model was that students didn't always get a chance to interact face-to-face with the instructor that they saw in the lecture videos. In upcoming years, we will make some changes to the team-teaching model to encourage instructors to have both an online and in-person presence.

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SOLVING REAL-WORLD PROBLEMS IN ACCOUNTING INDUSTRY USING CDIO FRAMEWORK

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ABSTRACT

This paper shares the work done by final year students from the Diploma in Accountancy (SP Accountancy) at Singapore Polytechnic (SP) in solving real-world problems using the CDIO Framework. Guided by relevant sections of the CDIO Syllabus and Standards, it explains how robotic process automation (RPA) is used to conceive, design, implement and operate to produce a suite of digital solutions covering accounting, auditing, tax and corporate secretarial needs of Accounting Entities (AEs) in Singapore. The prototype solutions proved useful to the accounting industry, resulting in the Institute of Singapore Chartered Accountants (ISCA) signing a Memorandum of Understanding (MOU) with SP to further help its members adopt digital solutions. Another MOU was signed with the Singapore Accountancy Commission (SAC) to fund SP's RPA projects for the industry.

The paper explains the challenges faced by the accounting industry to adopt digital solutions. It also explains the challenges faced by SP Accountancy in securing meaningful final year projects (FYPs) which become the motivation for change.

The paper then explains how the CDIO Syllabus was use to pilot a new approach to executing FYPs. The paper describes in detail work done during the four stages of conceiving, designing, implementing and operating the suite of digital solutions.

The paper shares the finding of students' learning experiences under the new approach, and examines whether it can better prepare them with the necessary skills for the industry. Feedback from industry partners, which has largely been positive, are also shared.

This paper concludes with the author's reflection to investigate how the CDIO Framework can be used to improve the teaching in SP Accountancy at the course-level; and plans to move ahead with this new way of executing FYPs by expanding into other areas in the sector.

KEYWORDS

Robotics Process Automation, Accounting Entities, CDIO Syllabus Parts 3 and 4, CDIO Standards 1, 2, 5, 9 and 11.

THE CHALLENGES FOR ACCOUNTING ENTITIES TO ADOPT DIGITAL SOLUTIONS

Accounting Entities (AEs) typically provide audit and assurance services as well as other non-audit related services such as basic accounting services, tax preparations, corporate advisory services and consultancy services. AEs in Singapore are split into three main categories: Big Four AEs, Large AEs and Small and Medium Practices (SMPs).

The auditing industry works long hours. Overtime is the norm, especially during peak season, and most auditors would desire better work-life balance. Auditors are cognizant that many of their day to day tasks are automatable and thus are more open to adopting new digital skills to remain employable (Lee & Loke, 2017). Thus, there is potential for automation to enhance the quality of their audits. Automation could allow for 100% testing of high-risk accounts, something which is currently almost impossible to do due to the high volume of transactions, tight deadlines and limited manpower budget (Ang, 2013). This would greatly reduce the sampling risk in the audit.

In the Singapore Accountancy roadmap, a Digital Transformation for Accountancy (DTACT) programme was set up to aid SMPs as they adopt baseline technology. This is funded by Enterprise Singapore and administered by the Singapore Accountancy Commission (SAC). Institute of Singapore Chartered Accountants (ISCA) also has funding support for SMPs for curated digital solutions.

Despite the push for digital transformation by the Singapore government, the SMPs' process of performing the audit has not changed much through the years. The audit, tax and corporate secretarial work are still mostly done in Microsoft Word and Excel which is labour intensive and time consuming.

The team investigated reasons for the low adoption of existing digital solutions and identified the following pain points:

i. The initial set-up and on-boarding of existing audit client data into new auditing software would be time consuming and voluminous. There would be a need to retrain existing staff and have sufficient IT support. This unfamiliarity and the huge amount of set up required to adopt the digital solution hindered the AEs from adopting the existing off the shelf solutions.

ii. Existing work processes would have to be redesigned so that employees could harness higher productivity gains. However, if staff are unable to overcome the resistance to change and do not buy into the digital solution, they may end up abandoning the solution or even wasting more time resolving IT issues. In order to be successful, the adopter needs to be ready to combine the adoption of automation, with the discipline of process redesign and continuous improvement (Davenport & Brain, 2018).

iii. Cost considerations also weigh heavily on SMPs. Given their relatively lower revenues, the additional costs of maintaining the digital software – both in terms of subscription costs and manpower costs – were another deterrence.

iv. There is a 94% probability that the traditional role of an accountant or auditor is computerisable (Frey & Osborne, 2017). This has made staff fearful of being replaced by robots and hence resistant to change.

THE CHALLENGES FACED BY SP ACCOUNTANCY IN OBTAINING FYPs

Singapore Polytechnic (SP) Diploma in Accountancy (SP Accountancy) introduced the Final Year Project (FYP) module in 2017, as an authentic learning experience to enhance the more theoretical learning of accounting in the traditional classroom context. The aim of the FYP was for students to apply their knowledge to the industry, build their portfolio and be better prepared for work or further studies. However, finding such projects was very challenging.

In the initial years, FYPs were pro-bono, and did not require complex accounting technical knowledge. FYPs were more focused on solving the physical manpower needs of the industry partners. Common project examples were physical stock-takes, reviewing inventory and fixed asset processes, performing fixed asset sighting, and data entry to adjust incorrect revenue journal entries. Other project examples included designing an analytics dashboard to track revenue and testing the usability of tax software. However, the outcomes of these project deliverables were commonly just prototypes, which the industry partners did not make use of. There was a mismatch of students' skill-sets and industry expectations. There was a gap between what the students learnt and what the industry partners required. The final year students had been taught basic accountancy skills in financial accounting, auditing, taxation and management accounting. However, the industry partners typically had more experience and technical competency than the students. Hence, it appeared that the industry partners did not have real needs for SP Accountancy students. It was challenging for the lecturers to find meaningful ways for the students to help the industry.

Furthermore, many other Institutes of Higher Learning (IHLs) in Singapore were also sourcing for accounting projects within the industry. These were students from the universities, such as The Singapore Institute of Technology's (SIT) Accounting Technology and Innovation Centre (ATEC) supported by SAC to work on projects for the accounting sector, and the Singapore Management University's (SMU) SMU-X program with pro-bono accounting projects. SP Accountancy students can be in a disadvantaged position as the university students tend to be viewed in a more favorable light, given their maturity (having served National Service) and studying in greater depth about accounting. SP had to compete with these universities for projects within the industry.

LECTURERS LEAD BY EXAMPLE BY APPLYING CDIO

The CDIO Framework was initially introduced to revamp engineering education. It stresses the process of conceiving, designing, implementing and operating a product, process, system or service that meets the needs of the industry (Crawley, 2007). Over the years, its adoption had expanded beyond the initial engineering disciplines to include other study areas such as biotechnology, food engineering, agriculture, textiles, and event management. The CDIO Framework consists of two major components: the CDIO Syllabus and the twelve CDIO Standards. The framework offers an alternative to produce better prepared and highly skilled engineers (Elamvazuthi, 2015), and could also be mapped in cross disciplinary curricula, such as Accounting, successfully. (Martin J., 2016)

To address the abovementioned challenges, the lecturers in the SP Accountancy team decided to adopt selected sections of the CDIO Syllabus, as well as several relevant Standards from the CDIO Framework to redesign how the FYP was executed. More specifically, the team took reference from Part Four of the CDIO Syllabus "Conceiving, Designing, Implementing and

Operating Systems in the Enterprise, Societal and Environmental Context: The Innovation Process", whereas the CDIO Standards made use of are: Standard 1 - The Context, Standard 2 - Learning Outcomes, Standard 5 - Design-Implement Experiences and Standard 9 – Enhancement of Faculty Competence.
The team then reviewed the skillsets that the SP Accountancy students developed in their three years in SP which could complement the needs of the SMPs and noted that there was a need to introduce IT centric modules in addition to their technical accounting knowledge. If the students are proficient in IT, they would be able to contribute to the digital transformation of the accountancy sector. The team identified Robotic Process Automation (RPA) as an emerging IT skillset to integrate into the FYP.

RPA uses logic-driven software applications that are programmed to execute certain tasks. RPA does not involve a physical robot that performs operational processes but a virtual robot on the computer. It also allows the user to automate manual and repetitive processes without needing any coding or programming background. RPA is able to integrate various software and processes can be completed with just the click of a button.

In 2018, only 1% of AEs in Singapore had adopted baseline robotic process automation (RPA). Though RPA had been implemented by many business organizations, the application of RPA to auditing remains largely unexplored (Moffitt, Rozario, & Vasarhelyi, 2018). From an auditing perspective, manual and repetitive audit tasks such as reconciliations, internal control testing, and detail testing can be automated (Huang, 2019). Based on the lecturer team's industry experience, other processes such as the annual roll forward of previous years' documents, reconciliations, and confirmations are some examples of repetitive processes which could be also automated.

SETTING KEY LEARNING OUTCOMES

As set out under the CDIO Standard 2 -- Learning Outcomes, the lecturers mapped out the desired learning objectives at each stage of the module as shown in Table 1:

Table 1: Learning Outcomes Mapped to CDIO

Assessment (Weightage for Final Grade)	Mapping to CDIO Syllabus	Mapped CDIO	Description of the Project Outcomes
CA1 (30%) Interim Presentation	2.1.1, 2.1.3, 2.4.4, 3.2.3, 4.3.1, 4.3.4, 3.2.2, 2.1.4, 2.4.3, 3.2.3, 4.4.1, 4.4.3	• Identify and formulate the problems and insights • Analyse interview and survey results • Evaluate needs and develop goals • Display critical thinking • Develop a Project Management Plan • Use correct grammar, spelling and logical organization in presentation materials	• Conduct quantitative user empathy studies and deep user interviews to develop insights on the project scope • Create persona • Conduct environmental scanning • Recommend draft solution ideas with prototypes • Develop a project management plan with timeline and team roles and areas of responsibilities • Demonstrate good presentation skills via infographics
CA2 (40%) Final Presentation	2.1.4, 2.2.4, 4.5.5, 2.1.4, 3.2.2, 3.2.3, 4.4.1	• Conclude study and make recommendations • Appraise possible improvements in knowledge discovery process • Evaluate the validation of performance to client needs (Improvements to make after clients mentoring session) • Conduct iteration until convergence to desired solution • Present recommendations • Demonstrate visual communication	• Produce a final output (dashboard, high resolution prototype, video, lesson package, RPA script, Caseware deliverable) by using technical knowledge • Make recommendations with technical knowledge • Make possible improvements using the feedback from stakeholders/clients
CA3 (10%) Reflection	3.2.2	• Identify key aspects of the learning process • Explain motivation for lifelong learning • Appraise one's own learning needs • Write with logical organization and clear language flow • Use correct grammar, spelling and punctuation	• Explain one key takeaway learnt in FYP • Explain one key challenge faced in FYO and how the student overcame it
PM (20%) Participation Marks	2.4.3, 2.4.4, 3.1.1, 2.5.5, 3.1.2	• Demonstrate creative and critical thinking • Form effective teams • Demonstrate respect for equity and diversity • Manage and participate in teams	• Attitude and aptitude: prepared for discussion, proactive participation, resourceful in resolving problems and self-directed learning to acquire new knowledge and skills • Teamwork: Display good team spirit, work well with peers and lecturers, proactively offer constructive feedback

To provide authentic learning experiences, a series of learning experiences were designed for students. These included field visits to AEs, deep user empathy studies, research on best practices and learning from industry subject matter experts. Facilitation and consultation sessions were also provided.

Students were grouped into teams of 4-6 members and are expected to work independently to collect data, provide interim updates, run a co-creation session and conduct the final presentation for the AEs. Teams will also have to work with each another to ensure that the final solutions are integrated, innovative, sustainable and viable. Students were also expected to apply knowledge and skills learnt from previously completed modules, such as Design Thinking in Year 2.

Each final year class consists of twenty students, on average. They were divided into four groups. The supervising lecturer assigned the students to groups based on specific criteria to form balanced teams using The Grumbler (Sparrow, 2021). The Grumbler teams were more balanced in terms of various criteria, such as gender, nationality, admission types, and grade point aggregate. These assigned groups replicate the real world working environment in the auditing industry as auditors are assigned into different teams to work on different audits. By ensuring that each team had a similar overall average GPA, each team was more likely to have the ability and capability to develop a successful solution for the project. Assigning students to groups has been shown to lead to better student performance and overall learning experience. (Colbeck, Campbell, & Bjorklund, 2000)

DEVELOPING FACULTY COMPETENCY IN TEACHING

If faculty are expected to teach a curriculum of personal and interpersonal skills, integrated with disciplinary knowledge, they need to be competent in those skills themselves. The lecturers first sought to enhance their existing skills by adopting a three-pronged approach:

i. Attend – All lecturers facilitating FYPs would first attend the RPA classes conducted by their experienced colleagues from another SP faculty so as to gain a basic grasp of the technology and start adopting the technology to automate their own work processes. The lecturers also took up online certifications by the software provider, which allowed them to learn at their own pace during their pockets of free time.

ii. Facilitate – The lecturers would then shadow their colleagues in teaching the RPA classes, to learn how to troubleshoot problems during RPA implementation and gather more real life use case examples.

iii. Adopt – the lecturers developed a basic RPA class, with real world accountancy use cases, for the Year 3 curriculum. Students who went through this class were expected to have basic RPA knowledge to start on simple RPA FYPs. Finally, lecturers marketed the student's RPA capabilities by offering them to existing AE partners as part of the FYP. This incentivised the AEs to try out a new software and gave the students and lecturers the chance to have the initial success stories for confidence building.

The supervising lecturer had the responsibility of engaging with the AEs before the students started on the projects, similar to how an audit manager would first attend a kick-off meeting with the audit client before the audit team started work. The lecturers would meet the AEs to firstly identify the specific needs and pain points of the AEs. This is a detailed understanding of the current processes of the AEs. The lecturer would then propose a skeleton solution to the AEs to assess the suitability, practicability and sustainability of the solutions. The lecturer's suggested solutions would be designed based on the capability of the students and the complexity of the project scopes, and also to manage the expectations of the industry partner. This also gives the lecturer confidence to be able to supervise his or her class with an expected outcome of the projects in mind.

CDIO – CONCEIVE & DESIGN STAGES

Under CDIO Standard 1, the Context, the concept of conceiving includes defining the customer and societal needs. This sets the context for the lecturers and students to better understand and define the AEs needs. Under the Conceive stage, the supervising lecturer had the responsibility of engaging with the AEs before the students started on the projects to firstly identify the specific needs and pain points of the AEs. This is a detailed understanding of the current processes of the AEs. The lecturer would then move to the Design stage, by proposing a skeleton solution to the AEs to assess the suitability, practicability and sustainability of the solutions. The lecturer's suggested solutions would be designed based on the capability of the students and the complexity of the project scopes, and also to manage the expectations of the industry partner. This also gives the lecturer confidence to be able to supervise his or her class with an expected outcome of the projects in mind.

When the students start on their projects, they are briefed on their project scopes. Each group will be assigned multiple processes to automate. The AE would have prepared the necessary documents and videos explaining the processes. The students would watch the videos and prepare a process map of all the current processes that they are working on.

During the kick off meeting, the students would interview the AE's staff. Each group would clarify any doubts about the existing processes. This is essential to understand the whole process so that the group can ensure the accuracy of their solution, and identify any pain points and needs of the AE.

Moving on to the Design stage, students would design an RPA script to automate the different processes. The students would combine their accounting technical knowledge as well as their IT skills to design the Framework of their solution. The lecturers would give feedback to help the students refine their prototype solution.

CDIO – IMPLEMENT & OPERATE STAGES

After incorporating the feedback from the AE, the students build the working robot to automate the process. The students would then visit the industry partner to implement the robot on their AE's hardware. The students would test out the robot on the AE's live data to check that the robot is working.

Typically, the implementation stage would be the most time consuming of the whole project. Hence the students would have, together with the help of the lecturer, designed the project management timeline to cater more time for implementation.

Table 2 below shows a summary of the different RPA robots that have been developed and deployed by SP Accountancy for our industry partners as part of the FYP.

Table 2: List of RPA robots developed and deployed by SP Accountancy students

Audit	Corporate Secretarial	Tax	Accounting	Others
• Confirmations • Preparation of audit documents • Roll-forward procedures • Automation of audit procedures • Automation of financial statements	• Annual General Meeting filing • Annual returns • Incorporation • Customer Due Diligence • Preparation, processing and managing of corporate secretarial documents	• IRAS tax filing • GST processing • Preparation of tax documents	• Data entry • Data extraction • Reconciliation of reports • Report generation and preparation • XBRL	• Timesheet • Practice management procedures • Automation of administrative procedures • Automation of payroll procedures

Once the robots are able to work with the live data, the students would guide the AE's staff to operate the robots. The students would prepare a manual to assist them in operating the robots. The students would also conduct a training for the AE's staff to use the robots. The students would do a final presentation to the industry partner to wrap up the project. This presentation would showcase the final solution, show the status of the implementation, and quantify the productivity gains.

EVALUATION OF WORK DONE: METHOD

The lecturer team investigated whether this new approach of integrating digital skills and adopting the CDIO method in the FYP better prepares students for the industry and the future.

Participants

To test the effectiveness of the FYP module in preparing students for their future careers, a pre-test and post-test survey was conducted with sixty students. We were interested in finding out if students achieved improvements in line with the Learning Outcomes within Table 1, such as critical and creative thinking skills and as well as digital skills. We were also interested in their perception of their futures in a field that seemed threatened by automation given that they now had a deeper understanding of the capabilities of RPA.

Data Collection

The data collection process began with the same survey sent out to students at the start of the FYP. The same survey was sent out to students after they had completed the FYP. The survey consisted of Likert-scale questions and one open ended question to gather other feedback. The following link shows the survey questions: https://forms.gle/2GYUZnRMqEUpiXnp9

Data Analysis

The survey results were exported into Microsoft Excel for analysis. The means were calculated for the different questions.

RESULTS & FINDINGS

Survey Results

The survey results show that students were able to apply design thinking to the projects (increase of 17%) and be more innovative and creative (increase of 14%) in their projects to produce an implementable and operating solution and not just a prototype. The survey results showed that students took more ownership and responsibility in their projects (difference of 4%). This is a result of and a co-relation to the high expectations of the AEs of the expected deliverables.

Table 3: Survey results on adopting the CDIO approach

	Pre-test	Post-test	Difference	Difference (%)
I was able to apply design thinking during the project.	3.72	4.33	0.62	+ 17%
I was able to innovate and be creative during the project.	3.72	4.23	0.52	+ 14%
I am responsible and take ownership of my work.	4.37	4.55	0.18	+ 4%

The survey results also show that students are more prepared for the industry as the new approach in the FYP module gives them the confidence that they have the necessary digital skills (increase in 13%), necessary presentation skills (increase in 12%) and the necessary accounting skills (9%). The experiment group shows that they have a better advantage (increase in 16%) over their peers in applying for university or work because the FYP gives them a better portfolio in their resume for university or jobs. This has differentiated our students from other IHLs, giving them more opportunities in their further studies or career. This has also allowed students who probably would miss the cut-off for universities, a second chance to get into the universities because of their FYP project.

Table 4: Survey results on preparation of students for the future

	Pre-test	Post-test	Difference	Difference (%)
FYP has given me an advantage over other peers in the hiring process / applying for university.	3.37	3.90	0.53	+ 16%
After doing my FYP, I am confident that I have the necessary digital skills for work.	3.63	4.10	0.47	+ 13%
I am confident that I have the necessary presentation skills for work.	3.75	4.20	0.45	+ 12%
I am confident that I have the necessary accounting knowledge for work.	3.72	4.03	0.32	+ 9%

After having examined the processes that could be automated as part of their FYP, students have a better perspective of what robots are able to do and not do. The survey results show that students are less threatened by robots (decrease in 11%) to replace their job roles, allowing them to see robots as a tool to leverage to face the future.

Table 5: Survey results on the perception whether robots will replace the accountant / auditor job role in the future

	Pre-test	Post-test	Difference	Difference (%)
Robots will be able to replace the accountant / auditor in the future.	3.27	2.92	-0.35	- 11%

The results of the survey were in line with the authors' expectations, in that an improvement in the overall confidence and technical skills was achieved.

Qualitative Feedback

Here is some qualitative feedback from the students which co-relates to the quantitative findings above. Overall, students had a positive experience in this module.

Feedback From Students

- "RPA helped me greatly in the aspect of critical thinking as well as honing my presentation proficiency. Compared to other non-accounting modules, RPA was definitely the one that I gained the most takeaway. In the future, I strongly believe RPA will be prevalent and I am grateful I had the opportunity to gain first hand exposure."

- "RPA would definitely benefit students and help them in their future from doing repetitive work. It also helps us to save time and be more productive to finish up certain projects as fast as possible. Investing ourselves in RPA would certainly be a very good investment for us in the future as I believe it will be a compulsory skill to have."

- "Since this project requires us to work together with real industry partners. It made me feel a sense of responsibility, that which I have not experienced before doing other projects. Personally, my FYP felt more than just a school project, it felt as though I had a legal obligation to ensure that our client was happy with our work, to the point that I would have continued to support our RPA robots if needed even after our FYP has ended. Not only that, through this project I was able to attain an important document which will improve my employability and acceptance to the university. That document is the testimonial letter from the industry partner, something which I would not be able to attain doing regular school projects. Furthermore, I was more industry ready as this project greatly improved my written and verbal communication skills."

INDUSTRY ENDORSEMENT

The AEs were impressed by what the students have automated in their projects. The following are some AE's testimonials from some of the FYPs:

- "Apen Chartered Accountants would like to commend Singapore Polytechnic for the successful execution of the RPA project implemented in our firm. Through the dedicated efforts of SP Accountancy students, the RPA project has automated and streamlined our firm's audit workflow. SP's strategic involvement in the project has enabled our company to increase its productivity and free up our auditors' time to perform more value-added work. We appreciate the excellent results produced by SP & its students and look forward to continued future digital project collaborations with SP to transform our firm!" - Apen CA

- "I am very happy to note that your project team has made good Progress on the RPA Automation Project, this tied in with the mission of AGN Network, which encourages close cooperation with Institutions of Higher Education to do R&D Work." - Audit Alliance LLP

By working on these RPA projects, the industry has recognised the importance and quality of the solutions done by the school. SP signed a MOU with the ISCA on 22 August 2019 to enhance the digital capabilities of the AEs in 2 main areas:

i. Developing certification courses in RPA that are customised for local AEs; and
ii. Supporting AEs in the adoption of audit software to automate and streamline their audit workflow.

The collaboration will allow SP Accountancy students to use RPA and other audit software to help AEs streamline their audit workflow and provide technological solutions. This collaboration is part of Infocomm Media Development Authority (IMDA)'s Accountancy Industry Digital Plan for the digital transformation of the accountancy sector in Singapore (IMDA, 2019).

On 11 May 2021, the SAC signed a MOU with SP to collaborate on a National Digital Consultancy Programme, through which SAC would fund RPA projects for AEs. This programme is called the RPA Adoption Support Scheme. SAC has also encouraged the other polytechnics in Singapore to scale up in RPA projects to help AEs in this national collaboration. SP will play a key role in training the other polytechnics and driving the adoption of RPA in AEs.

PLANS FOR FUTURE WORK

The lecturer team would also study the CDIO Framework in greater detail, for example, Standard 5, Design-Implement Experiences, to infuse these digital skills into the Year 1 curriculum at a basic level and begin performing simple RPA projects when attached to their internship companies when they come to Year 3.

Standard 7, Integrated Learning Experiences, can be further used to develop the students' personal and interpersonal skills through the integration of field trips, empathy studies and consultation with the AEs into the FYP journey.

The lecturer team is also looking into how the Framework can be used to improve the teaching in SP Accountancy at the course-level. One of the challenges faced during the project was the timeline in implementing and operating the robots which tended to be delayed. The team will review the timeline and project schedule to minimize such delays.

RPA can also be applied in other accounting areas such as forensic accounting, accounting analytics, financial accounting, management accounting and internal audit. The team plans to move ahead with the new way of executing FYPs by expanding into these areas, especially into forensic accounting and accounting analytics given that these are the two current trends in the sector.

CONCLUSION

It is important to infuse robotics and automation skills in the accountancy curriculum to prepare accountancy students to be industry ready. With the right skills and using the CDIO approach, this has allowed SP Accountancy students to innovate and develop various digital solutions for the accountancy industry. This has increased productivity in the sector and freed up time to allow the industry partners to focus on value-adding work. The project outcomes are successful and are recognized by the industry. This experiment has put SP Accountancy at the forefront of the transformation of the Digitalization Journey for Singapore's accountancy sector. Through these projects, our students are exposed to real world problems, making learning authentic and relevant.

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MAXIMISING THE PERFORMANCE OF MULTI-DIVERSE DESIGN TEAMS

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ABSTRACT

In our Integrated Product Design master at the Delft faculty of Industrial Design Engineering we see a growing diversity in our student population. Besides a growing number of different nationalities there are also significant differences in prior education, competences, and socio-emotional aspects. Within the Advanced Embodiment Design (AED) course, students work in teams on a client-based design project for one full semester. In 2018-2019, 22 student-teams started out their endeavour, coached by eight coaches. Within the course an important learning objective we want to offer students is the opportunity to experience and perform in a successful team, acknowledge all students' input, and experience a successful result. During the process of embodiment design, the project teams come across several hurdles which challenges team performance and their project progress, and thereby influences the project results. To maximise the performance of student design-teams we have conducted two studies researching the challenges these teams come across over the course of the semester. One study was based on the coaches' experiences during the project (Flipsen & Persaud, 2016), and the other one on the students' individual reflections on the project (Flipsen, Persaud & Magyari, 2021). The challenges our students come across are analysed and relate to becoming a team, doing the project right, and finalising the project successfully. The results of both studies are used to develop a framework supporting coaches in maximising the performance of multi-diverse design teams. The framework is built around the Theory U (Scharmer 2016), a model describing how teams work with each other, following the right path to success (presencing) or off-tracking by muddling through, or by absencing. To track the different team's performances, we use a project-group tracking-system existing of seven Key Performance Indicators combined with a coach journal. The combination of KPI's help the team of coaches to pinpoint lower performing teams and intervene when needed. In this paper we will present the framework, consisting of (i) preparatory activities to initiate trust, teambuilding, and a successful student cooperation, (ii) a system to track the student-teams' health and performance and pinpoint troublesome groups, and (iii) responsive activities related to the hurdles teams might come across and how to reverse them. To assist the individual coach, we have developed several responsive activities the coach can use to intervene, slowing down the process of dysfunctionality and revert the process towards highly performing teams. The activities are tested in the two cohorts following our initial studies in 2018-2019.

KEYWORDS

Multi-diverse, teams, lessons learned, reflection, team dynamics. Standards: 6, 7, 8, 9, 10.

INTRODUCTION

In the master at Industrial Design Engineering (TU Delft) we see a growing diversity in students. In recent years, the number of international students has grown by more than one third of the cohort's population. We also see differences in prior education and competences, especially compared to our own bachelor's degree. In the master course Advanced Embodiment Design, more than 100 students work in teams on a client-based design project. The project starts out with a physical prototype at Technology Readiness Level 2 or 3 (TRL2-3) as defined by NASA in the 1970's (Mihaly, 2017). Within the time given the student team's goal is to engineer the product to a near-production ripe product embodiment at TRL 5 to 6.

The course runs over a full semester and, when successfully completed, is awarded with 21 European Credits (EC), which encompasses a workload of 588 hours per student. Every team consists of 5 to 6 students who are taught in five expertise area, each encompassing 10% of the student's workload. The knowledge acquired in the expertise areas must be applied in the *Project Embodiment Design (PED)*, which encompasses 50% of the student's workload. The expertise areas are diverse and include the following variety of subjects (figure 1):

1. *Advanced Design Enablers (ADE*), where students learn about systems engineering and design (Bonnemat et al, 2016), dissecting a product in components and optimize for part and system functionality using finite-element analysis and rapid prototyping techniques.
2. *Advanced Ergonomics Feasibility (AEF)*, where students learn and apply physical and cognitive ergonomics, making a product more usable.
3. *Product Experience (PE)*, where students learn about user-product interactions that lead to pleasurable product experiences such as aesthetics, meaning attribution and emotional responses (Desmet & Hekkert, 2007).
4. *Sustainable Design Engineering (SDE),* where students will analyse the project on the triple bottom line, people, planet, and profit using the sustainable development method developed by Ashby (2016).
5. *Smart Systems & Technologies (SST),* where students are introduced IoT systems and tools and methods around electronics, data collection, data analytics, and machine learning to support the design of smart product-service systems.

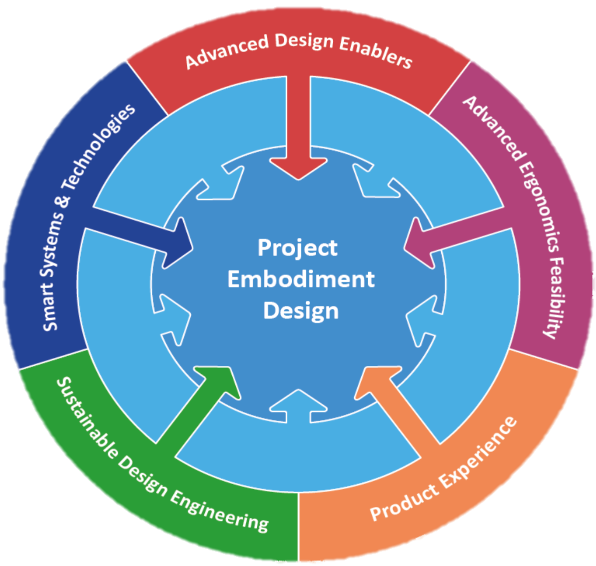

Figure 1. Five expertise areas giving direction to the Project Embodiment Design.

Workflow

During the first 3 months of the course students will focus mainly on the five expertise areas and partially on the project. Activities related to the project consist of getting started within the team, setting up a planning and communication protocol, analysing the product system's architecture, and defining the main challenges of the product-system. During the mid-term presentation the student teams are up-and-running and will present their main challenges which they will tackle during the second part of the semester.

Diversity in teams

In an ideal world the student teams will get into flow fast and finish the course successfully without issues, but in most cases, discord is already happening during the first weeks of the course, the team-building phase. The student teams either consists of a group of friends who want to work together on a project, or the team is put together based on their project preference. 50% of the students are bachelor students from the TU Delft doing their master at IDE, and 50% have been schooled at other universities globally. 1/3rd of all students are foreign students coming from all over the world. The diversity within the team due to differences in nationalities, prior education and design approaches, emotional differences, and in skills and competences, can and will lead to confronting situations within the teams when working for such a long time together on a project (Flipsen, Persaud & Magyari, 2021). Examples of hurdles teams must overcome are communication confusion, frustration, and sometimes interpersonal collisions (Flipsen & Persaud, 2020). There is a growing gap between the team members on cognitive and socio-emotional aspects and their ability to deal with this constructively. We also noticed that for the team of coaches it became more difficult to coach these increasingly more diverse student groups because of a lack of knowledge in dealing with it.

Coaching multi-diverse teams

The final deliverable for a team consists of an embodied design of a product. However, the major learning is not in designing the product, but in working together and inclusively in the design-team. The experience of differences between team members and learning to trust each other is the basis of a functional team (Lencioni, 2002). To support our students in a safe way during this process, we need to professionalize our coach team and focus more on team dynamics, getting in flow with the project team, and experiencing a higher level of collaboration.

This paper will present our approach in maximizing the performance of multi-diverse teams using (i) preparatory activities to initiate trust, team building, and a successful student cooperation, (ii) a system to track the student-teams' health and performance and pinpoint troublesome groups, and (iii) responsive activities related to the hurdles teams might come across and how to reverse them. The preparatory activities consist of getting to know each other on a deeper level and build trust among the team members. The Theory-U (Scharmer, 2016) is used as basis for guiding teams in the right direction of presencing. The experience of "wandering of the right path" (either by muddling through or by absencing) is not something we don't want our students to experience, but when it happens, we want the team to reverse this process and return to the presencing field as soon as possible. To reverse this process, we propose several techniques to get to real solutions for teams to work together in a professional fashion. Reflection (Schon, 1991) and dialogue (Isaacs, 1999; Cooperrider & Whitney, 2005) are techniques used in this process.

In the next section we will explain the coach framework, where we use *Theory U* as the basis for good teamwork, and how *dialogue* is used to improve team communication. To pinpoint off-tracking teams, we have developed a *Performance Dashboard* to track the team-performance while running the project. When teams are off tracking, we have developed several exercises to reverse that process. Both the tracking system and the techniques used to reverse the process of muddling through or abscencing, are discussed in the follow-up sections. We will conclude this paper by reflecting on our learnings when applied in the latest runs of the course.

COACH FRAMEWORK

Theory-U as basis for good teamwork

The context and reality of the AED project is important to understand. The traditional context of teamwork as described by Tuckman and Jensen (1977) and Smulders et al. (2012) is a hierarchical step by step approach of Forming, Storming, Norming, Performing and Adjourning. Although Smulders does address student teams, he does not consider the diversity and iterative developmental nature of the AED student teams. Miller (2003) and Senge et al. (2004) views on teams are more related to the AED context. Groups are developmental dynamic social systems with personal and group related processes of creativity, introspection, and intuition. Many of the design challenges far exceed the knowledge and skill that any one student can possess and therefor teamwork and collaboration are very important.

Theory U is a model developed by Scharmer (2016) that applies well to AED teams. "It transfers easily from an individual to a collective context and holds great potential to spark the learning that is necessary to improve team functioning and enable greater performance" (Hays, 2016). It also applies well to the AED design process, where the 20 weeks duration provides a long enough timespan for the U processes to take place.

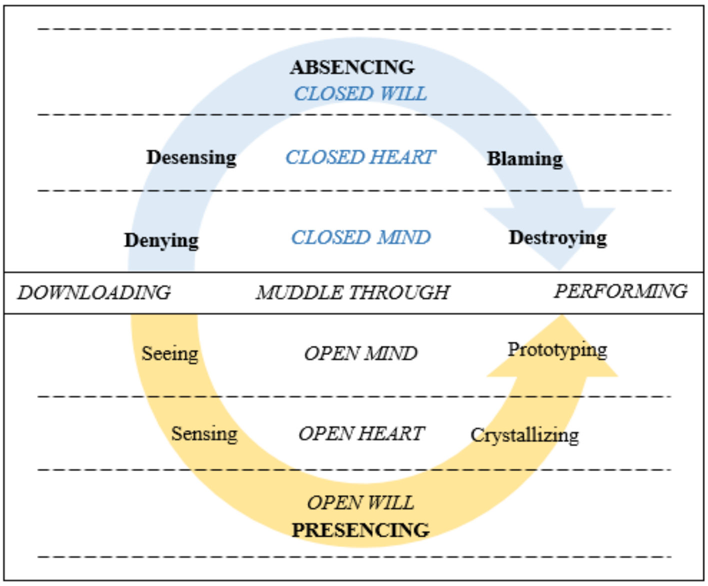

Figure 2. Theory U, adapted from Scharmer (2016).

Theory U describes two opposing processes of presencing and absencing. Presencing is a process of collaboration and embracing emerging possibilities, where absencing is a process of disconnection and getting stuck in old habits. Scharmer also identifies a process of muddling through, where teams are in between presencing and absencing.

As figure 2 shows, both pathways contain five phases built upon three elements of communication the mind, the heart and the will. Each team starts from the stage of "downloading", where students get together and engage based on past patterns. The first phase teams go through is communication from the 'mind'. It is described as non-judgmental (seeing), or judgemental (denying) communication of team members based on prior experiences. The second phase is where teams develop communication from the 'heart'. It is about the emotional connection (sensing) or disconnection (desensing) of team members. The third phase is when teams communicate from the 'will' or the ability (presencing) or disability (absencing) of a team to act in an instant. When following the pathway of presencing, the following phases are crystallizing (open heart) and prototyping (open mind). When following the pathway of absencing, the following phases are blaming (closed heart) and destroying (closed mind). In the dynamics of the design project, the student teams will develop towards one of three pathways: presencing, absencing or they muddle through.

Dialogue as basis for team communication

Within Theory U, communication within the team is central in the team process. Scharmer (2016) describes four types of conversations:

(i) *Talking nice*, confirming the positive aspects, the goodwill, filtering, politeness, and self-censoring.
(ii) *Talking tough*, responding to counter others' arguments, such as debate, discussion, and conflict.
(iii) *Reflective dialogue*, understanding and accepting the others perspective without feeling the need to disagree with them and allowing diversity of perspectives.
(iv) *Generative dialogue*, focussing on the human experience of the other and what resonates with their own humanity, sensing the wholeness of which we are part, unity in diversity.

Talking nice and talking tough is prominent in the absencing process and reflective dialogue and generative dialogue are applied in the presencing process.

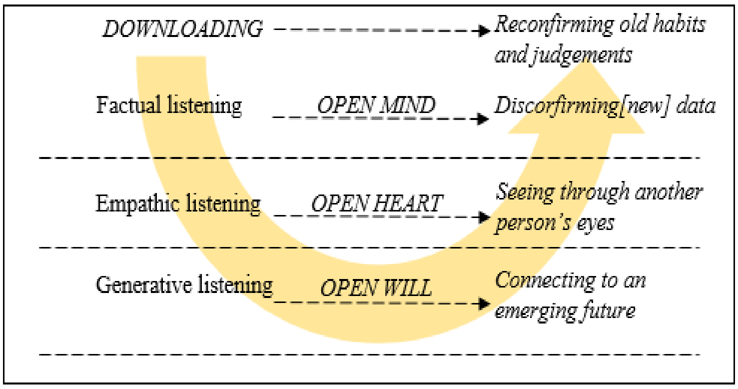

Figure 3. Four types of listening adapted from Scharmer (2016).

Within these fields of conversations, Scharmer (2016) also describes four types of listening corresponding to the phases of the presencing process. These types of listening support teams for moving through the u process and transferring "Reflective Dialogue" to "Generative Dialogue" (figure 3):

(i) Downloading: listening from habits of judgement.
(ii) Factual listening: listening from outside and noticing differences, listening with an 'open mind'.
(iii) Empathic listening: listening from within, sensing, listening with an 'open heart'.
(iv) Generative listening: listening from source, from what is emerging, listening with an 'open will'. This communication approach can shift the teams to see and use the differences as an asset instead of a hinderance.

TRACKING TEAM PERFORMANCE

Performance Dashboard

To implement a quick and easy overview of the performance of our student teams we started out with a project-team tracking system, which kept track of the performance and the healthiness of the student team on a regular basis. We used Google forms to aggregate data in a weekly coach journal. Every week all our coaches entered their journal in the sheets which on its turn was used as input for our weekly meeting. The performance is tracked by means of 6 key performance indicators (Marr, 2012), and a textual journal consisting of problems within the team, project progress and other stuff. We differentiated between strategic KPI's, which monitors the progress of the student team in relation to the end goal, and operational KPI's, which monitors the team dynamics. Strategic KPI's consist of progress of defining (i) the key challenges, (ii) the research questions, and (iii) the method of approach. The operational KPI's consist of (iv) project management, (v) planning and on-time completion, (vi) group dynamics, and (vii) perceived stress levels (Flipsen & Persaud, 2020).

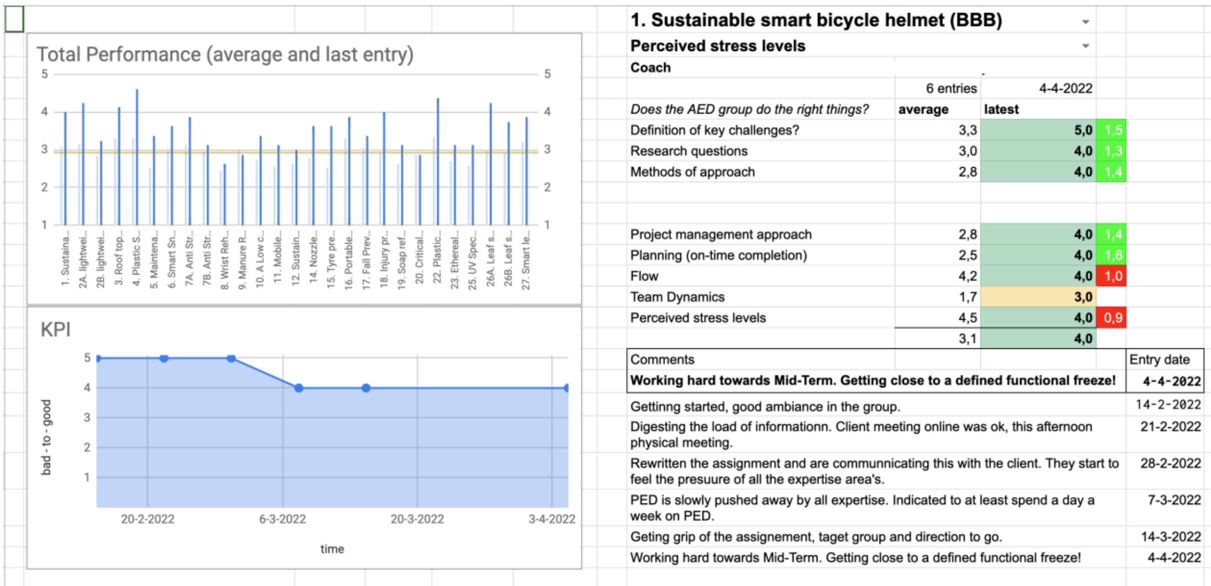

Figure 4. An example of the Performance Dashboard used to track student team's performance.

To present the data in a quick and handy format we produced a performance dashboard using Google Sheets (figure 4). This gave us a quick insight in the performance of the different groups relative to each other, see top left bar chart. With the historical average (light blue) and the current team performance (dark blue) we can pinpoint the low and high performing teams and discuss them using the project-specific data, see top right. Besides the team's name and coach this data consists of average historical performance per KPI, the latest update and the positive (green) or negative (red) changes in performance over time. In the example, for instance, it shows that team 1 has improved on all aspects but for the "flow" and "Perceived stress levels" where the performance dropped with 1.0 and 0.9 point. Besides the quantitative KPI's the dashboard also shows the coaches' journal about the team (down right). This journal is used to pinpoint the exact problems with this group, fire-up the discussion within the coach team and come to solutions on dealing with them. With this tracking system we quickly pinpoint troublesome groups, eg. team 8 is underperforming in this phase of the project. The comparison and insights from the dashboard are used to lead our discussions during our weekly coach meetings. Instead of discussing all student groups individually we herewith can focus on problematic groups and come to solutions which are implemented immediately. Solutions are found within the diverse knowledge fields from within our own team of coaches or were introduced by external experts. Issues concerning, amongst others, multi-cultural differences and socio-emotional aspects are in this way effectively tackled without loss of time and is discussed thoroughly in one of our earlier papers (Persaud et al., 2021).

The tracking system helps in classifying teams to one of possible responses within a team (Schamer, 2016): muddling through (denial), moving apart (absencing) or moving together (presencing).

Reflection

Besides coaches reflect on student-team's performance, we promote self-tracking of the team and team members to become a professional reflective designer. Students are introduced to Reflective Practioner (Schon, 1991) and different reflection methods (Gordijn et al., 2018) during the course, reflect as a team during the mid-term and individually at the end of the course.

REVERSE OFF-TRACKING

Based on previous research (Flipsen & Persaud, 2020) we identified the key issues which made student teams move from presencing towards muddle through or abscencing. We have identified four types of diversity consisting of differences in: (i) cultures, (ii) design approaches, (iii) socio-emotional background, and (iv) competencies. To address these four differences affecting team dynamics several methods have been collected to help the coaches in addressing them.

Preparatory

At the beginning of the project, we use several startup exercises to get a jump start in the downloading phase and getting used to communication through (generative) dialogue. The following exercises have been used in the past course runs:

- *Who are you:* In this exercise both students and their semester coach make a poster to present themselves. They visualize and textualize answers to questions, to show their personalia, personal values, needs, strengths, etc.
- *Best meal ever:* Students talk to each other about their favorite dish. They support the person who is talking by asking questions about the content, situation, preparation etc. It is an exercise to learn about listening, talking and supporting.
- *Roses and thorns:* Each meeting students start with a check-in round. They share what is on their mind before they start with the design project content. Roses are about personal nice things that recently happened, and thorns are about the things that are bothering now. It is an exercise for empathic listening, sharing and reconnecting.

Intervention exercises

Using the performance dashboard, we discuss the most troublesome teams in the cohort. The coaches share their experiences of discussion, debate and conflict within the student teams. These are signals of “talking tough” and indicate muddling through or absencing. Signals could be voices of judgement, cynicism, or fear which manifests themselves as quick judgement without questions, making fun of others, blaming, punishment, lying, or not showing up. Coaches then share thoughts about which key issues could be most relevant and use specific exercises to support the team to open and move towards the presencing pathway.

The following exercises have been used in the past course runs to get teams up and running again. The exercises are based on dialogue (Isaacs, 1999) and appreciative inquiry (Cooperrider & Whitney, 2005):

- *Design approaches and competencies:* When students are judgmental on the quality of work or debate approaches and design strategies, the *"Belonging, Being, and Becoming"* exercise is helpful. Students make a poster-visualization and address three elements of themselves. Belonging: where are you from, and to whom, where, and what are you connected? Being: what design-engineering or other skills and knowledge do you have now? Becoming: where are you going, where do you want to be, what do you want to know, what do you want to be able to do after AED? They must collaborate with someone from the team, who will present the others' poster and the team can ask questions.
- *Socio-emotional differences*: When coaches notice that students are self-censoring, cynical towards each other or blaming others we have two exercises for support based on sharing personal histories. "*Cool elementary school"* is an exercise where students share the nicest moment or experience from their elementary school. Other team members ask clarifying questions and listen to their stories. "*Mother and Father"* is another exercise where two students talk about their parents. One student talk, and the others listen and ask questions, after which they share each other's stories to the rest of the team (think-pair-share).
- *Cultural differences:* When a coach notices students have a cultural bias, the exercise of "*Team Culture Mapping"* (Meyer, 2014) is used. The method defines eight areas where cultures vary along a spectrum between two opposing extremes. It provides a framework for teams that face cultural differences. Team members analyse the position of their culture relative to one another. This enables them to decode how culture influences their collaboration. The space in between the extremes can be considered as a continuum. Within the range of behaviours of a given culture, individual differences occur. The goal of using the model is to support interacting between team members and improve watching more, listening more, and speaking less.

REFLECTIONS AND CONCLUSIONS

We believe that well-functioning teams will work towards high-quality results. Dysfunctional student teams will struggle through and fail the learning objectives of the course, but also loose trust in team performance. By pinpointing and act on issues as early as possible in the team process, all student teams experience a successful project and learn from the hurdles they come across. The last couple of cohorts, we notice that student teams are more in flow and that concerns on team dynamics are pinpointed and addressed at an earlier stage in the course. The use of the previously discussed exercises using dialogue and reflection are fruitful in preventing escalation and developing an open attitude of all team members. Even troublesome teams are managed to work in a professional manner, even thought they might never become friends.

Student teams will become better when their coach is also functioning on a higher level. Within the team of coaches, we also noticed biases due to diversity of team members, and difficulties in conversating. To become better coaches, we needed a base of trust within the team, where all members can be vulnerable, and open to each other. We therefore had to learn to move towards presencing and must become aware of each other's (in)capabilities and unconscious bias. In previous papers we have discussed the coaches' and students' perspectives on hurdles within multi-diverse teams. With these insights we have professionalized our coach team to cope better with issues in student teams. We have aggregated and developed several exercises to empower coaches in doing their work and being confident about it. Within the coach team we discuss possible exercises and how well they fit with the coach in question. Discussing and involving all members of the coach team in this process grows trust within our team, which constitutes to a learning environment where not-knowing and failures are accepted. We monitor each other's work, learn, and adjust without prejudice.

Given the high grades and international prices different student teams have won, we don't see an inflation in the results of the student teams. We therefor believe this approach is successful but need to be aware of the possibility for losing focus on content-related learning objectives. We therefor mainly work with design professionals who are parttime self-employed or work in a design agency. To keep the standard high, we are also mindful about course evaluations and student's reflections to improve the course continuously.

Every year part of the coach team is renewed, where team members leave, and new coaches are introduced. Coaching on team performance is different from the existing coaching on results, which requires extra attention during onboarding of new coaches. We therefor are working on educational materials which help coaches in becoming more confident and professional working with multi-diverse student teams.

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EXPLORING ADVANCED PROJECTS AS MEETING-POINTS BETWEEN STUDENTS AND INDUSTRY

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ABSTRACT

This study includes survey of the Swedish companies and other potential employers perspective/view on the computer science students´ projects as well as the opportunities and limitations for the students. This is the first major study we have undertaken within this bachelor programme to, in depth, investigate both the company and the student views of how we should incorporate industry-oriented working methods in the context of CDIO. From the companies´ perspective, for example we are evaluating questions related to the projects´ size and projects´ output; the confidentiality of the projects; the communication aspects, like how early and how often a company need to meet the students; the job opportunities after graduation; or if the company is interested in other ways of being involved in the bachelor program. Two courses in the last semester, in the Bachelor Programme in Computer Science and Engineering, are implemented as work-based projects. Here, the students have an opportunity to work with an advanced project incorporating both prototype building, software development and academic research. The full time twenty-week project is incorporating the Conceive, Design and Implement parts of the CDIO concept. For the last three years, the proportion of work-based projects have varied between 40 % and 80 % and has mainly been done in co-operation with private companies. A few projects have been done in co-operation with none-profit organizations. The students' perspective is very important and is therefore included in this study. The students from the bachelor programme as well as alumni have participated in the survey. The student survey focuses on expectations, experiences, and reflections from the interaction with the companies. The survey also includes questions related to acquired skills and abilities, limitations and difficulties, as well as job opportunities after the graduation.

KEYWORDS

Advanced projects, IT-Industry, Computer Science and Engineering, CDIO Standards: 2-3, 5-8

INTRODUCTION

Higher engineering education in Sweden contribute not only to educate students with a scientific basis, but also with a high degree of employability for them. According to Swedish Higher Education Authority, a majority students who graduated in the 2017/18 academic year were established in the labor market 1–1.5 years after graduation. The highest establishment had graduates from nursing educations and engineering educations (UKÄ, 2021).

There are at least two reasons behind this high employability, namely the labor market that needs engineers and good education adapted to it. An online documentation review shows that all engineering programmes in Sweden offer education in close relation to the industry through various activities such as study visits, guest lecturers, as well as different kind of projects and degree theses often with companies as customers. Of course, the cooperation between academia and industry is nothing new and has been discussed not only in Sweden. The questions here are: What expectations have the students and the companies? How to prepare the new generation of students to meet the companies´ s requirements? How to meet the academic requirements?

Different methods have been implemented by the academia. One example we find e.g., in (Einarson & Lundblad, 2014), where the integration is carried out within the frames of a Software Engineering course of 15 credits, and where a small number of the 3rd year volunteer students from two universities (HKR and Lund University, Sweden) have participated in projects with low demands on participation from the companies. The project, called DEMOLA, is mentioned as a bridge to inherent a gap between the industry and academia. The authors evaluate the project according to the CDIO standards 1, 2, 5, 6, 7 and 8.

At Turku University, Finland, a student-centric learning environment called “the FIRMA” that works like a company has been implemented (Säisä, Määttä, & Roslöf, 2017). The model is based on project-based learning. The ICT-students are not only practicing different roles like CEO, project manager, service providers, helpdesk but even develop the projects to internal and external customers. The authors write that the students gain competences relevant for the work-life requirements as well as improve the CDIO skills like teamwork, communication, leadership, analytical reasoning, and problem solving.

At Mongolian University of Science and Technology, the authors (Batdorj, Purevsuren, Purevdorj, & Gonchigsumlaa, 2018) present their experiences on teaching and learning activities as well as the assessment results of four project courses taught during the 3 years period. Even here, the program is based on CDIO syllabus, and the Degree project is the last ‘project in this progression line.

Working as an engineer in Computer Science incorporates a vast variety of different types of work, where the CDIO framework is an excellent guideline to follow. The Bachelor Programme in Computer Science and Engineering, specialization in the Internet of Things at Kristianstad University (HKR, home university of the authors of this paper) in Sweden offers a broad education with a wide horizon of future employment. Most of our engineering students may work as software engineers or mixed software/hardware engineers after their studies. Following CDIO principles since 2014, we prepare students for the future through work-based education and design-build-test by the projects integrated in the courses. After more than 7 years´ experience, we wanted to evaluate the work-based projects as a meeting-points between students and industry.

This article contributes with the structure of the engineering program, including a brief description of the courses of project work, a survey based on the questionnaires sent to industry, students, and alumni, as well as an evaluation of the program.

BACKGROUND

The Bachelor Programme in Computer Science and Engineering, specialization in the Internet of Things at Kristianstad University, is a three-year programme and is provided for both national (Swedish) and international students. The program has existed since 2009 and has undergone three major changes in recent years. In 2013, the programme underwent an extensive restructuring that led to a clearer focus on Embedded Systems. In 2017, further changes were made to the program, with a clear progression between the courses as well as a progression in academic skills. Further improvement of the programme was adopting constructive linking (Biggs & Tang, 2011). Constructive linking is based on the idea that the course's teaching and learning activities as well as its examination and assessment methods should be linked to the course's learning objectives.

As seen in Figure 1, the programme structure is built up by progression chains within and between four subject groupings. The focus has been changed to Internet of Things (IoT). New courses were introduced to strengthen progressions in mathematics and physics (see Figure 1, the blue track), programming (the yellow track), computer science (the violet track) and computer engineering with the main specialization in IoT (the green track).

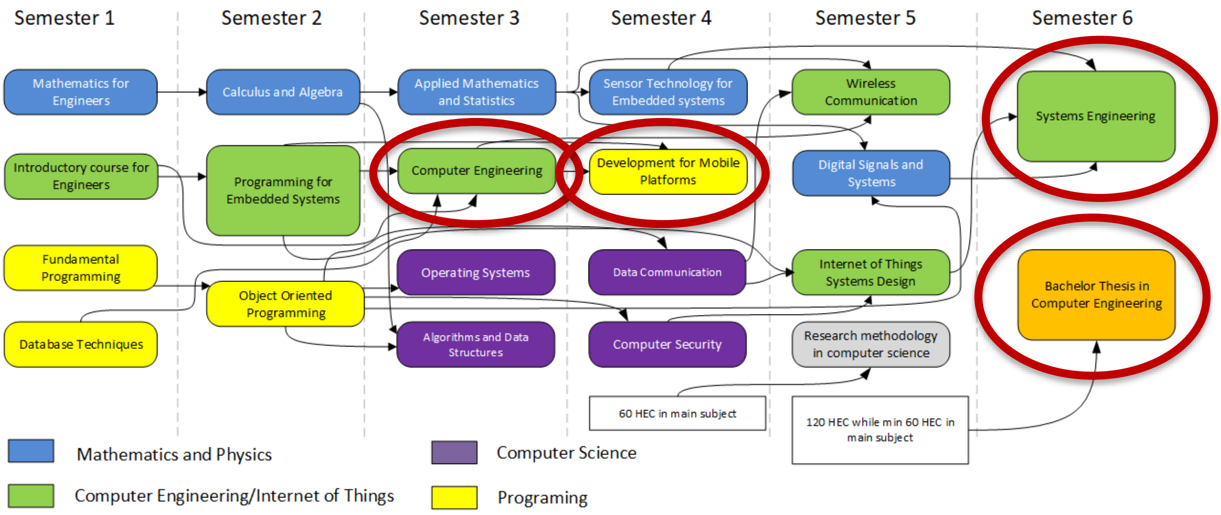

Figure 1: Bachelor Program in Computer Science and Engineering, HKR, (TBIT2, 2020). The courses including the project work are enclosed by red circles.

The students, as future engineers must be trained to work in projects, especially in close relation to the companies. The courses including the project work are enclosed by red circles in Figure 1. Two introductory project courses, Computer Engineering and Development for Mobile platform are given during the second year of the study programme. In both these courses the students are introduced in agile project management. Systems Engineering and Bachelor Thesis in Computer Engineering contain advanced projects and are given during the last term of the study. These two courses in the last semester are incorporating a large part of the different subjects and are the last step in the constructive linking in the programme.

In the last revision, that was introduced in 2020, a new course has been added, "Research methodology in computer science" to ensure research connection and raise students' scientific attitudes as well as prepare students for the Bachelor Thesis.

The Computer Science department has been a member of the CDIO initiative since 2014 and the program is organized according to the principles of the CDIO initiative. Connections to the industry are achieved in the program through Work-based education and "design-build-test" - projects integrated in the subject courses. The learning objectives that are described in CDIO syllabus, are divided into 4 sections: 1) knowledge in the discipline, 2) personal and professional skills, 3) teamwork and communication, and 4) Conceive, Design, Implement, Operate.

Development for Mobile Platforms – 7,5 credits
Here, students practice a purely software engineering project. They are free to choose the content of the project, but only with the restriction that it must be an application running on a mobile phone. This leads to different projects for the different student groups. There is no specific project management model used in this course. At the project start the students need to write the requirements of their app as well as an estimation of the time needed for the different project tasks. The project is summative assessed at the end of the course by looking at the code and the requirements list.

Computer Engineering course – 7,5 credits
The students practice both hardware and software development in the course project, as well as agile project managing in an introductory level. Project management is a key purpose of the course and to convey the importance of agile management the related lectures are helped by an agile project management specialist with hands-on experience of agile project management in the IT-industry. A formative assessment of the project is used like in the Systems Engineering course.

Systems Engineering course – 15 credits
The main purpose of the course is to give the students a hands-on experience of prototype development of a system comprising of both hardware and software development. The project model used in the course has evolved from an iterative project model to an agile model over the years, with a formative assessment. The course has since 2018 been joined with the Bachelor Thesis course (Klonowska, Frisk, & Einarson, 2021). The students have the possibility to join the project in this course with the Bachelor thesis, which is promoted.

A significant part of various projects has always been carried out at companies in the IT industry or other IT organizations. Business projects were promoted by both universities and students, who contacted companies on their own. Since 2020, Work-Based Learning (WBL) (UHR, 2021), (Einarson, Frisk, & Klonowska, 2022) has been an integral part of the course. The WBL integration does not change the purpose of the project and the assessment in the course. It is still the responsibility of the students to find a project carried out at a company. During the last two years the university has intensified the support for the students in finding projects in the IT-industry.

Bachelor Thesis in Computer Engineering course – 15 credits
The aim of the course is for the student to develop in-depth skills with independently planning, realizing, and presenting (in writing and orally) an in-depth project within a defined area in computer engineering and technology, using scientific methods. The work takes place in pairs of two students, unless there are special reasons for doing otherwise, in connection with academic supervision. The student must define the task in writing at an early stage, conduct an analysis of the hypothetical/problem, and produce a schedule in collaboration with the academic supervisor. The students have a possibility to do their thesis at the company as well as a joint project with the Systems Engineering course described above.

QUESTIONNAIRES

Two questionnaires were sent in the end of November 2021 to both companies and students including alumni. The questionnaires were essentially divided into three parts: (1) Cooperation between students and employers in our study programmes; (2) Content of student projects; and (3) Structure and content of future cooperation. These questionnaires were also used in the second authors paper (Einarson, Frisk, & Klonowska, 2022) and only a subset of the questionnaires is discussed in this paper.

The first questionnaire consisting of 46 questions was sent to 30 contact persons in companies and organizations cooperating with our department, with 11 employers responding to the questionnaire. The companies and organizations will be referred as employers for short.

The second questionnaire consisting of 49 questions was sent at the same time to our first-, second-, and third-year students in both undergraduate programmes as well as to our alumni, who have finished the programmes during the last five years. In total, around 200 students and 200 alumni were reached. Approximately 25% of the students and alumni have responded to the questionnaire, distributed as given in Table 1.

Table 1. Number of responses from students and alumni, in total 104.

	Engineering Programme	Software Development Programme	Total
Year 1	5	11	16
Year 2	11	23	34
Year 3	4	19	23
Alumni	8	23	31

Involving first- and second-year students gave us information about future expectations from them. The third-year students and alumni gave us information about both expectations and feedback from completed projects.

QUESTIONNAIRE RESPONSE

Cooperation between students and employers in our study programmes

In the questionnaires both students and employers were asked about what kind of interaction they have participated as a part of our study programmes. The most common interaction between the students and employers is a guest lecture by a company employee, 44 out of 104 students have participated in a guest lecture. Of the 11 answers from employers only 1 company has held a guest lecture. Two students have made a study visit to a company while 25 students have made some other type of interaction, such as, “We had alumni from companies who came and held guest lectures.” and “I was brand ambassador for Consid and invited Consid to come present themselves at campus.”

Content of student projects

Out of 104 responses 8 students answered that they have participated in a project at a company during the education. Out of 11 responses 5 companies have supervised students during the thesis and/or larger project. There should be noted that the responding employers have not supervised any of the responding students. According to the students, the project idea was equally proposed by the students and by the company.

For all companies involved in student projects, the results of the projects are used further after the project was finished, except one. Three out of five ideas for student projects were conceived within the company. The purpose of the student project where mainly product development and product tests, but also getting to know the students for eventual future employment.
The students working with a project within a company seems to be satisfied with their work. One comment is that they created a product that works, another comment is that the student got employed after the project where finished. The employers are as well satisfied with the work by the students, mainly by two reasons, firstly the result of the project was useful for the company and secondly the students were ambitious and engaged in their work at the company.

Structure and content of future cooperation
From the limited response one can see that the companies have a preference to provide student projects both in a project course or/and as a thesis in front of other types of cooperation as guest lectures and study visits or WBL. The companies answered that the ideal length of a project spans from 1 month to a full semester, which is seen in Figure 2 below. The students are interested in larger/longer projects, in average, compared to the companies.

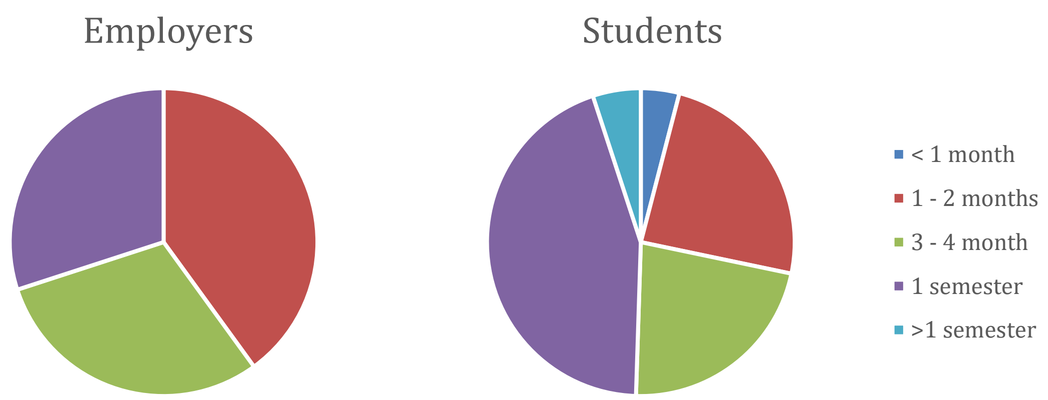

Figure 2: Comparison of wanted project length between employers (10 answers), students and alumni (99 answers). On average the students want a longer project length than the companies.

The wanted project length is broken down into study years regarding the students, also the alumni responses are separated in Figure 3 below. The project length of one semester is preferred more and more, as the student progresses through the education.

The students´ wish of future cooperation with companies are very diverse. It is a range from visits, guest lectures, internship to larger projects. A large part of the student answers expresses a wish to build contact with companies for increasing the probability of finding an employment after the studies.

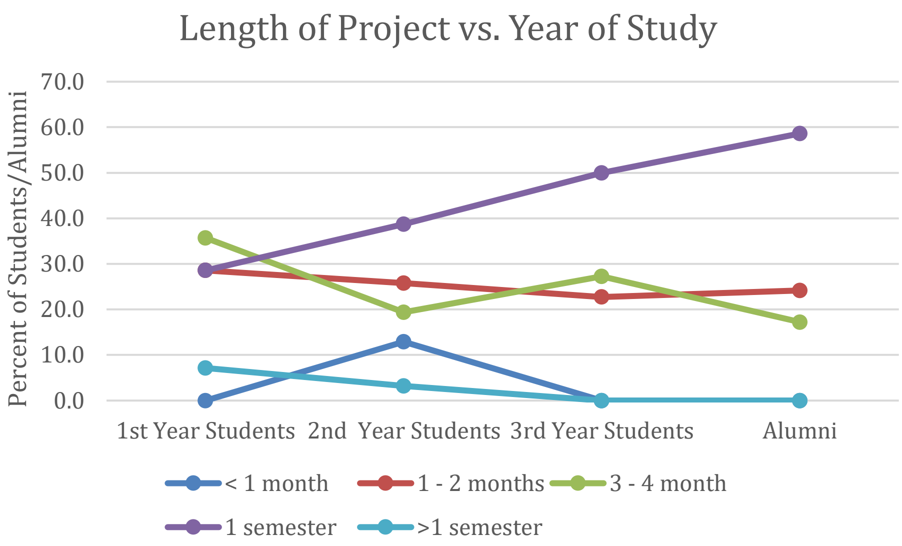

Figure 3: Wanted project length from students and alumni. The percentage wanting a project length of one semester increases almost linearly as the students' progress through the education including alumni.

The companies' preferred future forms of collaboration with students have a focus on product development and research, as seen in Figure 4.

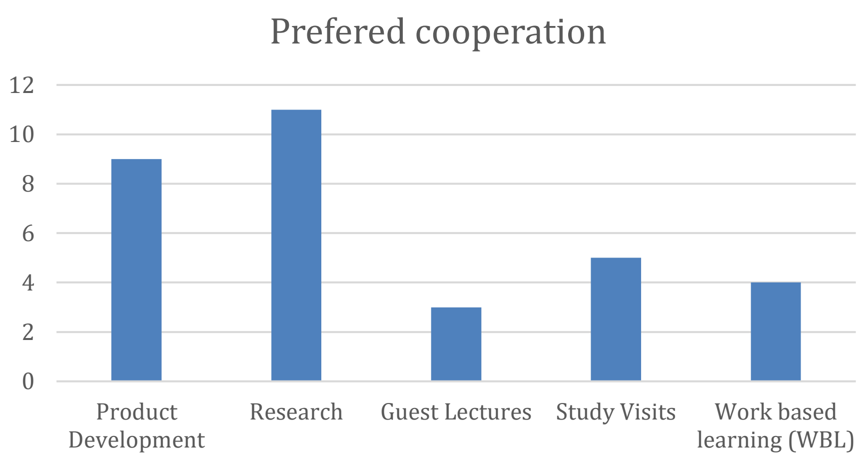

Figure 4: Company preferred forms of future cooperation.

PROGRAM EVALUATION

In 2021, HKR had carried out evaluation of all programmes through an extensive survey among alumni. The survey was sent to 1906 alumni from 14 programmes, with a response rate of 32 percent. The purpose was not only to map the alumni's establishment in the labour market and how the academic education had prepared them for working life but even how the degree goals required by the academia are used in their daily work.

Labour market questions
For the Bachelor Programme in Computer Science and Engineering, 16 out of 60 alumni responded to the survey. 87% (corresponding to 14 alumni) of the respondents are currently working, 7% (= 1 alumni) are studying and 7% (= 1 alumni) is unemployed. 33% has got a job before graduation, 53% directly after graduation (up to 6 months), 13% have not got a job related to the education. 93% answered that they have a job that corresponds to their education, while 7% (= 1 alumni) has a job that does not corresponds to the education, but the respondent answered: “No, I benefit from my education in my work”.

Education-related questions
The alumni were allowed to assess 14 academic skills: "To what extent do you use these skills and abilities in your work?" and "How well did these abilities develop during the education?" The skills are presented in Figure 5.

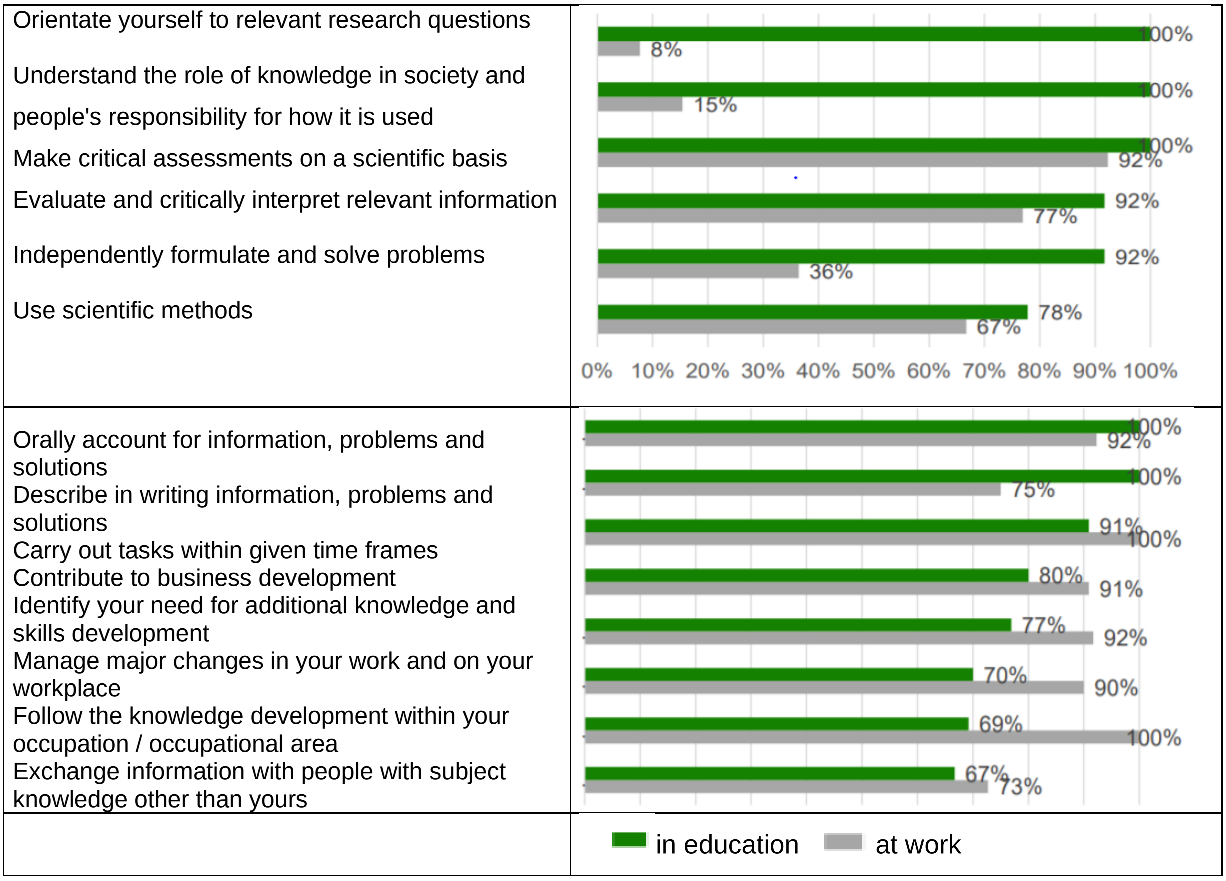

Figure 5: Academic skills, use at work and how well the education developed these.

On the question: “From the experiences you now have from work life, do you miss something in the content of the education, or would you need to train more in something?”, several answers imply a wish of more interaction with future potential employers, e.g., “Better integration with companies in the industry, and the opportunity to meet entrepreneurs / alumni” and “I would have liked to have seen some form of internship, to prepare one for how a workplace works and looks.”

DISCUSSION

The questionnaires are still open, and we are positive of receiving more answers from both employers and students. An example of inconsistent responses is, for example, regarding the guest lectures, where almost 50% of the student have participated but only 14% (1 company). We have only six responses from students who say that they have worked with a project in the industry, out of 17 responding alumni. This is clearly an underestimation, most of the degree project are taking place outside the university at a company. The last three years more than 60% of the degree project has taken place at a company or another external organisation.

A positive response is that we can see is that the results from all projects carried through at a company is used further by the same companies, an example is the evaluation of new product prototypes. Even though we only have three companies answering this question, it is an indication that the companies find the projects useful. The response rate is low can certainly be explained by the short amount of time between when companies were contacted, and today's date (*today's date is 2022-01-15, the result will hopefully be complemented with further information in a possible later version of this paper*).

CONCLUSIONS

The survey shows that both companies and students are positive about facilitating and participating in projects that are run or initiated by companies. The companies think that the project results are useful for further development and the student feels that the project work in a company a motivating way of learning how to learn how to work in "real" projects. Both companies and students think that the projects are a segway to possible future employment. From the company perspective we can see that the product development and research is the preferred collaboration with the university and student, Not saying that the other forms of collaboration is not desired.

The students want more interaction with companies and other organizations, as well as the companies want to continue the collaboration with the university and our students. The survey also shows that the students prefer longer projects, up to one semester, which is longer than the companies state. We interpret the desired shorter project time from the companies as a resource limitation. The companies say it takes between 5-10 hours a week to supervise the students, which can be a limitation for longer/larger projects.

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BIOGRAPHICAL INFORMATION

Fredrik Frisk has a PhD in Mathematical Physics and has several years of experience in teaching Computer Science, project management, and Physics. Furthermore, he has several years of experience of product development from Industry.

Kamilla Klonowska has a PhD in Computer Systems Engineering and has several years of experience in teaching Computer Science. She has also been active in developing and revising educational programs at the Computer Science department with a focus on increasing quality as well as emphasizing the academic skills of students.

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PROJECT BASED LEARNING AND REFLECTION IN A MANUFACTURING ENVIRONMENT

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ABSTRACT

In engineering education, many initiatives aim to close the gap between theoretical knowledge and practical/industrial application. The course depicted here focuses on the injection moulding of an elementary plastic product, and aims to address the full development cycle, ranging from product idea, via 3D modelling, simulation of injection moulding processes, mould design, process planning and milling of the mould, to the actual injection moulding. In this, continuously reflecting on the initial ideas, new acquired knowledge and information, provided limitations and intermediate steps by the students themselves drive the iterations in the overall cycle. The course has a specific focus on acquiring needed information, the students are assumed not to just study and apply existing (design) rules for injection moulding; they rather are challenged to deduce the design & manufacturing rules that bear relevance and give guidance for their development cycle. In this, basic knowledge is provided to the learners in short lectures, videos, and tutorials, albeit they are simultaneously challenged to obtain, digest, and apply additional knowledge on the various topics if and when needed. Over the past five years, over 100 injection moulds and products were created, for an equal number of student groups. This demonstrates that second year students (in this case Industrial Design Engineering students) can successfully associate with such a complex development process. Evaluation among the students indicates a high level of understanding and motivation linked to the creation of their own actual product. By means of the approach chosen, the course not only aligns the intended learning outcomes, the learning activities, and assessment tasks. It simultaneously triggers the learners to build expertise and experience at different levels of aggregation, in a self-propelled manner, with full ownership of the project.

KEYWORDS

Project based learning, Plastic injection moulding, Development trajectory, Standards: 5-8

INTRODUCTION

The educational programmes in engineering at the University of Twente have a long tradition in applying project-led education as a means to inspire and challenge students and to allow them to study and experience the relation between theoretical knowledge and (industrial) practice (Dankers et al., 2013). Especially in the BSc. programmes, the curriculum is characterised by the amalgamation of projects and theoretical courses; in every educational module of ten weeks, students enrol in a project that thematically coheres with adjacent courses. Dependent on the specific project and level of studies, typical group sizes range from 4 to over 15 students per group, where the efforts involved in the project represent 20-50% of the overall study load. In the projects, students inherently need to take ownership of their own projects, take the responsibility for the outcome, but also for the process that led to that outcome. By steadily reflecting on the learnings and progress, student motivation to internalise knowledge increases, as is their inclination to purposefully apply that knowledge. This also makes assessing education more transparent and purposeful (Biggs & Tang, 2011), as students themselves are involved in correlating activities to goals and deliverables. In the curricula, different projects immerse students in different perspectives, with different starting points, scopes and development approaches. With that, students are inherently accustomed to dealing with different situations and the uncertainty involved. This challenges them to not 'just' straightforwardly try to solve the problem at hand, but to also look at the consequences of solution for other perspectives, to establish co-operation over different disciplines but also to question or reformulate the problem statement (Fresemann et al., 2018; Luttikhuis et al., 2014; Berglund et al. 2007). This allows students to emphasise their own profile within the programme, as they can focus on different roles in subsequent projects.

Within the context of project-led education, the educational programme Industrial Design Engineering continually strives to offer original educational approaches, thus applying the originative character of the programme – not only as the content is concerned, but also addressing novel educational approaches, software, technology and relations with industrial reality. This publication depicts a course in the second year of the programme that allows students to transcend the scope of an individual design step or production process.

COURSE SETUP

In the course, students peruse the development process of an elementary plastic product. They do this in small groups, of four to six students each, in a ten-week project that covers around 20% of the nominal study load. The development of the elementary plastic product starts with a straightforward challenge that is assigned all (around 30) groups before any knowledge transfer takes place: "design a plastic product that can be produced using a single-sided mould". The students are given complete freedom in their design decisions in terms of for example geometry. However, the students quickly understand that this uncomplicated assignment implicitly incorporates a wide range of limitations and perils related to individual process steps, manufacturability, feasibility and quality of their design (Andersen et al., 2021), but also to managing the entire development cycle. Moreover, given the number of students involved, a number of more pragmatic restrictions are imposed from the perspective of course management. In the first seven weeks of the module, students address the full development cycle, ranging from product idea, via 3D modelling, simulation of injection moulding processes, mould design, process planning and CAM (see figure 1), using industrial software.

The remaining three weeks are used for production of the mould (two weeks) and the actual injection moulding (one week). With around 30 moulds to be manufactured in a time span of two weeks, and the capacity of the workshops at the university, the lead-time for all the moulds is a main bottleneck in organising the course project. This entails that the students are provided with several technical design limitations – simply to enable mould production for all groups. At the same time, those limitations immediately confront students with the fact that downstream processes do influence early design decisions. On the one hand, the limitations help groups to make the assignment more manageable. On the other hand, groups that reflect on the cause of the limitations and can generalise that reflection can benefit significantly in addressing other phases in the course. Another origin of technical design limitations is the fact that the design must be injection moulded on the one available machine. Hence, together with the assignment, the students receive information on and specifications of the injection moulding machine setup. The course setup corresponds well to all four sections of the CDIO Syllabus 2.0 (Crawley et al. 2011).

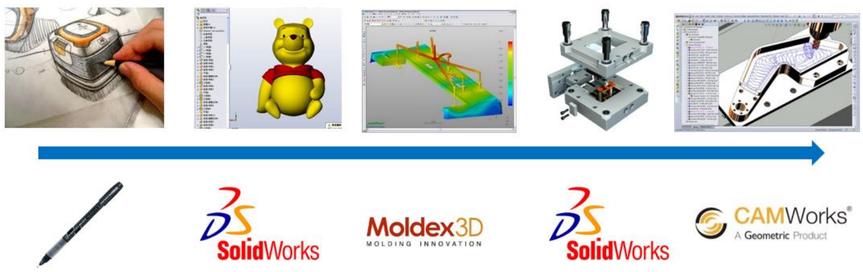


Figure 1. Schematic representation of the course phases/topics and their dependencies

Injection moulding machine setup

The practical orientation of the course requires a series of production machines, tools and standard parts in order to successfully injection mould the products designed by the student groups, in a setting that can be characterised as a learning factory (Abele et al., 2017). For injection moulding, a BOY 22E injection moulding machine is used. This is an industry standard machine suitable for small products with a maximum shot volume of 47 grams, a maximum injection pressure of approximately 1000 bars and a clamping force of 22 tons. The students need to interpret the implications of these machine characteristics for their own design, especially during the simulations of the injection moulding process.

For reasons of handling and flexibility, the injection moulding machine has a so-called unit die holder. The unit die holder developed for this course contains e.g., cooling channels, the ejector plate, sprue bushing and numerous guide pins and bushes (see figure 2). It acts as a base for the mould inserts created by the students, making the inserts simpler hence allowing for faster milling. The mould insert, from here on referred to as mould, is an aluminium block measuring 160x140x25 mm. Whereas moulds for mass production are made of hardened steel for durability, this project applies aluminium to significantly reduce milling times. For the milling of the moulds two Datron M8 Cubes and a DMU CNC milling machines are available.

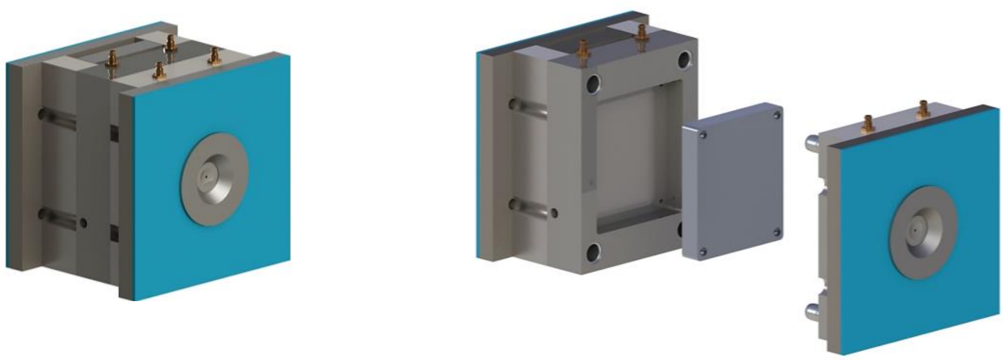


Figure 2. unit die holder with mould insert and second mould half.

Limitations

At the start of the course, students are exposed to a scenario that introduces them to the actual production of the moulds and their actual plastic products. At the same time, this scenario is the basis for the students to foresee and understand technical limitations that will play a role in the decision making in their project. In short, the scenario shows the groups that, to contain the complexity of the design assignment and to allow for the production of all moulds, groups are limited to a single mould side, the cavity. The other mould half, called the core, is a simple flat side with the plastic injection point located at the centre. This centre point, the so-called runner-start point makes the connection between the sprue and the runners in the students' moulds. The dimensions and shape of this start-point are stipulated and provided as a 3D CAD model. The designed moulds are made by milling, in which a specific set of milling tools is available, a.o. flat end, ball nose and tapered end mills. The minimal tool diameter and allowable cutting depth can significantly impact the final product geometry and the surface quality. For example, the minimum available tool diameter is 1 mm, resulting in minimum applicable corner radius of 0.5 mm.

Once the mould is mounted on the injection moulding machine, the machine parameters in production should be underpinned by decisions in design and simulation activities. Adding to that, after opening the mould halves, the product can be ejected automatically by the ejector-pins. The location of the ejector pins is limited due to the construction of the unit die holder. The centre of the mould allows for freely positioning ejector pins in a region measuring 95x75 mm, which is considerably smaller than the region available in the mould. Also, the ejector pins have a fixed diameter of 3 mm and standardised lengths. The length of the pins is linked to the depth of the cavity measured from the mould parting surface. Pins for depths of 1, 1.5, 2, 2.5, 3, 4 and 5 mm are available.

Presenting the student groups with a scenario like this allows student groups to contextualise their design decisions, to look beyond the 'next' decision, but foremost to challenge them to structure their own project and to take ownership thereof. Together with the straightforward assignment, this contextualisation presents the student groups with an actual and concrete challenge, in which they themselves have to uncover, retrieve and generate the information that will allow them to reach the decisions they consider to be contributive to their project. Over the years, this approach has been the basis to really immerse the students in challenge-based learning – especially as the groups can actually produce their designs and as the groups tend to start a competition amongst themselves.

COURSE PLANNING

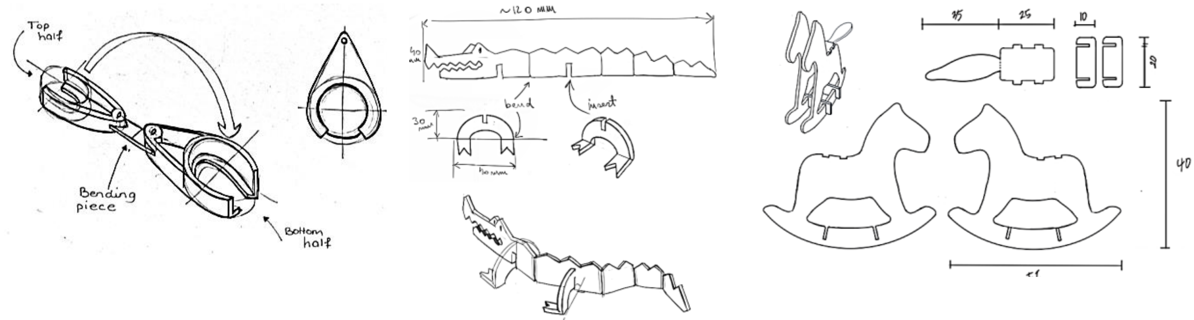
Week 1 and 2

The first week of the course is used to explain the course setup (as shown in figure 1) with all the different phases and software programs the groups will be using in the subsequent seven weeks. The assignment is introduced, together with the scenario that outlines the technical data of the machine tools, tools and processes involved and the resulting (im)possibilities and limitations. Obviously (and intentionally), this overwhelms the students, because not all information seems immediately relevant for the first design phase. Consequently, the students need to analyse and internalise the information and underlying knowledge provided to single out which information is relevant when and what information may be incomplete, uncertain or lacking. For example, providing the clamping force of the injection moulding machine might seem to only bear relevance for the final stage of setting up the injection moulding machine. However, together with the injection pressure, the clamping force is inextricably linked to the maximum frontal surface area of the mould cavity. A product designed with a large frontal surface area might exceed the maximum clamping force of the machine, resulting in failure during production. Therefore, students have to deduce that clamping force and thus surface area are relevant already during the first design phase. Another example of information that seems only relevant for the final injection moulding process is the length of the ejector pins. If during the design phase this pin length is disregarded, the product thickness will not match the available resources – in this case leading to clear imprints of the pins and thus surface imperfections being visible in every product produced.

To provide guidance to the students in the process, short lectures introduce topics related to the design and manufacturing of plastic projects and create awareness of the interdependencies of the topics involved. Lectures include general design guidelines, mould design and layout, and an introduction into melt flow characteristics in cavities. Again, students are assumed not to just study and apply existing rules for injection moulding; they rather are challenged to deduce the design and manufacturing rules that bear relevance for their own product and development cycle. As the design freedom in the assignment yields a huge variety of resulting designs, no lecture provides knowledge that is fully and unequivocally applicable for any individual design. Again, this stresses the need for students to revise all input to render it meaningful for their design. To aid students, throughout the entire development process, teaching assistants are available for consultation. The combination of design freedom and working in groups creates a de-centralised teaching setting, where groups can get feedback and guidance, linked to their design, but based on generic theoretical knowledge.

To spur decision making, groups have 1.5 weeks before they have to hand in the final product idea containing sketches (see figure 3), explanations, and substantiations of their design. Each group receives feedback, based on the guidelines used, envisaged manufacturability of the mould and producibility of the product. Based on the feedback, students can iterate on their design, their assumptions and their design decisions before starting the first simulations.

From figure 3 it is clear that the given limitations, especially the use of a single-sided mould, results in 2.5D products. Most final products are built by combining different 2D parts into something of a 3D structure using slots or hinge mechanisms. Such mechanisms entice students to learn about e.g., material behaviour and tolerancing/accuracy while also introducing additional interrelations between the design and downstream processes.



a) Coin holder b) Crocodile c) Rocking horse

Figure 3. Examples of product idea sketches

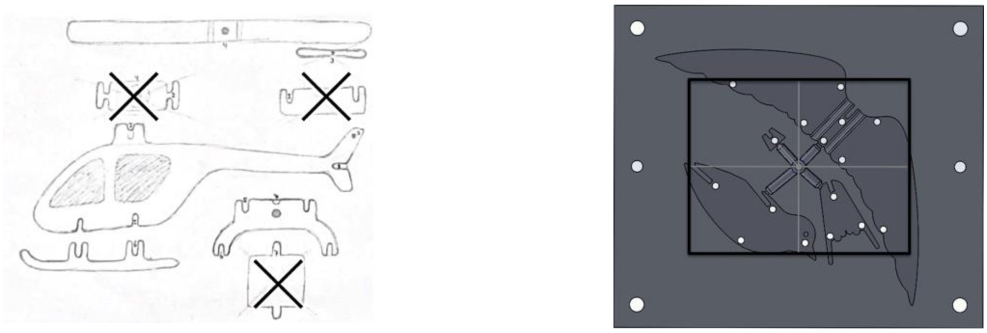
Week 3, 4 and 5

After finalising the product concept, 3D SolidWorks models are created by the students to prepare for injection moulding simulations. For the simulations the software package of Moldex3D is used. This software program is one of the two main simulations packages used in the injection moulding industry and thus a great way for students to get acquainted with such specific software. In this phase of the course, the students will establish the first feedback on their insights on the producibility of the product. The first step in the simulation is the determination of the gate location (the melt inlet for the product cavity). The software has a built-in tool to determine the optimal location, but students still need to correctly setup this optimisation and reflect on the results. For example, the gate cannot be positioned on surfaces that interfere with the functionality of the product. Figure 4a shows the optimal gate location according to the software, but this location coincides with a slot for combining parts. The students could overrule the software and decided to reposition the gate to the best possible position close to the optimal location without interfering with the functionality (see figure 4b).

a) Gate location optimisation by software b) Adapted gate location by students

Figure 4. Example of adaptation of gate location

Before starting a complete filling analysis, the students need to determine the position of all parts in their mould. This first positioning is done based on the information provided during the lectures on mould layout in combination with the area that is available for ejector pins. Each year, multiple groups have to iterate on their design or have to reconsider earlier design decisions (for example to simplify their design or remove small parts, see figure 5a) because of the lack of ejector pin options. Figure 5b shows a tight arrangement of parts within the mould in such a way that every part has ejector pins at proper locations.

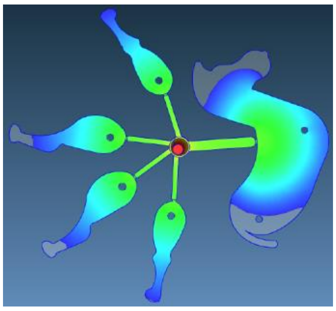


a) Reducing parts because of ejector pins b) Part arrangement to pin region

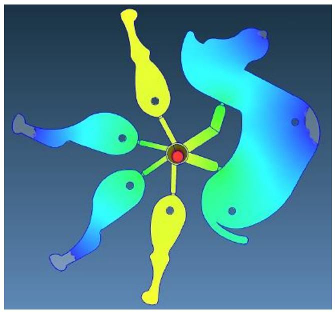
Figure 5. Ejector pin positioning

The next step is to simulate if the part cavities can be filled with plastic by setting up a flow simulation. This is where the product really comes to life for the first time and students start to realise that if these simulations are not successful, the actual injection moulding process would fail accordingly. This clearly and visibly motivates groups to critically reflect on all simulations and simulation results – also urging them to iterating on their own design. In all simulations students asses the values, impact and mutual dependencies of over 20 different process parameters and characteristics, including e.g. the location of airtraps and weldlines, temperatures, pressures, stresses, clamping force, shrinkage and warpage. To help the students with the interpretation of the results, short videos about individual parameters and characteristics are made available.

An important aspect in injection moulding is the simultaneous filling of all cavities in a single mould. Any mismatch in filling time will result in pressure differences that can lead to differences in shrinkage and other deformations. Especially student groups that designed 3D products build up by 2D shapes, as seen in figure 3, will have to monitor this closely. For example, the figure 6a shows the melt flow for a 3D Zebra where two of the legs are filled at 81% of the total filling time. This is well below the industry standard of 90%. After several iterations, the group concluded that the body needed two gates instead of one. Where this causes the two legs to now be filled at around 91.5% of the total filling time (figure 6b), this solution will inherently introduce a weld line, forcing the students to assess and prioritise the (dis)advantages of either approach.



a) Flow simulation, two legs filled at 81%



b) Flow simulation, two legs filled at 91,5%

Figure 6. Example of melt flow optimization

Week 6 and 7

After finalising the simulations, the last two weeks of the 7-week development cycle are spend on creating the CAM files for the production, see figure 7a. The first step for the students is to create the negative imprint of their product resulting in the mould block with product cavities. This forms the basis for the creation of the process plans, using the software package CAMWorks. The software contains all tools that are available for milling the product cavities, together with the proper machine settings. To help the students, a tutorial and videos describing all steps, for a similar product, are made available.

Creating the milling toolpath often reveals design errors that have gone unnoticed before. As mentioned in the section about limitations, the smallest available mill has a diameter of 1 mm. This means that no toolpath can be created for cavity parts that are less than 1 mm in width. Every year, multiple groups are confronted with the significant consequences of this constraint. For example, if the gate is made too small and must be enlarged, this invalidates the previously made simulations, gate size has a significant influence on pressure, melt flow and more. Groups are forced to redo parts of the simulation to verify again that the product can be produced. Examples like this clearly show the complex and iterative development process the students are faced with. Another example with milder consequences is the impossibility to create sharp internal corners with rounded tools. Every internal corner will have a minimal radius equal to the radius of the used tool. When creating the toolpath this often leads to geometry left un-milled at these locations, slightly alternating the final product geometry. These changes do not have a large impact on the simulations but will change the appearance of the product and will also influence the exact amount of material required in injection moulding. To avoid this, students are encouraged to think about the negative or imprint of their product during the first stages of the design process.

a) CAM file containing toolpaths b) CNC milling of the moulds

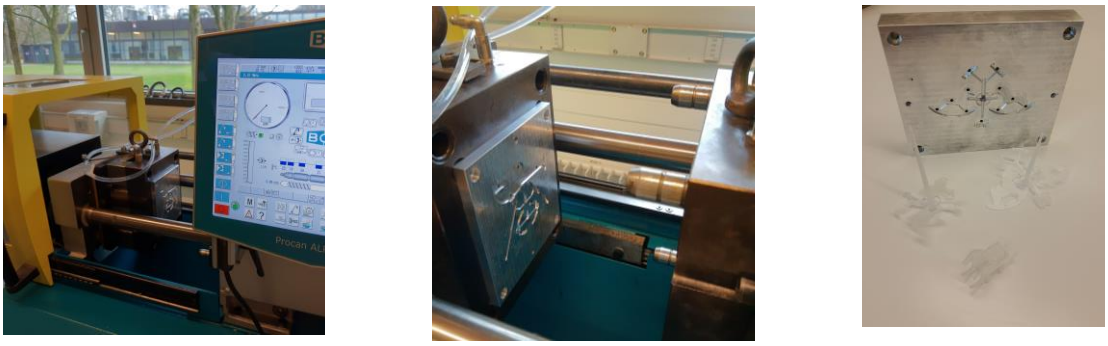
Figure 7. Mould production from CAM file to CNC milling

Week 8 and 9

In these weeks the production of the mould takes place (see figure 7b); for safety reasons the CNC-machines are operated by members of staff. Moreover, all CAMWorks files, containing the CNC code with all necessary milling steps and setups are checked extensively. This is a very labour-intensive task for the lecturer. However, this check not only ensures that all steps and setups are correct to prevent failures during production, but the files also provide valuable insights in the decisions, assumptions and quality assessments by the students in the group. Consequently, these files do also play a role during grading. When files contain too many or significant errors, groups are notified, provided with feedback, and asked to provide improved versions. In the same two weeks the students have time to finish the project documentation containing design information about their product, the underpinning and results of the simulations performed and the analyses, evaluations of and reflections on the simulation results and on the development process that led to those results.

Week 10

The final week of the module is used to produce the products. In a session of approximately 45 minutes per group, students will mount their mould on the injection moulding machine (see figure 8a) and propose machine settings based on the simulation outcomes. If those setting are considered viable and safe, they will be used in the first injection moulding run. Together with the lecturer the group can then advance in obtaining more appropriate/optimal process parameters, based on the available simulations and based on observations and measurement on the actual injection moulding machine. In general, this optimisation process (see figure 8b) takes 20 minutes. The remaining time is spent on fully automated production, resulting in a product every 30 to 45 seconds, depending on the cooling characteristics of the design.



a) Mould mounted into the injection moulding machine b) Final product

Figure 8. Injection moulding in the final week

COURSE EVALUATION

By now, the course yielded over 100 moulds for injection moulding, for as many student groups in the past five years. In these years, four groups failed to deliver a CNC worthy mould and around 25% of the groups had to do some supplementary work before mould production could start. The final injection moulding of the products also exposed design flaws. Common design flaws are i.a. too few ejection pins, missing of draft angles, too small gates. Overall, 10-15% (per year) of the products are stuck in the mould due to this, ranging from the need of manual removal to complete fixation of the product in the mould. Other mistakes common in industry like short shots, excesses clamping force or acceding any machine limits never happened, proving that the simulations are properly performed by the students. Also, over the years the complexity of the products increased, as students have explored (and tried to push) the boundaries of what is possible within the technical limitations. Complex snap fits, hinge mechanism and metal inserts with over-moulding have successfully been produced. This demonstrates that second year students (in this case Industrial Design Engineering students) can successfully associate with such a complex development process. The increased complexity also means that students learned from and built on the work of previous generations.

The successful implementation is underpinned by figure 9, showing the grade distribution of the final course grade per individual student over the past five years. Students are graded on the CAM file, project documentation and final product. The CAM file and project documentation are graded by criterion referenced grading using a checklist/scorecard and rubric, respectively. The final products are norm referenced graded between all groups.

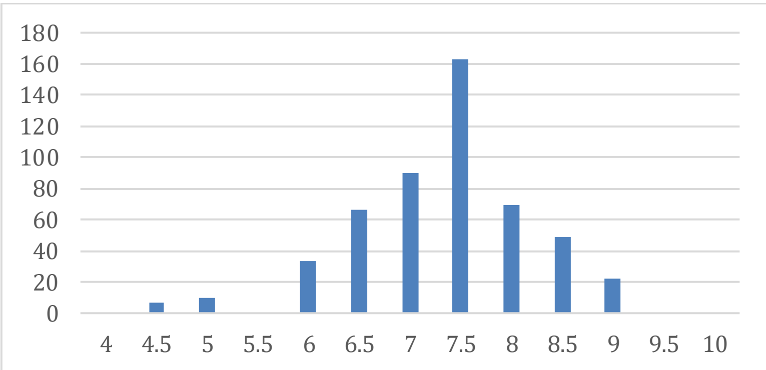


Figure 9. Grade distribution over the period from 2017 till 2022

Evaluations among students, performed every year after the course has finished also show the successful implementation of the injection moulding development process in education. The sessions are attended by approximately one third till halve of the students enrolled. Remarks that were mentioned several times during these sessions over the years include i.a.

- “It was nice that we did design our own product and we saw our own product being injection moulded. This was really motivating to work on the assignment.” Mentioned over 40 times in the last three years of course evaluation.
- “Interesting and fun course, learned a lot by completing the entire development process.”
- “The course taught students quite a lot and was relevant to their growth as industrial design engineers.” Mentioned over 20 times in the last three years of course evaluation.
- “It was a good way to learn about injection moulding, not only using theory, but also putting it to practice.”

Other feedback includes positive remarks on the multi-disciplinarity of the course, the hands-on approach, the opportunity to use ‘industrial’ software and machines and the ability to consult with the lecturer on all topics involved. Besides the predominantly positive feedbacks some students indicate that they would like to see a subsequent course that would allow them to work on a ‘real’ industrial product. Moreover, the student group size is and probably will be a point of criticism. Most students indicated that a group size of four to six students is too large for this course. However, from the perspective of course management, smaller groups, and thus producing more moulds, is simply not attainable, also because this would significantly impact the time for per-group feedback and pre-production checks. At the same time, the teaching staff is convinced that remarks on group size more often than not are actually reflections on team-work in role distribution in the group; where this is not an explicit learning goal in this course, the students clearly engage in thinking about their own and each other’s roles, interests, work-load, and responsibilities in the project. All in all, the evaluations performed during the five years of teaching this course, endorses the impact of the course and the effects of challenge-based learning at project level in manufacturing environments.

CONCLUSION

The developed course has proven that second year bachelor students can successfully, in small groups, go through the complex development process of creating an injection moulded product in a timeframe of 10 weeks. Simultaneously, the course is manageable for the staff, by tailoring the restrictions conveyed to the students carefully against the available capacity of staff and equipment. Also, active teaching efforts are gradually supported by providing access to theory, knowledge and best practices by means of short lectures, videos, tutorials and by making previous results of student groups available for scrutiny and as inspiration. The project-based approach challenges students to take ownership of and responsibility for their own injection moulded product and development trajectory. Groups continuously reflect on the evolving ideas and progress, while acquiring knowledge and dealing with restrictions. Such acquired knowledge drives the iterations in the development cycle, inheriting from industrial development trajectories. Because of the synergy between theoretical knowledge and practical/industrial application, the course allows students to see the full development cycle of injection moulding from multiple perspectives. Course evaluations are positive and indicate high levels of understanding and motivation linked to the creation of an actual product. Other feedback highlights multi-disciplinarity, the hands-on approach, the opportunity to use ‘industrial’ software/machines and the ability to consult with the lecturer on all topics involved. For subsequent versions of this course, focus will be on the way in which a structured information backbone (as an evolvement of the videos, tutorials etc.) can provide students with a contextualized, semi-industrial working environment. Also, an additional focus will be on design rationale and the deduction of design rules.

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INTEGRATION OF LEARNING AND RESEARCH IN A MULTI-PERSPECTIVE LEARNING FACTORY

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ABSTRACT

Many technical universities and polytechnics have manufacturing environments or learning factories to teach students about production and assembly processes. The University of Twente currently establishes a new workshop, including a specific learning factory. In this learning factory, design choices are made in such a way that the organisation, appearance and comportment of the learning factory can be harmonised with the learning intent, the learning path and the levels of experience and expertise of the learners or trainees involved. The learning factory serves different levels of learning simultaneously. To this end, a recursive master-apprentice model is ingrained in its design. This approach aids in implicitly blurring the distinction between 'learning' and 'research'. Although all participants have their own interests and goals, they strengthen each other's learning and research. The learning factory caters for addressing multiple perspectives simultaneously, ranging from e.g., a production process and quality monitoring, via logistics and real-time location systems to workplace ergonomics. This is only possible if a flexible and versatile architecture underpins the learning factory, based on serious gaming and digital twinning. In the learning factory, research initiatives thrive on the activities of learners; concurrently, learners benefit from the research initiatives and underlying systems – interfaced by e.g., serious games and digital twinning. The learning factory is under development, in which the paradigms of the learning factory are applied: it is infused by students and researchers working on prototype projects/solutions; this allows them to study the topics involved, while anticipating the structure and working of the learning factory in a way that vouches for the envisaged openness, flexibility, and manageable indeterminacy.

KEYWORDS

Learning factory, recursive master-apprentice approach, serious gaming, digital twinning, integration of education and research, Standards: 3, 5, 6, 8, 9

INTRODUCTION

There is no such thing as sudden experience. In production industry, vocational training and academic learning alike, conveying explicit theory may establish factual knowledge, but for obtaining insight, acumen and underpinned expertise, sheer theory does not suffice. Moreover, the intent of learning is often to establish the ability to make decisions in an informed, judicious and creative manner. This requires tacit knowledge, habitually transferred by 'learning-by-doing', from which learners build mature understanding. Traditionally, a master-apprentice approach allows for introducing learners to new processes, environments and knowledge. However, in highly optimised production environments, such approaches are well-nigh impossible. Especially in mass-production or large batch production, there is no room for interruptions – let alone errors. Over time, this has led to a variety of initiatives to replicate the primary processes in safe and permissive environments as the basis for teaching and learning. Such replicated environments have purposeful applications in education and academia as well. Students can get acquainted with production environments, they can be confronted with their own decisions, and as such, they can build elementary experience in dealing with production environments. Such 'learning factories' provide a reality-conform learning environment, in which trainees can discover and test approaches or conduct experiments on technological and organisational industry-related issues (Abele et al., 2017; Abele et al., 2015; Kreimeier et al., 2014). Learning factories provide the ability to support methodical modelling of effective competency development, enable feedback processes for the learner, and simultaneously open possibilities in production research. Establishing a realistic learning factory, however, comes with significant investments in terms of efforts and costs. In companies, the envisaged environment is often well-defined, and the learning objectives, the learning approach and the assessment ('readiness for the job') are inherently aligned (Biggs & Tang, 2011), often as a part of life-long learning initiatives. In academia, establishing effective and efficient learning factories is more intricate. After all, students are not being prepared for defined tasks, nor is the aim to convey replicable skills. Moreover, optimisation and evaluation can generally not be based on any 'real' production line or primary process. Hence, learning factories can mimic a specific (imaginary) industrial environment, or have a generic constitution (Abele et al., 2019). In both cases, limitations relate to the resources needed, scalability, mobility and effectiveness of learning factories (Tisch & Metternich, 2017). There is also a considerable risk of descending into a definite, rigorous (and perhaps even stifled) environment with predefined workflows, expected/predictable outcomes and ordained behaviour. This can be prevented by making the design of the learning factory an inherent constituent of its operation, challenging learners to deal with and influence changing circumstances. With this, the learning factory can become more versatile for multiple types of learners, but also become a breeding ground for research – related to the production environment, but also to the learning involved.

This publication depicts the design of a learning factory to demonstrate how multiple perspectives (ranging from production processes and quality monitoring, via logistics and real-time location systems to workplace ergonomics) can be involved in a factory for learning and research. Based on the background of the new learning factory and its educational approach, it elaborates on the contemporary master-apprentice approach that is introduced, in relation to the integration of learning and research that is anticipated. To orchestrate the learning factory and its (didactic) organisation, a background in serious gaming is used, in which a variety of digital tools are prerequisites, but simultaneously are tools for further development.

CONTEXT AND SCOPE

The Faculty of Engineering Technology at the University of Twente hosts educational programmes in (among others) Mechanical Engineering (ME) and Industrial Design Engineering (IDE) at BSc./MSc. level and has a variety of PDEng. and PhD. trajectories. With around 450 first-year students per annum, the programmes aim to educate professionals with in-depth technical expertise and know-how, with a particular focus on interdisciplinarity and on specific competences in addition to only technical knowledge. The programmes integrate education, research and (industrial) practice, to allow for concurrent knowledge generation, reflection and contextualisation. One of the main agents in education is project-led education.

Project-led education

Both for ME and IDE, the programmes build on project-led education, mainly to immerse students quicker and more profoundly in the fields of expertise involved (Dankers et al., 2013). Students work in 10-week projects, covering 30-50% of the nominal study load, in groups ranging from 4 to over 15 students. Projects are not fully pre-structured, challenging the students to take control and ownership of their own learning. Given the impact of educational projects of considerable scope, complexity and scale on the overall program, adequate balancing of the learning aims, and implementation of projects and courses is essential (Fresemann et al., 2018; Luttikhuis et al., 2014). Project-led education instigates a demand for understanding/learning or creating knowledge, while carrying responsibility for the results, while focusing on the contents of the field of expertise as well as on social and communication skills. After all, the 'best' idea or concept is only viable if supported by the entire team – requiring adequate presentation with appropriate persuasiveness.

In engineering, project-led education confronts (groups of) students with the consequences of their decisions in design and development trajectories, by challenging them to implement or materialise their ideas/concepts. In this, focus and reflection on all different fields of expertise involved, but foremost on the subjacent design/development processes are essential (Tomiyama et al., 2009), to challenge the engineer's ability to approach problems from different perspectives (Damgrave et al., 2021; Damgrave & Lutters, 2016). This strengthens the ability of students to not only acquire knowledge but to become a versatilist: an engineer who can be a specialist for a particular discipline, while at the same time being able to change to another role with the same ease. Consequently, students 'experience' projects and education, but from the start, they are immediately dared to control, govern and take ownership of their projects. With that, students initially take pride in more or less succeeding to produce prototypes; later, with more advanced topics and more perspectives involved, they become eager to get more grip on and control over the processes involved. Ultimately, students should inherently anticipate foreseeable consequences of decisions in design and development trajectories. To achieve that for topics ranging from fabrication processes, assembly processes, quality control, process planning, production planning to facility/asset management and factory lay-out, the access to a well-equipped, adaptive and flexible learning factory is an essential prerequisite.

Development of a new learning factory for education and research

Over time, deliberately enforced by project-led education, the workshops at the faculty transformed from 'exclusive domain of trained technicians' into a coherent set of shared facilities where students, staff and technicians co-operate to produce prototypes, test designs and build research setups. At its core are workshops that offer access to elementary production machines. As satellites, workshops related to e.g., metrology, additive manufacturing, Virtual/ Augmented reality, Smart Industry and plastics processing are connected. With an ongoing increase in student numbers, the facilities needed increased capacity. At the same time, the educational projects call for the incorporation of innovative production processes and for integrating digitalisation initiatives. Likewise, operational management of production machines, assets and factory environments receive increasing attention in education and research. Moreover, the evolvement of educational and didactical approaches calls, and allows, for advanced interactions between theoretical discourses and industrial applicability. Here, possibilities prompted by digitalisation/Industry 4.0 infuse thinking on learning factories in terms of flexibility, modularity and reconfigurability that was previously impossible or infeasible. All in all, the shared facility required reinvigoration beyond 'continuous improvement', in which explicit attention for the principles of learning factories can play a significant role.

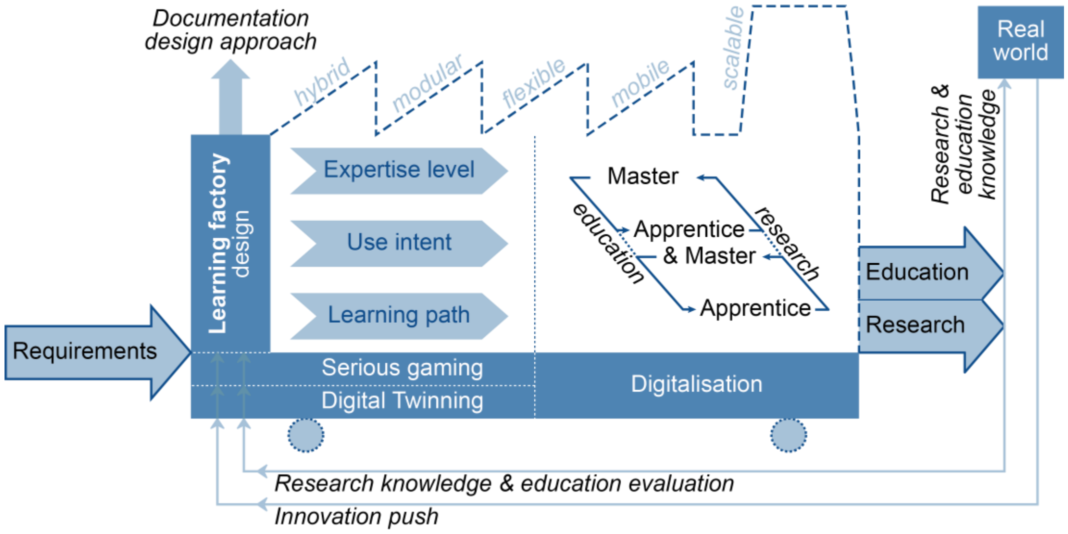

Figure 1. Schematic overview of the design and embedding of the learning factory

Currently, the concept and design of the new workshop is finished, and construction is about to start. The workshop will cover around 3000 m^2 with different ‘environments’, hosting specific sets of processes/materials, at multiple levels of aggregation. Thus, activities range from exposing learners to individual production processes, via process planning to establishing planning/monitoring approaches for multiple environments. Whereas the entire facility essentially acts as a learning factory, there is one ‘environment’ that is referred to as a specific learning factory. This learning factory (of around 150 m^2) allows for repositioning/ reconfiguring assets and resources to set-up modular production or assembly lines; it is explicitly based on the learning factory philosophy, but with a few twists. Figure 1 depicts a schematic overview of the thinking behind the learning factory. To counteract challenges as mentioned above, the design of the learning factory is inherently modular, reconfigurable and flexible. This avoids rigidity over time, but it also allows for different types of involvement for students with different perspectives or at different levels. Beginning undergraduates will experience the different production/assembly stations as a means to understand the processes and the workflow involved; at the same time advanced learners may be responsible for configuring/optimising the production/assembly line the inexperienced students encounter.

Inherent to the focus on project-led education and challenge-based learning, the new workshop has been designed in such a way that it indeed (within reasonable limits) facilitates student-driven operation and learning, and can engage in all nonconforming ideas, plans and ventures that are the outcome thereof. After all, whereas exposing inexperienced students to production/assembly lines sounds excellent in theory, there are obvious risks – especially if the line is setup/ran by other students. The main pitfalls relate to safety and to the investments in assets, resources and tools. After all, if inexperienced users are given the responsibility to operate machines at their own discretion, clear and explicit precautions should be taken. In ‘traditional’ learning factories, the inherent response often is to introduce workflows to assure safety and to protect machinery. It is not uncommon that students are required to hand in plans and can then observe how a trained operator executes these plans. As such, this may avoid risks, but it certainly impedes purposeful, effective and efficient immersion of learners in a production environment. Yet, by design, risks related to safety or damage can be mitigated. Not only is safety made an inherent topic in all projects, in the workshop, access to dangerous or vulnerable equipment is arranged on a per-machine basis, registered on student ID cards. Access is granted after passing e.g., a safety training, introductory practicals or basic operator training. Dependent on the machine type, a minimum number of students/staff can be required to check-in at a machine before it may be operated. Next, the production/assembly line in the learning factory employs a specific type of equipment: lower-force/scaled machines, but with control systems identical to the controllers on industrial-scale counterparts (see figure 2). With that, the students experience the same interfaces and programming as used in industry, yet at relatively low-cost machines, rendering any errors, mistakes or experiments significantly less impactful. For example, in the assembly line, different types of robots are used that 'speak the same language' (in this case Robotic Operating System (ROS)) as any full-scale version. The same yields true for e.g., the automated guided vehicles (AGV), or controllers of the desktop CNC-machines. With that, it is certainly not the intent to make the learning factory as robust as possible – rather, by design, resilience is an inherent part of the thinking behind its design.

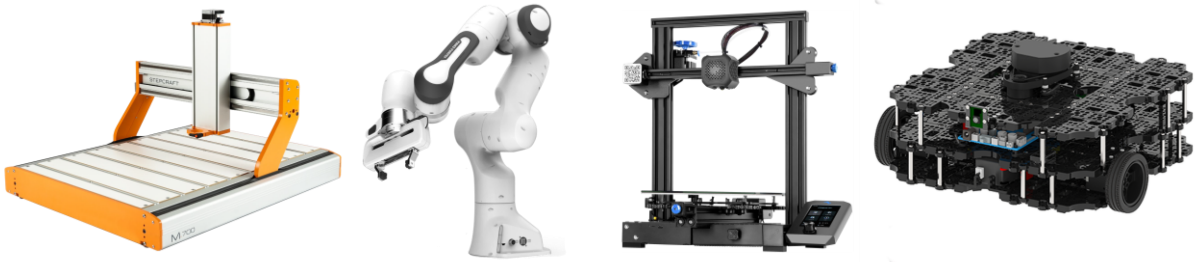

Figure 2. desktop production assets (low-force/scaled) with industry-standard interfaces.

RECURSIVE MASTER-APPRENTICE APPROACH

The learning factory foremost facilitates education and learning. Yet, the activities of students and staff determine the effectiveness, efficiency and impact of the learning that takes place. In this, the 'traditional' master-apprentice approach has significant advantages, especially as the conveyance of tacit knowledge is involved. It facilitates addressing multiple perspectives in an integrated manner and it offers an adequate manner to focus on both theory and its practical implications (Loyer & Maureira, 2014). Foremost, it allows for implicit and explicit reflection on activities, their underlying decisions and the decision-making processes. At the same time, 'traditional' master-apprentice approaches habitually rely on all parties being present at the same time at the same location while co-operating on the same task. Given the attainable student-to-staff ratios, and the different fields of expertise involved in academic education, such an artisanal approach becomes infeasible. Therefore, a contemporary interpretation of the master-apprentice approach is required, which allows for differentiation in time and location of staff, but also for inherent quality control of the knowledge that is transferred. This involves solutions that virtualise processes, observations and training to transgress simultaneousness of activities and locations. For this, a sound information backbone is required, which monitors, guides and controls what information is available to whom in what format. To this end, digital twinning is integrated in the learning factory, as an approach to transcend rigidity by process orientation (Lutters & Damgrave, 2019); to allow for, and control, flexibility and the change of perspectives, serious gaming is used. This digital twinning and serious gaming (described in later sections) give context to both the master and the apprentice in their endeavours. Foremost, however, the contemporary interpretation can introduce a way of thinking that is related to the different levels of aggregation in the learning factory. As mentioned, beginning undergraduates may be executing tasks that are defined/planned/optimised by graduate students, and these graduate students may be studying optimisation methods in the context of a PhD. research trajectory. Alternatively, undergraduates may be studying takt time variations, contributing to a sensitivity analysis performed by graduate students. Thus, what may be a challenging learning intent for some students, may be input for advanced learners. With this, different students work simultaneously on similar topics at their own level, but also provide a wealth of information, input, reflections and creativity for learners at a different level. This implies that teaching staff is no longer the only instigator in teaching, but that they inspire, guide, and motivate students to engage in a master-apprentice relation themselves, co-operating in peer learning at different levels. Coached, steered and assessed by staff, this is beneficial for all learners involved, as beginning learners have access to experience of and contextualisation by advanced learners, and the advanced learners benefit from the output of the beginning learners. Moreover, advanced learners also (implicitly) benefit from being forced to explain/teach their own work and considerations. Such aspects add value over the already existing way of working: the topics that will be addressed in the learning factory are already part of the current educational programme, yet in a less connected and integrated manner. By bringing these topics together in the learning factory, courses and projects (even over different educational programmes) become more entangled, leading to a more realistic environment for exploration, but also for peer learning and for students that learn new topics while simultaneously guiding beginning learners. This implies that a master-apprentice relation can become a relative notion. A recursive master-apprentice approach embeds students in the knowledge and insights of advanced learners and staff, thus allowing and challenging them to progress to levels and topics that enable them to council subsequent 'beginning learners'. A student will thus be master and apprentice at the same time. This forces them to internalise knowledge to the level that they can convey it to their 'apprentices' – where experienced staff provide safe, constructive and contextualised environments. This makes learning more active, and challenges learners to replicate, use, reformulate, reflect on, and creatively use the expertise they are building and conveying. With that, explicit and tacit knowledge are less disparate, allowing learners and educators to focus more on the rationale in and of decision making than on the sheer 'correctness' of solutions. This also impacts the assessment in education: in concordance with project-led education, emphasis can be more on formulating, developing and evaluating knowledge and decisions than on replicating factual knowledge. Still, factual knowledge is a clear proviso for reaching adequate decisions; and thus (access to) such factual knowledge is an agent that no longer needs not be examined as a learning objective in itself.

Integration of learning and research

As the recursive master-apprentice approach entangles learning activities at different levels, the distinction between learning and research blurs. After all, where undergraduates may still work within explicit, closed and pre-defined boundaries, their work may simultaneously be part of a more explorative research project. As a practical example: undergraduates use virtual or augmented reality solutions to be taught/instructed on an assembly process, whereas the development and testing of such solutions is part of a research project. With that, students get acquainted with research, research methods and new developments in a 'living environment', whereas the researchers have direct access to a purposeful and realistic testbed. If staff incorporate such dependencies in their educational efforts, students see and use research outcomes, and they are directly challenged to reflect on the applicability and (dis)advantages thereof, as this forms valuable input for the research projects. This again contributes to making the student learning experience more realistic and immersive.

In the learning factory, many integrative approaches are employed to spark engagement, motivation and creativity – of learners and researchers alike. Firstly, such integrations relate to the different levels of aggregation; as students that learn/experience production line concepts like Kanban, quality monitoring, or collaborative robots, can simultaneously participate in research related to planning strategies, quality management, or workplace ergonomics. Secondly, integrations can address different perspectives/aspects that play a role in the learning factory; students use technology like IoT sensoring, assets under development, automated guided vehicles, real-time location systems (Thiede et al., 2021) as facilitators in their work, whereas their activities are simultaneously a significant testbed for research on Industry 4.0 or Smart Industry. With that, the learning factory acts as a pilot production plant (Lutters, 2018; Lutters & Damgrave, 2019), being a facility that allows a company to develop, test, improve and upscale (parts of) a production environment while not hampering primary processes and avoiding investments where possible. Next to the engineering-oriented integration of education and research, also integration with other aspects or research domains are envisaged. One of the most obvious is to render the learning factory an environment that allows for educational research. However, also user-oriented research related to, for example, user interfaces, manuals, repair, maintenance, behaviour design, organisational issues, and even workplace wellness are integrated in the foundations of the learning factory.

SERIOUS GAMING

The learning factory under development is an open, indeterministic, volatile and only partially defined environment, characterised by uncertainty as well as ambiguity. Such variability and ambivalence are intentional and inherent to the design, implementation and its use. Hence, also its organisation, management and control mechanisms must be imbued with the ability to act on open situations, behaviour and internal as well as external stressors. As the learning factory cannot thrive on closed or rigid methods or processes, as mentioned, a different approach is found in applying serious gaming as a driver and instigator of activities as well as of the environments in which the activities are contextualised. Serious gaming allows staff and students alike to create, capture, simulate, assess and replicate situations or conditions in the learning factory. These situations can for example replicate industrial situations, exemplary use cases, specific setups or tasks, conditions for decisions, or even uncertain, unspecified or arbitrary situations. With that, serious gaming can be a way to expose learners to a situation and simultaneously a way to guide, influence and contextualise their attempts for finding, evaluating, probing and evaluating solutions. Additionally, serious gaming is inherent to education in the learning factory itself, as it allows for easy simulations and what-if scenarios, especially if the digital underpinning of the factory (see next section) provides adequate foundation and support. Whilst the focus of serious games often is on improved learning outcomes of learners, serious gaming can also consider the impact of gameplay on other stakeholders like the education provider and facilitator, the training instance, and the real-world system or environment portrayed (Von Leipzig et al., 2022). Moreover, personalisation of learning trajectories by integrating different perspectives and variable scenarios is possible. Serious games offer a platform to aggregate learner behaviours and results, and use these to dynamically configure, adjust and tailor the game or environment to individuals and contexts, ultimately providing a learning environment of improved quality, effectiveness and efficiency. In research on modular, re-usable and configurable serious games, an architecture has been developed (Von Leipzig et al., 2022) that is largely also applicable for learning factories. The main justification for this is that, like the learning factory, the serious game architecture considers an environment as being open, dynamic and prone to stressors. Moreover, different levels in the serious game architecture (e.g., modularity, re-usability, parametrisation and contextualisation) are in line with what is required in the learning factory. An especially useful aspect of the serious game architecture is the 'bidirectional' learning approach, enabling the contextualized adaptation of learning material, experiences and learning trajectories based on the aggregated behaviour and results. This is relevant for the design and organisation of the learning factory, but foremost for the recursive master-apprentice approach.

DIGITAL(ISATION) PREREQUISITES & OPPORTUNITIES

Where openness and indeterminacy are essential characteristics of the learning factory, it is obvious that its government and control cannot be based on settled process descriptions and workflows. With advancing digitalisation and Industry 4.0 approaches, also industry explores changing attitudes towards process-driven conventions. To allow for the required flexibility and to exploit and research digital(isation) prospects, the learning factory (and the overall new workshop) embraces an information-driven approach. As this approach can be ingrained from the design phase, digital representations of the learning factory can be the basis for its operation, but also for its management and control. This is done by means of digital twinning (Lutters & Damgrave, 2019), which allows for capturing the as-is current situation, but also for exploring potential futures in providing simulated could-be representations of the learning factory, or parts or aspects thereof. The information that enables such representations is integrated in the design of the learning factory; the production/assembly line will apply not only IoT based sensoring for process conditions and for line behaviour, but also real-time location systems and e.g. vision systems or motion capturing. This transpires in the context of industrial software systems for production/logistic control and management (like ERP, MES, CAQ), again allowing learners to use lifelike systems in a low-risk environment. Conjointly, the elements in the environment not only provide control mechanisms based on condition monitoring of the learning factory, but it also allows for exceeding individual levels of aggregation as the information can be used by different perspectives involved for different purposes. This immediately facilitates and strengthens the recursive master-apprentice approach. Moreover, the digital twinning approach allows the learning factory to have a hybrid constitution: with all the information that is available, the learning factory can be accessed physically, but also in virtual reality. Next to 'acknowledged' use of virtual/augmented reality for instruction and training, the learning factory also uses virtualisation to, for example show/experience alternative solutions in decision making, to switch/integrate different perspectives, to role-playing in serious gaming, to contextualise process/production planning, or to immerse in potential future configurations in the learning factory. Such techniques take learners along a learning curve that can be comprehensive, contextualised and effective – whereas all technology also allows for singling out and spotlighting hurdles or omissions in a student's ability to fathom a topic. By generalising and aggregating such meta-information, the learning factory as a whole can 'learn' from how it's being used (Von Leipzig et al., 2022), enabling bidirectional learning, but foremost inherent optimisation of the learning factory (Thiede et al., 2016) and its educational/didactical approaches.

Conjointly, this approach means that the system architecture and the IT-backbone of the learning factory require significantly more effort than is necessitated by the simple production/assembly activities taken places. However, like the machines (in figure 2) use industrial interfaces, also allowing the students to experience and interact with industrial-scale infrastructure and systems adds to the learning experience and the realism of the environment. Moreover, the digital backbone of the learning factory is instrumental in integrating the different perspectives involved. It facilitates beginning learners to do and contextualise their work (as 'employees on the production line'), it allows advanced learners to aggregate information for planning or factory lay-out purposes (as 'managers of the production line'), and it constitutes a vast testbed for researchers. The digital(ised) version of the learning factory is instrumental in assessing learning and learner's progress, in identifying threshold concepts, in indicating/ interpreting behaviour, but foremost as an inherent resource in learning and research involved.

In delineated prototype environments, students are already studying the system architecture for the learning factory, by establishing variants, implementing and examining system components, and also by testing prototypes in other student projects. In this, co-operation with industrial suppliers of e.g. ERP and MES software has been established, to the benefit of learners, researchers and the companies alike. Especially the multifarious use of digital twinning and virtual/augmented reality receives ample attention in prototyping, which confirms that learners as well as researchers do benefit from virtual access to simulated foreseeable consequences of their intended decisions. Learners and researchers manifest the importance of the ability to correlate and contemplate risks and opportunities.

IMPLEMENTATION

Whereas the new building for the expanded workshop and learning factory will be completed in early 2023, this does not mean that the establishing of the learning factory is dependent on that. Over the years, already many small projects have been executed to experiment with the philosophy that will underlie the learning factory. In several selected educational projects, students have already been working in ways that partially represent the situation and possibilities in the learning factory. As these projects have only been possible in segregated groups, locations and periods and could not yet have the foreseen common core, the envisaged overall integration has not yet been achieved. Nevertheless, multiple projects already clearly demonstrated added value for the learners, but also for the learning factory under development. For example, using the desktop machines with industrial controllers (see figure 2), groups of students have already been establishing initial versions of modular and reconfigurable production and assembly lines. Such initiatives are assessed on technological and educational merits and are used as the basis for simulations of the learning factory under development.

Mindful of the recursive master-apprentice approach, these lines were tested in an undergraduate project, whereas the development took place in the context of a PhD project focusing on the digital twinning of production lines. Likewise, students have been working on establishing serious games to introduce new students to machines and processes in the workshop, to adequate preparations to enter the workshop and to safety and working conditions. Not only did the students that were involved acquire more profound knowledge in a more (inter)active manner, but their work did also actually influence and change the design of the new building and the envisaged process architecture for the educational environment. The same yields true for multiple groups of students that have been working on topics like digitalisation, IoT, virtual/augmented reality, synthetic environments and location systems. Quite some infrastructural decisions in the design process of the new workshop have been influenced by such projects – even changing some guiding principles in thinking about educational workshops. Moreover, well-nigh all student groups involved did inherently phrase a ‘the bigger picture’ of their work, providing themselves with better understanding of their project and with a framework for decision making and reflection, while supporting the faculty in establishing and maintaining the paradigm for the new workshop and learning factory. If this ‘bigger picture’ can be shared based on the envisaged learning factory, student groups will benefit even more in terms of sharing, re-using, improving and reflecting on their own project in its context. Here, again, it is essential that the learning factory remains partially unpredictable, indeterministic and even incomplete – to avoid rigidity as well as straightforward and ascertainable project outcomes. After all, foreseeability would entice students to state the correct answer rather than to establish and internalise ways to obtain an underpinned solution. However, if students in their project can set the stage for the context in which other students do their projects, variation and volatility are safeguarded. Until the workshop building is finished, groups of students continue to work on developing and establishing parts, aspects and approaches for the learning factory, in consultation with researchers and teaching staff. With that, the implementation trajectory itself adheres to the reasoning behind the learning factory, employing the recursive master-apprentice approach. This has the advantage that efficacy and pellucidity of the efforts involved are inherent to the approach, but that, to elucidate and convey learnings on e.g., financing and staffing currently require complemental efforts.

CONCLUDING REMARKS AND OUTLOOK

In an environment characterised by increasing pressure on the existing workshop facilities, the design and realisation of a new, larger and more elaborate workshop environment and an associated learning factory are characterised by a learning-by-doing approach. Given the envisaged openness, adaptability and volatility of the new environments, there is no primary or overarching process that ordains the development activities. Here, that is seen as an advantage: an opportunity to make flexibility inherent to the structure and scheme, but also to integrate new (and even currently unknown) technology/ies in the learning factory. With that, there is ample room for the recursive master-apprentice approach that has already been implicitly identified and staged in a variety of educational projects but is now pointedly identified as a viable means to convey, contextualise, and internalise knowledge in an effective and efficient manner. Although not instigated and driven by a predefined research question and methodical, quantitative scrutiny, there is broad consensus that the emerging recursive master-apprentice approach is effective and purposeful. Because of its paradigm, and the opportunity to incorporate digitalisation and new technology, it is considered an evolvement of the already implemented project-led education. Moreover, it will enable further integration of education and research in an environment that confers industrial reality, albeit in an open and flexible manner.

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ENHANCING STUDENTS' COMPETENCIES BY INTEGRATING MULTIPLE COURSE-UNITS ON SEMESTER PROJECTS

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ABSTRACT

Despite the important advances observed, nowadays, the Engineering programmes keep being challenged to better prepare their students to work on complex and multidisciplinary projects while demonstrating awareness of environmental and socio-economic issues and other soft skills as communication and teamwork. Recently, to meet these challenges, the ISEP' Informatics Engineering programme (LEI) successfully adopted a project-based learning approach. In this approach, throughout the entire semester, students develop a real-world project that allows the application and assessment of the competencies taught by all course units of the semester in an integrated, multidisciplinary, and transversal way. In this paper, the authors (i) present this approach as well as the main challenges faced in implementing it; (ii) report the major findings and the perceived benefits and drawbacks; and (iii) discuss the on-going adaptations and/or others seen as required to improve the approach and its results.

KEYWORDS

Project-based Learning, Informatics Engineering Degree, Multidisciplinary and Multi-Course Project, Standards: 3, 5, 7.

INTRODUCTION

Currently, in addition to intrinsic technical competencies, an Engineer must be prepared to work on complex, multidisciplinary projects and with the capacity to adapt quickly to change (Mazzurco, Crossin, Chandrasekaran, Daniel, & Sadewo, 2020; Centea & Srinivasan, 2021). Soft-skills (such as communication and leadership skills, teamwork, and an awareness to environmental and socio-economic issues) are also becoming increasingly important (Chen, Kolmos, & Du, 2021; Centea & Srinivasan, 2021). Moreover, despite the significant advances that have taken place in recent decades in the teaching practice of Engineering (Chen, Kolmos, & Du, 2021), it is still observed that Engineering programmes and their respective course units continue to be excessively oriented towards (uni)disciplinary/technical content and the resolution of small and simple problems/projects, providing students with a reduced: (i) integration between the covered technical topics; (ii) ability to manage complexity; (iii) relationship with current industrial practices; and (iv) quantity and diversity of design-implement experiences (Mazzurco, Crossin, Chandrasekaran, Daniel, & Sadewo, 2020; Centea & Srinivasan, 2021; Chen, Kolmos, & Du, 2021; Routhe, et al., 2021; Thevathayan, 2018).

In this regard, it is worth highlighting that the importance of the above mentioned competencies and concerns are also acknowledged by well-known international organizations responsible for worldwide (i) promoting Engineering education best and modern practices as the CDIO Initiative (cf. section 2.4, 2.5, 3.1 and 3.2 of the CDIO Syllabus and Standards 5 and 7); and (ii) carrying out the accreditation of Engineering programmes such as the European Network for Accreditation of Engineering Education (ENAEE) which awards the EUR-ACE quality label or the Accreditation Board for Engineering and Technology (ABET) as is easily observed on the respective accreditation criteria (cf. (ENAEE, 2015) and (ABET, 2020)), namely the ones regarding the expected programme outcomes.

Being aware of these demands, since the Bologna implementation process on 2006, the 1st cycle programme on Informatics Engineering (LEI) at the Instituto Superior de Engenharia do Porto (ISEP) follows/adopts best international practices, namely the ones promoted by CDIO, and is awarded with the EUR-ACE quality label since 2013. Although LEI-ISEP's approach allows achieving very relevant results highly recognized by the programme stakeholders (i.e., students, the software industry, research centres, and the society in general), after a decade of Bologna operation, it is considered by past and current LEI-ISEP management as well as by several faculty members that it falls short on what is intended. An overview of LEI structure, (past) operation and found limitations is provided on the next section.

Taking into consideration the above observation, between the 2015-16 to 2018-19 school years, a pilot approach was carried out on the 4th and 5th semesters (Martins, Bragança, Bettencourt, & Maio, 2019), comprising approximately 30 (out of 400) students on each semester, where all the course units of the same semester participate in the development of a single complex software project throughout the entire semester. This software project, usually proposed in a partnership with a company, allows the application and evaluation of the various competencies taught by all courses of the respective semester in an integrated, multidisciplinary, and transversal way. Along the academic years this pilot has run, several refinements were progressively introduced having in mind the feasibility and challenges of expanding this teaching-learning approach to all LEI' students and faculty. In this work, we describe how this approach, called Semester Integrative Project-Based Learning (SI-PBL), was expanded and is being successfully applied to all LEI students as well as we present and discuss preliminary results, faced and open challenges and ongoing/future work.

OVERVIEW OF LEI-ISEP PROGRAMME

LEI-ISEP is the largest Bologna 1st cycle programme on Informatics Engineering / Computer Science in Portugal, admitting between 300 and 350 new students every year and producing over 200 graduates per year.

It is sought after mostly by two different target audiences: (i) students that have recently completed their high school studies (a total of 12 years study) and are willing to continue their education on a Higher Education Institution (HEI); and (ii) persons that by some reason (e.g.: economical) are working (usually) on a non-qualified job and are seeking to improve their qualifications to change to a career on the software industry. Considering this, LEI-ISEP is provided on two consecutive shifts: (i) the daily shift from 8 a.m. to 6 p.m., mostly attended by the former audience and (ii) the after-work shift from 6 p.m. to 11.30 p.m., mostly attended by students already working (the latter audience). Students enrolled in the after-work shift correspond to approximately 17%. Moreover, this also impacts the students' commitment with the programme since approximately 23% of students are enrolled in partial time.

Structure and Operation

LEI-ISEP is structured in 6 semesters (cf. Table 1) and consists of two distinct sets of course-units:

- Disciplinary (or Traditional) courses: focused on conveying technical and disciplinary knowledge and competencies adopting a more traditional approach. These ones can also be split on two sub-sets:
  - The ones dedicated to conveying core concepts of mathematics (i.e.: ALGAN, AMATA, MATCP, MDISC), basic science such as physics (i.e.: FSIAP) and management (i.e.: GESTA, CORGA) considered as fundamental to any engineer; and
  - The ones dedicated to conveying technical aspects regarding software engineering (i.e.: APROG, ESOFT, PPROG, BDDAD, ESINF, EAPLI, LPROG, ALGAV, ARQSI), computer networks, graphics, and systems (i.e.: PRCMP, ARQCP, RCOMP, SCOMP, ASIST, SGRAI) and experimental procedures (i.e.: ANADI, INFOR).
- Integrative and project-based courses: focus on the application and integration of the knowledge, skills and competencies introduced and acquired previously by the disciplinary courses. These courses (i.e.: LAPR 1 to 5 and PESTI) are seen as a design-build courses fully aligned with the CDIO Standard 5 (CDIO Standards 3.0, 2020) incrementally ranging from a basic level of complexity/difficulty (LAPR1) to an advanced one (LAPR5 and PESTI).

Table 1. LEI-ISEP structure and previous operation method.

		Week 1 to 12	Week 13 to 16
1st Year	**1st Semester**	ALGAN, AMATA, APROG, PRCMP	LAPR1
	2nd Semester	ESOFT, MATCP, MDISC, PPROG	LAPR2
2nd Year	**3rd Semester**	ARQCP, BDDAD, ESINF, FSIAP	LAPR3
	4th Semester	EAPLI, LPROG, RCOMP, SCOMP	LAPR4
3rd Year	**5th Semester**	ALGAV, ARQSI, ASIST, GESTA, SGRAI	LAPR5
	6th Semester	ANADI, CORGA, INFOR, PESTI	

Each semester is 20 weeks-long and worth 30 ECTS. The first 16 weeks are devoted to classes and continuous assessment while the last 4 weeks are exclusively for final exams (written or oral). Furthermore, during the first 5 semesters the classes period is split on two distinct sub-periods: (i) a 12 weeks-long period for traditional disciplinary courses; and (ii) 4 weeks-long period for the respective integrative and project-based course (i.e.: LAPR 1 to 5). Yet, it is worth noticing these courses aim at introducing and practicing some of the software industry best practices and methods such as teamwork, adopting an agile (iterative and incremental) approach, continuous integration/deployment (CI/CD) and software testing. The technical requirements of the projects are fully aligned with the disciplinary subjects learned during the first 12 weeks of the semester. These courses are a key component of LEI, as they allow students to practice and enhance their skills in larger projects. The last semester is mostly dedicated to the capstone project/internship (18 ECTS) usually developed on a software company or research center located in the north region of Portugal.

Students Assessment

There are school-wide pedagogical rules/recommendations trying to promote students' assessment during the classes period and, therefore, reducing the weight of the final exam on the course grade or even eliminating the final exam. Despite that, most ISEP courses do have final exams. Within the LEI programme there are three major scenarios: (i) traditional courses of math, basic science, and management whose final exam have a weight of over 50%; (ii) most of the other disciplinary courses also have final exam with a weight ranging between 30%

and 50%; and (iii) the integrative courses whose assessment is 100% based on project development without any final exam. As so, due to continuous assessment, most of the LEI disciplinary course units already have one to three assignments, being its majority of a practical nature based on small and/or simple problems/projects developed in teams that (i) are somehow lacking a more realistic and broader context; and (ii) do not foster and/or value the correct adoption of best professional practices by students.

Finally, it is worth stressing that to avoid personal drifts and enforce consistency among courses, a pedagogical consensus was achieved around the definition of common rules and pedagogical patterns that should be adopted by all courses (Martins, Ferreira, & Costa, 2016).

Found Limitations

As previously stated, this structure and operation allows achieving relevant results that are highly recognized by the programme stakeholders. Even though, in the context of a continuous improvement process of the LEI-ISEP programme (cf. compliance with Standard 12) the following major limitations and concerns were identified:

1. The overall students' effort required to complete the practical assignments during the classes period is often seen as being exaggerated, namely due efforts resulting from students constantly changing from one (unrelated) project context to another.
2. The lack of a broader and more realistic context means that students often do not feel motivated towards the technical aspects addressed in the disciplinary course and/or have difficulty understanding its usefulness, integration, and relevance in larger and more complex projects.
3. Since most practical assignments carried out in the disciplinary courses do not adequately promote and/or sufficiently value industry best practices, it contributes, on the one hand, to students not to internalize these best practices and, on the other hand, to students acquire inappropriate practices that, once internalized, are difficult to combat later in the integrative courses (LAPR 1 to 5).
4. On the contrary, assessment of the integrative projects tends to (over) value criteria related with the development process, methods, and tools as well as the fulfillment of functional requirements at the expense of technical quality criteria, which are mostly considered as being previously assessed on the disciplinary courses. Despite that being true, there is no guarantee that students achieve the required technical quality during the development of the integrative projects. Faculty often argues that ensuring such technical quality is a very time demanding task to which there is not enough available time.
5. Although projects developed in the context of the integrative courses (LAPR 1 to 5) provide students with short team-based system-oriented development experiences applying an iterative and incremental (agile) methodology as well as other best practices quite common in the industry, the short timespan (4 weeks) does not allow more than 2 or 3 iterations of very limited scope. It is too short and too fast; thus, it does not promote reflective observation as it should. From evaluation it becomes evident that some of the results were not going beyond the "apply" Bloom level (Krathwohl, 2002).
6. The short period of time devoted to the integrative projects together with the fact that projects are entirely conceived and operated by faculty is inhibiting fully simulating an agile software development context in line with best practices, while exploring real contexts and conditions such as the need to seek requirements clarifications from the software client, dealing with evolving requirements and evolving architectures as well as cultivating a biggest and deepest integration among the topics addressed in the disciplinary courses.

The operational changes introduced in LEI-ISEP to overcome/minimize these limitations and concerns are described in the next section.

SEMESTER INTEGRATIVE PROJECT-BASED LEARNING

Initially motivated by the conclusions of (Edström & Kolmos, 2012) that Project-Based Learning (PBL) can be productively combined with CDIO principles and standards to equip graduates fully and better for engineering practice and, further, reinforced with our 4 years-long pilot experience (Martins, Bragança, Bettencourt, & Maio, 2019), its results and lessons learned, a Semester Integrative Project-Based Learning (SI-PBL) approach for 4th and 5th semesters of LEI-ISEP was devised and put in operation since the school year of 2019-20.

Approach Overview

While devising the SI-PBL approach, it was clear that some hard constraints need to be mandatorily satisfied, namely that neither the curricular structure of LEI-ISEP nor the programme learning outcomes could be changed/revised. Moreover, as a soft constraint, there was no will or intention to revise courses' contents and/or courses' learning outcomes. Thus, the SI-PBL approach was restricted to only revise programme and courses operation together with the employed teaching-learning process.

At the LEI-ISEP operation level, two major changes were introduced:

- It was created the notion of a Semester Integrative Project (SIP) common/shared by all the course units of the respective semester. The SIP general idea is to be used as a replacement for the smaller and/or simple projects/problems of each course unit and an extension for the LAPR courses, thus fostering the integration of cross and multidisciplinary knowledge and competencies earlier in the semester.
- The original model of 12+4 weeks of classes was replaced by a new one as depicted in Figure 1. As can be observed, each semester is split into four periods (a.k.a. sprints) and the end of each sprint also represents a semester milestone. Contrary to sprints B, C and D, the first sprint (i.e.: A) is 6 weeks long mainly by two reasons: (i) to let faculty provide students with a minimal background/theoretical knowledge and skills required for SIP development; and (ii) to teams' formation and general setup of the project environment (e.g.: source code repositories, CI/CD tools). The last week is exclusively devoted to concluding students' continuous assessment.

Thus, through the entire semester, students are focused on developing a single but complex software project that allows the application and assessment of the wide-ranging competencies taught by all semester' courses in an integrated, multidisciplinary, and transversal way to the courses. Yet, the integrative project allows for four iterations on the requirements in which students gradually deepen the theoretical knowledge of each course and apply it to satisfy these requirements, which, in turn, focus on the complementarity of knowledge between course units and not on its exclusivity.

To operate in this manner, a few generic basilar rules/guidelines were also established:
R1. SIPs must be conceived, preferably in a partnership with a software company, to (better) encompass, for instance, environmental and socio-economic issues, among others. Furthermore, SIPs should be designed to be ideally developed in teams of 4 students working in an iterative and incremental way. However, to accommodate foreseen exceptions it might be prepared to fairly be adjusted for development by teams of 3 to 5 students.

R2. At least two courses should be committed to the SIP development throughout the entire semester. This is ordinarily ensured by the integrative course unit (i.e.: the LAPR course) and a technical disciplinary course covering software engineering topics (e.g.: EAPLI, ARQSI).
R3. A late adherence of a course to the SIP development is left open to the course coordinator and validated by the LEI management during semester planning meeting(s). However, such adherence is only possible to occur at the beginning of a new sprint (at weeks 7, 10 or 13) and, after adherence, courses remain committed to SIP development until the end of the semester.
R4. In the scope of each SIP' adherent course, each sprint must be thought as a students' assignment through which faculty can provide students' feedback and/or to assess the students' achievement of (some) course learning outcomes.

As a result of this change to the semester, each course revised/adjusted as needed (i) its operation mode (including planning); (ii) its pedagogical approach; and (iii) the learning outcomes assessment methods to better fit in with the general semester' operationalization.

Learning Outcomes Assessment

The described transformation naturally led to adjustments/adaptations in the way students' learning objectives are transmitted and assessed. Regarding assessment, these adaptations aimed at two aspects: (i) to avoid duplication and/or overlapping of assessment criteria among the courses involved in the SIP and (ii) to respond to limitations 3 and 4 previously presented.

Therefore, integrative courses (i.e.: LAPR) are focusing on the fulfillment and adoption of best practices related to the software product development methodology/process itself. This involves criteria that goes from interacting with the client for requirements clarification as well as demonstrating the fulfillment of those requirements, passing to the way how the team organizes itself, distributes the tasks among its members and works, towards the team members' ability to understand and communicate about the project as a whole and not simply as a set of disconnected modules/components. In this sense, the names of some well-known ceremonies in agile methodologies, namely in Scrum (Sutherland, 2014), are formally introduced and applied (in an adapted way) as follows:

- *Sprint Planning*: takes place at the beginning of each sprint (i.e.: first sprint week) with the aim of supporting students to plan and distribute tasks in a suitable way.
- *Sprint Review*: takes place at the end of each sprint (i.e.: during the week after the sprint ended) to assess the level of satisfaction of the sprint requirements from a functional and/or quantitative point of view as well as the communication capacity of the team about the project/sprint and its functioning as a team.
- *Sprint Retrospective*: it also takes place at the end of each sprint, without direct faculty intervention, aiming to promote the students' ability to improve by themselves the way the team is functioning.

Complementarily, the technical disciplinary courses are focusing, as was the case before, on technical aspects (from practical to theoretical) and mostly adopting a qualitative perspective. In this sense, after the end of each sprint, it is common that each course carries out a *Technical Sprint Review* session with the aim of, on the one hand, to provide feedback to students and, on the other hand, to assess the degree of the learning objectives achievement. Optionally, some courses also support students regarding task distribution, namely, to ensure that every team member is allocated to requirements involving the application of some sort of the course technical components.

This approach also allows for strengthening and consolidating the application of some pedagogical patterns presented in (Bergin, et al., 2012) and that were already being adopted in the LEI-ISEP (Martins, Ferreira, & Costa, 2016). In this respect, it is worth noticing that each sprint assessment provides "*feedback"* and "*early warning"*, so students can "*embrace correction*" and therefore justify "*grade it again, Sam!*" (NB.: pattern names are denoted in quotes and in italic). Moreover, regarding teamwork "*Fair Project Grading*" and "*Fair Team Grading*" are applied too.

Implementation Details

This integrated project-based learning approach has been implemented in the 4th and 5th semester of the LEI-ISEP and, currently, is running for the third consecutive year.

In the 4th semester, the SIP focus on developing an information management system (e.g.: shop floor data collection, processing, and management system) for a given business area (e.g.: cutlery production) adopting a Domain-Driven Design approach (technical content of EAPLI). The resulting system comprises more than one application to enforce students employing by the first-time some client-server communications according to an application protocol (technical content of RCOMP) and, therefore, to apply some parallel and/or concurrent computing techniques (technical content of SCOMP). Some system requirements also lead students to specify and interpret some simple but effective task-specific languages (technical content of LPROG). The courses' adherence to the SIP development throughout the semester is depicted in Figure 1 (Left side). Accordingly, LAPR4 and EAPLI participate on all project sprints while RCOMP, LPROG and SCOMP participate only on the last two sprints.

Regarding the 5th semester, the SIP focus on developing another information management system adopting a full web-based client-server architecture (technical content of ARQSI), comprising multiple server-side applications, each one developed in a distinct technology (e.g.: ASP.NET, NodeJS, Prolog) and, at least, one client-side Single Page Application (SPA) for user interaction. Client-side application is also enriched with a graphical 2D/3D visualization module of some information (technical content of SGRAI). On the server-side, one application is devoted to providing some "intelligence" to the system through the application of some advanced algorithms (technical content of ALGAV). At last, students also must study and develop a Disaster Recovery Plan as well as configuring and monitoring a system infrastructure for system deployment (technical content of ASIST). The courses' adherence to the SIP development throughout the semester is depicted in Figure 1 (Right side). Accordingly, LAPR5 and ARQSI participate on all project sprints while SGRAI, ALGAV and ASIST participate on the last three sprints. GESTA does not adhere to SIP mainly because it is a management course shared by multiple programmes running at ISEP and, therefore, it operates identically on all such programmes.

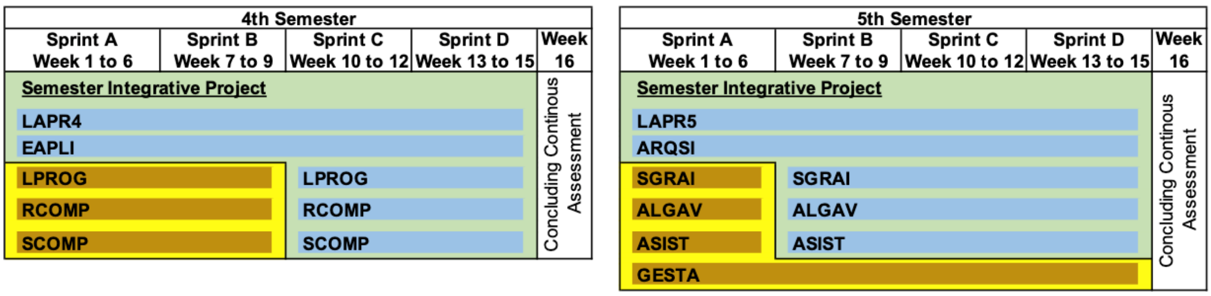

Figure 1: Courses' adherence to the SIP development through the respective semester.

RESULTS & DISCUSSION

In this section, we discuss and evaluate this approach using objective and subjective data considering four inter-related dimensions: (i) the semester and courses operationalization; (ii) students' feedback; (iii) the faculty perspective; and (iv) the companies' appraisal of students during their internship (capstone project) and of fresh graduates (i.e.: first job position).

Operationalization Dimension

This approach implies, at every course, an even more careful and rigorous planning of the pedagogical activities than before, since the occasional existence of any deviation may influence the development of the integrative project and, consequently, negatively impact the other courses as well. As such, the initial planning of both courses and SIP, includes some margin/flexibility to accommodate potential deviations more easily. Over these two years, this margin proved to be, in fact, useful and necessary.

Another aspect that cannot be neglected is the teams' formation. Ideally, each team has 4 students enrolled in all courses of the semester. This is achieved almost autonomously by students in a large majority (75% to 80%) of the cases. However, the remaining cases, caused by students that for some reason (e.g.: enrolled in partial time; have previously reproved) are only enrolled on 1 to 3 courses, imply an additional effort of faculty to ensure that these teams also have the necessary conditions to succeed. Preferably, these cases are solved by distributing these students to the remaining teams, working as a 5th element of these teams. Given the high number of students enrolled in each semester (approximately 400), these cases need to be seen with some naturalness. However, regarding the after-work shift students, we acknowledge that this aspect is particularly relevant and needs to be improved.

The effort to design, for each semester' edition and in partnership with a company, a distinct SIP capable of conveniently integrating the contents of all adherent courses is significant, but not exaggerated. Considering the courses' contents and its greater/lesser complementarity and interconnection, this effort is slightly greater in the 4th semester than in the 5th.

Students Dimension

Concerning students, we attempt to assess two criteria: (i) the students' general feeling/perception regarding the integrated approach; and (ii) the (in)existence of an abrupt change/variation in the effective approval rate of students per course.

Regarding the former criterion, a students' survey was considered. However, due to some pedagogical survey's constraints, this option was discarded. Instead, it was decided to carry out informal conversations between several professors and students of different classes and enrolled in different shifts and (amount of) courses. Overall, students, even those who showed some sort of disappointment, acknowledge that this integrative approach brings added value to their training. This acknowledgment is even greater on students enrolled in the after-work shift which is reasonable due to their greater maturity. Nevertheless, the after-work shift students together with students enrolled in partial time are the ones that more frequently express the most restrictions, constraints, and difficulties to the adoption of this integrative approach. There is here a kind of paradox that is justified by their status as a student worker, which usually implies having less time available for project development outside of classes when compared to regular (full-time) students. Regardless of the shift in which students are enrolled, regular students stated they felt more motivated by this approach, which helped them to better understand how the diverse contents were inter-related and have considered this approach as being positive or even very positive. As strengths points of this approach, students often mention (i) the existence of a single context/focus of work, i.e.: the project; (ii) the project realism given by the fact of knowing that there is a company supporting it; (iii) the similarity with the way of working in companies; (iv) the need to interact with the software-client. As weak points students often mention (i) the team formation issue described before; (ii) lack of faculty support on some classes and/or courses; and (iii) their afraid of being failing to one course, being failing to all, which obviously there is no reason for that, but they felt it anyway.

The latter criterion is of special interest since the courses' learning objectives have not changed, but the assessment method has undergone some/a lot of changes (depending on the course). Using the effective approval rate of students in 2015-16 as reference, Table 2 shows the percentual variation observed to the reference value throughout the further years.

Table 2. Variation on students' approval rate per course using 2015-16 as reference (%).

School Year	4th Semester						5th Semester					
	Cov. 19	EAPLI	LAPR4	RCOMP	LPROG	SCOMP	Cov. 19	ARQSI	LAPR5	SGRAI	ALGAV	ASIST
15-16	N	ref.	ref.	ref.	ref.	ref.	N	ref.	ref.	ref.	ref.	ref.
16-17	N	5.50	-4.04	1.65	-5.01	-9.81	N	22.96	31.37	28.79	2.20	-2.39
17-18	N	-6.67	6.27	-2.12	-12.97	5.71	N	9.21	28.43	47.10	7.77	-5.00
18-19	N	-7.95	-1.59	9.29	-5.46	-6.79	N	3.47	28.43	40.53	5.05	-1.93
19-20	Y	-1.29	2.98	1.76	-4.78	1.19	N	13.35	34.31	53.05	19.04	2.39
20-21	Y	-10.41	-0.96	-0.71	-12.17	-7.44	Y	8.28	26.61	53.83	20.73	3.86

Accordingly, there is no abrupt change and/or one that deserves any particular attention between the approval rates obtained within the 12+4 weeks model (2015-2019) and within the integrated approach (2019-2021). As so, the registered positive/negative variations are seen either by the courses' coordinators as by LEI management as being inside the usual and acceptable range. At this respect, it is important to stress out that due to Covid-19 pandemic only the 5th semester of 2019-20 results were not affected by changes (e.g.: switching from face-to-face classes to online classes) motivated to properly respond to this new reality (cf. "Cov.19" yes/no column). Thus, comparing the 5th semester results of 2019-20 with 2020-21 suggests that the integrated approach was quite resilient to measures taken due to Covid-19. This resilience is somehow also supported by the results achieved on same years by the 4th semester courses. Despite that, in the last two years, it has been noticed an increase (>12%) on the approval rates of SGRAI and ALGAV courses when compared to the previous editions. Comparing the last two years results of the 4th semester courses, a decrease (>7%) on the approval rates has been observed in LPROG and EAPLI courses. This variation cannot be endorsed to the integrative approach as both results were obtained adopting the same approach. Moreover, currently, the 4th semester is also a time of adaptation for students that come from the first three semesters used to the 12+4 weeks model and now, get in contact, for the first time, with this integrative approach. This fact might somehow partially justify this variation. However, this situation will deserve our future attention.

Faculty Dimension

When the decision to proceed with the implementation of this approach was made, the reality is that there was a non-negligible number of professors who, in a more or less clear/direct way, showed that they were facing this change with some/very concern and caution for diverse reasons such as (i) considering that they would not be prepared; and/or (ii) that it would require a greater effort from them; and/or even (iii) natural human-being resistance to change. However, after 2 years of being applying SI-PBL approach, most of these professors no longer manifest or manifest on a much lesser degree these initial concerns, and many of them are even quite satisfied and are recognizing the added value of the approach to students training.

Among the professors that are courses' coordinators, they have been quite satisfied with the change and are rejecting the hypothetical idea of going back to the previous model. As evidence of this greater acceptance by faculty in general and, namely, by courses' coordinators, it has been suggested to apply on a trial basis this approach also to the 2nd and 3rd semesters.

Companies Dimension

Through direct interaction with companies, typically, while assessing the capstone project, it is quite noticeable that companies are extremely satisfied with the overall quality and technical competence of our students. However, through this interaction is less noticeable their satisfaction regarding aspects of human, societal, and environmental nature. As so, to objectively measure this perception, companies usually offering internships to our students were asked to fill in a survey regarding our freshly graduated students who have been recently employed by their company. The survey consisted of 4 questions to be answered on a Likert scale, from 0 (bad/not at all) to 5 (very/excellent). The survey questions are:
A. Do they demonstrate lifelong learning ability?
B. Do they demonstrate high-level professional computer engineering skills?
C. Do they reveal appropriate human, social and environmental attitudes?
D. Do you have the ambition of professional achievement?

By the time of writing, from the 16 answers obtained, the average of the results is: A-4.50; B-4.25; C-4.25; D-4.00. These results clearly support the initial perception regarding their technical competencies (cf. answers to question B) as well as suggests that their training process is promoting soft-skills and other relevant competencies (cf. answer to question A, C and D) that are hard to assess at courses' level.

CONCLUSION AND FUTURE WORK

Overall, we are strongly convinced the SI-PBL approach has shown to be adequate to increase/improve the students' soft skills to the high levels currently required in the practice of informatics engineering. Simultaneously, this approach has also allowed to solve/minimize all the identified limitations, namely, through (i) a general reduction in the effort load of students in carrying out practical assignments while increasing their motivation (cf. limitations 1 and 2); (ii) the continuous promotion and enhancement, consistently across all courses, of the acquisition and application of the best engineering practices (cf. limitations 3 to 5); and (iii) a greater students' exposure to real software development scenarios (cf. limitation 6).

In addition to operationalization issues, this approach implied and still implies significant changes (i) in the students, regarding their level of commitment to the programme and to the teaching-learning process, in which they are required to have a more active attitude (Standard 8); and (ii) of faculty, regarding the courses' preparation and the required time synchronization between courses, as well as in improving the alignment between learning assessment and outcomes (Standard 11). Yet, in respect to faculty, it is also worth highlighting that this change lead, in some cases, to enhance some faculty teaching competences (Standard 10) as well as showing the need for it and, in other cases, to increase motivation for teaching.

Furthermore, on one hand, this approach has significantly contributed to increasing the quality of the design-implement experiences (Standard 5) and of the integrated learning experiences (Standard 7) provided to LEI-ISEP graduates. On the other hand, despite it has attested that LEI-ISEP curriculum is designed with multiple complementary and mutually supporting disciplinary courses on the 4th and 5th semester (Standard 3), it has also shown there is some room for improvement (e.g.: to foster courses' adherence to SIP earlier).

At last, we aim to consolidate the SI-PBL approach (e.g.: to better accommodate the diversity of students' enrollment situations that naturally exists when there is ~400 students/semester) and incrementally expand its adoption to the 2nd and 3rd semesters of the LEI programme, which has started on the 2021-22 school year and, thus, can be seen as success evidence.

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PEER REVIEW IN A PRODUCT DEVELOPMENT COURSE – IMPLEMENTATION AND RECEPTION

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ABSTRACT

The use of peer review as a teaching and learning activity has gained lot of ground during the last decade. Effective peer response is characterized by students' engagement and gives students the chance to practice both their ability to review by reading and commenting on other students' work and to receive and address feedback from others. There is also a driver that using peer reviews can separate formative and summative feedback and make the feedback loop quicker.

In this paper we describe the introduction and implementation of a particular peer review intervention involving peer review from many students in a project-based product development course taught in the second year at a five-year mechanical engineering programme at Chalmers University of Technology. To find out how the students' perceived the peer review activity, a student survey and in-depth interviews with students as well as interviews with supervisors were performed. Overall, the response from the students is positive and more so when a year passed compared to the ones who just completed the course. The few negative aspects are things to improve rather than discarding the method. The supervisors' response is likewise positive and highlights the additional skills developed by the students, such as critical thinking, resulting in a more effective learning environment.

The conclusion is that the peer review in this course benefits students as well as the supervisors. It gives quicker response form more participants. The grades in the course, which are based on a combination of a grade from the group project work and an individual grade based on their peer review, became fairer after implementing peer review.

KEYWORDS

Peer review, supervisors, Group work, Project Work, Assessment, CDIO Standards: 8, 11.

INTRODUCTION

The issue of feedback has been highly debated within higher education in the last decade. The debate emanates from various stakeholders withing higher education, for instance student complaints about the lack of feedback, instructor concerns about providing feedback to increasing numbers of students and general concerns about when and how feedback is given to students. The discussions have involved general perspectives on teaching and learning in higher education (e.g. Nicol et. al., 2014; Boud & Molloy, 2013; Carless, 2016) but also more specific aspects of feedback, such as written feedback for the purpose of language learning (Bitchener & Storch, 2016). Studies have also addressed the roles and activities of students and instructors in feedback processes. Cho et. al. (2006) were particularly interested in student roles and the potential of student evaluations by comparing evaluations of writing assignments made by instructors as well by randomly selected groups of students. The authors found that ratings of assignments made by at least four students or peers within a course were both as reliable and valid as instructor evaluations. It is important to note that the focus of the study was on evaluation rather than feedback and learning, but the study still indicates the potential of using multiple peers for feedback purposes.

The interest in student peer review has also grown as studies indicate that students learn not only from receiving feedback but also from giving feedback (Cho & Cho, 2011; Lundstrom & Baker, 2009). The activity of reading someone else's paper about a topic that one is involved with makes the reviewers reflect on their own writing and the content of their own paper. It has also been argued that the ability to give high quality feedback is an essential skill for students graduating from higher education (Nicol et. al., 2014). Research has however also shown that certain circumstances need to be fulfilled for student review process to be effective. First of all, students need to be introduced to and trained in giving feedback (Nicol, et. al., 2014, Lundstrom & Baker, 2009). Secondly, feedback needs to be followed by student activity and engagement (Boud & Molloy, 2013). Simply telling someone or being told by something that something needs to be revised is not enough. It needs to be followed up by revision, and ideally careful revision that does not only involve changing simple surface errors. In the words of Boud & Molloy (2013, p. 702), feedback is within such a perspective on feedback understood as "information used, rather than information transmitted".

Peer feedback comes with a number of challenges. The first, and principle one, is if the peers have enough competence to give effective and accurate feedback. In addition, there are challenges connected to how peer feedback should be organised, if it is fair, if the students wil take it seriously, and what the role of the tutor or instructor should be. This paper focuses on students' perception of the introduction of student peer reviewing in a project course in product development and how the reviewing affected the project.

Integrated Construction and Manufacturing is a project course for students in their second year of study, where the students get to work with problems that companies hand out to them. The companies have the role of an external stakeholder and the students find themselves in a consultancy role. The course aims to give the students a deeper experience of modern ways of working as an engineer and develop skills in product development at the same time as they learn leadership. In the course, problem solving, and analytic knowledge are required by the students. These skills are developed from courses taken during the first two years of study, and include mechanics, strength theory, material science, machine elements and manufacturing technology and are to be applied in as realistic scenarios as possible, in order to prepare students for the future work life. The skills include abilities to work in groups and be able to share ideas and solutions without being defensive. The course has been a mandatory course during the second year of the 5 years M.Sc. program (civilingenjör) within Mechanical Engineering at Chalmers University of Technology for over 15 years. Within a course that has been given for many years, there are always elements that are working well, but also challenges, discovered with course evaluation, that needs to be elaborated.

One of the challenges that has been discovered is that different supervisors give different feedback which, in some cases, can be unfair. Another challenge was that the individual assessments of each group member was based solely on one supervisor's observation. This made it difficult to know if a group member had knowledge in the course, especially since the students in groups often tended to cover up for each other if no major conflict was revealed. A third challenge was that the course is given in Swedish, and the students work is written in Swedish while some of the supervisors are international. This made it difficult for these supervisors to give feedback on the technical style, grammar and so on and therefore students had a harder time improve their writing.

To address these problems and to strengthen students' understanding of central concepts and processes in the course, peer review was introduced as a central component in the course. The rationale of the design is based very much on student activity and student engagement, and an attempt at using multiple rather than single reviews, following the work by Cho, et. al., (2006).

We use the term peer review rather than peer response, even though peer review is easily confused with peer review connected with academic publication processes. Peer response is in many ways a better term, but we use peer review as we approach on (Nicol, et. al., 2014, p. 103) definition of peer review: "Peer review is defined here as an arrangement whereby students evaluate and make judgements about the work of their peers and construct a written feedback commentary. In effect, students both produce feedback reviews on others' work and receive feedback reviews on their own work".

In this paper a detailed description of the integration of peer reviews and its contribution to addressing the challenges above is studied. Interviews and surveys are used to get students' impression of peer reviews, but also supervisor interviews to get their observations.

Aims of the study

The aim of this study is to evaluate if peer review improved any of the challenges and how it affected the students and supervisors. The following questions framed the study:

1) What are the students' general perception on peer review in the course Integrated Construction and Manufacturing?
2) Are the individual assessments of each group members knowledge more accurate when using peer review as an examining part?
3) How does the integration of peer review affect the students' writing processes?
4) How does the supervisor perceive the integration of peer reviews and its effect on student texts?

METHODOLOGY OF IMPLEMENTING PEER REVIEWS IN THE COURSE

Active learning, such as peer review, is a part of the CDIO (Conceive-Design-Implement-Operate) standards. “Teaching and learning based on active and experiential learning methods.” (Standard 8, CDIO). Design-implement courses is one kind of course where active learning is considered as an experiential learning method that gives the students a chance to simulate professional engineering practice. *´The CDIO approach to engineering education’* was a project at Chalmers during the beginning of the 21st century. Johan Malmqvist (project leader), Mikael Enelund and Stig Larsson research, Integration of Computational Mathematics Education in the Mechanical Engineering Curriculum (2011) has shown that CDIO-approach have been beneficial when designing and reforming the education in the MSc program in mechanical engineering at Chalmers.

Integrated Construction and Manufacturing is a 7,5 credits course, with approximately 160 students, during the second year of Mechanical Engineering at Chalmers University of Technology. The course runs during an entire semester parallel with other courses and the students are supposed to spend ten hours a week on this course. The students are divided into about 30 randomized groups of five group members, and have a supervisor who is responsible for about six groups in total. The groups with the same supervisor get the same problem. The case problems that are handed out from companies are different every year. For example, one problem could be to find a product to keep a patient warm during surgery or design an ergonomic knife handle. Each year there are new, unique problems for the students to solve and if a company finds the product satisfying, they might launch it.

Before 2020, while working in terms of engineering with the problem the students also documented their work in form of a number of written sub-assignments and one final report. Each sub-assignment was handed in to the supervisors who gave detailed feedback on the work and then the students had the opportunity to hand in a revised version for grading by the same supervisor. The feedback from the supervisors were not always detailed enough to be productive and helpful for the students.

In 2020, peer reviews became a part of the course and the students started to give each other feedback on their work, instead of the supervisors giving feedback, before handing in a revised version. Reviews were given on each sub-assignment. The peer review system for this course was designed so that each group member reads, and gives feedback, on one report from another random group, and their own report is reviewed by five other students in turn. In other words, the students are influenced by ten other reports and points of views in their group. The assigned report is randomized each time. The students had up to three hours for each peer review and were told to focus on the content. Things like grammar, word choice and spelling were encouraged to review as well, although it would not merit a higher assessment than focusing on content.

To make sure that the student took the peer reviewing process seriously, the peer reviews were each graded from 0 to 2 points and counted towards the final grade. The final grade is a combination of the grade from the group work and the individual grade from peer review, which is shown in Figure 1. If a group would get a high grade, but one student in that group received a lower grade on their peer reviews, that student’s final grade would be lower than the group grade. If a student would get a higher grade on their peer reviews than on their group grade, that student’s final grade would be higher than the group grade. This system is used to keep up the motivation for the peer reviews as well as to ensure the individual assessment of each student. If the written reviews were not graded there is a chance that the student would not make an effort while writing it.

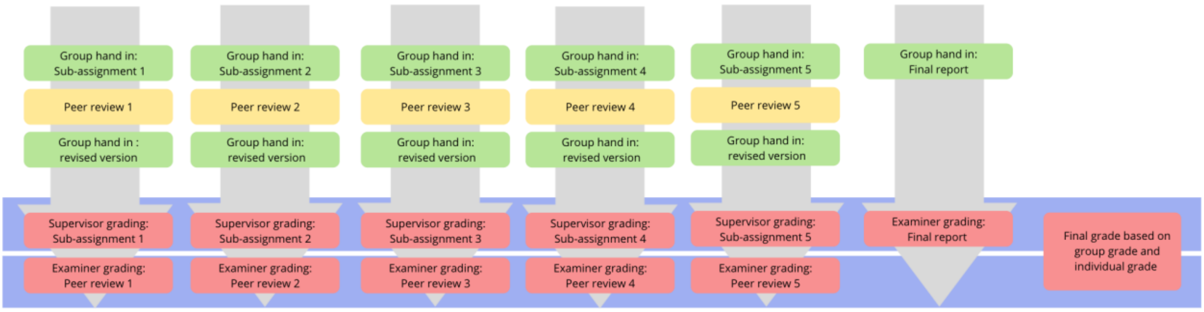

Figure 1: Grading structure in the course

METHOD FOR EVALUATION OF PEER REVIEWS

To do this analysis, student-survey and interviewing were used. The target of the analysis was the two classes from 2020 and 2021, who had taken the course during the time peer reviews has been implemented, and the supervisors who were involved during and after the transition. The analysis was decided to be executed after the course, to be able to use both student classes from 2020 and 2021, to have the opportunity for an evaluative study. It must however be recognized that the students in 2020 had the course a year ago and might not have been able to recollect the course accurately, on the other hand, some affection frustration from the course might have settled. Also, since they have completed their bachelor thesis project it might warrant a different perspective on peer reviews.

Method I: Student Survey

Firstly, it was necessary to get the overall student opinion of peer reviews, the course and to what extent the peer reviews contributed to the project or assignments. This was done with two questionnaires or surveys; each questionnaire was sent to the two groups. The first group was second year students who took the course in 2021 and the other third-year students who took the course in 2020. The survey was based around general questions such as advantages and disadvantages, and their thoughts on having peer reviews as a graded requirement. The survey was anonymous to make sure every student who answered it would feel fully comfortable expressing their opinion. The survey was sent out to 200 students and answered by 57 and was equal distributed between the two years. The questions asked in the survey can be found in Appendix A.

Method II: Student Interviews

The student interviews were done to get more in-depth responses and to be able to ask follow-up questions. It was agreed to keep the students anonymous. The selection process was based upon the student project groups to make sure there were not students from the same group since they would have received the same response. The number of students were narrowed down to seven from each class, 14 in total. The questions asked were the same for all with some follow up or clarification questions and can be found in Appendix B.

Method III: Supervisor Interviews

Because peer review was introduced recently it was interesting to investigate how this affected the students' text from a supervisor's perspective since they work closely with the students with weekly follow-ups. To receive this perspective, interviews were conducted with five supervisors; two supervisors who had been working with the program for over two years and therefore been in the course during the implementation of peer reviews, and three supervisors who started this or last year were interviewed. The focus was to see if the students improved by having peer reviews compared to getting feedback from the supervisors. The questions that all interviews were based on can be found in Appendix C.

RESULTS

Result I: Student survey

The survey showed that the overall impression (Figure 2a) of peer review was good and got an average mark of 3.81 out of 5. In Figure 2b, it can be seen that generally, students were happier about receiving peer review (4,0 out of 5), than giving response to other (3,3 out of 5).

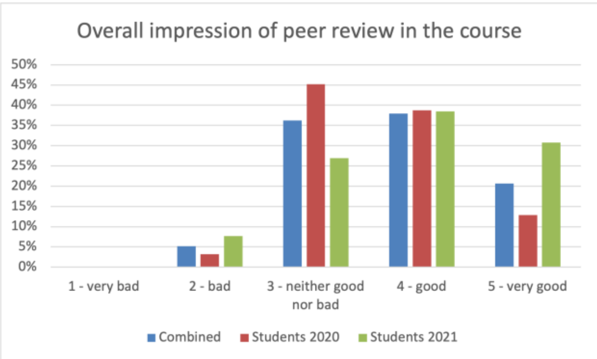

Figure 2a. Overall impression of peer review

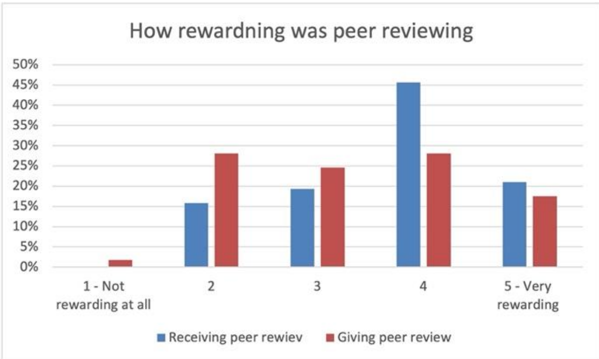

Figure 2b. How rewarding was peer reviewing

Figure 2. Data from survey

From the survey it could be seen that a lot of students said that they found it inspiring to read other groups work to get inspiration and insight of how you could solve the same type of assignment in different ways. One student wrote *"You got to take part in several projects with different approaches. This contributed to a greater understanding of the different steps within each submission. That is, you could pick up certain steps / sub-steps that you might have missed in your own project."*. They also saw it as a practice for upcoming courses. The downside of writing peer review, the students thought, was that it was time consuming and took the focus away from the rest of the work.

Most students where positive about receiving feedback on their own text in form of peer review. They wrote that it was nice to have someone reading your text and find errors before handing it in to the supervisor. Also, that it is easy to just choose one path and then following it and by getting others' opinions you will see the bigger picture and developing their work. Even if it was mostly positive comments, some students wrote that receiving peer review did not help at all and that the feedback from other students could be wrong.

The average opinion about that the opportunity to use peer review as a way to show how much the students understand in the course was neither good nor bad. Most of the students did not feel like they could show if they had knowledge about the course or not by giving peer review and they neither felt that peer review affected their learning.

Result II: Student Interview

The student interviews showed that all students that were interviewed considered peer reviews to be a positive experience but with some frustrating elements. They said "*It is good to be able to influence your own grade so that everything is not based on the group work".* Most of the students said that it was a good opportunity to compare others' texts and get inspiration and ideas. While reviewing someone's report they could find things they had missed in their own report. "I found it *really positive, it is required in order to develop your own text and writing, and for those you give the feedback, it is always good to get a second opinion*". However, they also expressed things as "*When the only feedback you get is from students, there can be unclarities, if there is something most students have not understood the group miss it*" and the overall though was that they found it frustrating when peer reviews were not useful, for example when the review only had comments on grammar, or the information was wrong.

Towards the end the students felt that their written peer review became succinct, and that they felt more comfortable and knew what to check for. Since they received peer reviews from a different person each time, the student did not feel that they could say if the quality on the received peer review changed over time.

The students from 2021 felt that peer reviews gave a fair image of what they have learnt in the course and that it was good that the grade had an individual part. However, they felt that it was hard to know what to write in the peer review since the grading criteria was not known and the grade was the focus. Students from 2020 also found the grading criteria hard to understand but said that their focus more that they learned to be constructive and got to double check their knowledge. If the student had misunderstood some theory in the course, students found that peer review could help them to be aware of this.

All student from both years said that they learned how to give and receive feedback and evaluate texts. A lot of students also anticipated to use peer reviews in the future. Students 2020 say for "*maybe smaller things*" while others have already recognised the benefits "*well we have done some more peer reviews in later days and it was good to know how to do it*".

Result III: Supervisor Interview

Overall, the general thoughts on peer review were that it was good that the student learned more and that it provides a different perspective than only supervisors' comments would give. They also said that it is good to have a first round of filtering and help each other. On the other hand, they said that sometimes students give each other the wrong information and if a group had missed something crucial it could be frustrating since they did not have all the information. So even if the thoughts were mostly positive, they mentioned that they could not guarantee that the students get proper feedback.

The supervisors who had been in the course both before the implementation of peer review, and after, thought that the quality of the students' reports had gone down since the time when the supervisor gave feedback, but that was expected since the supervisor comments are often more correct. They felt that the students should have an opportunity to change things after the supervisor's response to increase the learning and quality of the project process.

DISCUSSION

The following questions were framed to evaluate if the implementation of peer review improved any of the challenges mentioned in the introduction and how it affected the students and supervisors:

1) What are the students' general perception on peer review in the course Integrated Construction and Manufacturing?
2) Are the individual assessments of each group members knowledge more accurate when using peer review as an examining part?
3) How does the integration of peer review affect the students' writing process?
4) How does the supervisor perceive the integration of peer reviews and its effect on student texts?

Earlier research, done by for example Cho & Cho (2011) and Nicol, et. al. (2014), has shown that the students learn from critically reading other students' and giving feedback. In the study done in this paper, many students are supportive of the benefits of peer review, but there are also who find it less useful as they are uncertain about whether the feedback they get is accurate or not. The positive comments primarily concerned the giving of feedback while more the critical comments were about the reception of feedback. The survey data showed a similar trend with more students ranking the reception of feedback higher than giving feedback. The reason behind this trend could be that the students want to hand in as good assignments as possible and therefore feel like the received feedback affects their assignment more directly. Another reason could be that the students are not used to writing peer reviews and that it is a greater chance to dislike something they do not feel comfortable with, compared to receiving feedback, which they are more used to. The findings are in line with previous research and highlight the need for training students to do and use peer response (Nicol, et. al., 2014, Lundstrom & Baker, 2009). It may for instance be beneficial to talk to students about what happens with the feedback given to show the value of the given feedback. It also important to for students to realise the importance of actively using the feedback and to show that feedback is not only about passively receiving feedback (Börjeson & Carlsson, 2021).

To conclude, if peer review is a more accurate way of showing knowledge in the course it is important to evaluate the method compared to how it has been. Earlier, when the individual assessments of each group member was based on how the supervisor thought they performed, it was easy for a student to hide the fact that they did not have any knowledge by hiding behind their group members. Now, when there is an individual written part, this is something they cannot do that anymore. Even though the students found it hard to understand the grading criteria, they thought that it gave an accurate picture of their knowledge. When students write a peer review, they need to have knowledge of the subject for them to be able to give appropriate feedback. Therefore, it can be assumed that using peer review as a way of individual assessment is a way of making students more engaged in and aware of that assessment.

Even though all supervisors agreed that integration of peer reviews was good for the students' learning process and that it gave the student several new perspectives than what comments from themselves would do, they thought that the quality of the students' texts had gone down.

These perceptions are not based on actual comparisons, and it is therefore not certain that quality has gone down. In order to qualify such claims and perhaps also consider how to address problems of quality, comparisons between texts should be made. It is also possible that the process should be improved to increase quality of the final paper, for instance by letting students revise the text also after they have received feedback from supervisors. In addition, the quality of the text is only one indicator of student learning, and in order to assess the quality of peer work in the course, further analyses on the influence on content learning as well as text quality need to be made.

There are always challenges when implementing changes in a course. The current study points to advantages and disadvantages of the design implement and gives indications of parts of the course and the intervention that can be developed further.

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Appendix

A. Student survey questions

1. What was your overall impression of peer review in the course?
   1) very bad
   2) bad
   3) neither good nor bad
   4) good
   5) very good

2. How much time did you spent on average at each peer review?

3. How rewarding did you find receiving peer reviewing? 1 (Not rewarding at all) – 5 (Very rewarding)

4. How rewarding did you find giving peer reviewing? 1 (Not rewarding at all) – 5 (Very rewarding)

5. What is the benefits with receiving peer review?

6. What is the benefits with giving peer review?

7. What is the disadvantages with receiving peer review?

8. What is the disadvantages with giving peer review?

9. Do you feel that peer reviews gave a fair picture of what you learnt in the course?

B. Student interview questions

1. How rewarding was it to give (do) peer reviews?

2. Did you notice any differences doing peer reviews between the start vs the end of the course? How come?

3. How rewarding was it to receive peer reviews?

4. Did you notice any differences receiving peer reviews between the start vs the end of the course? How come?

5. Do you feel peer reviews gave a fair image of what you learnt in the course up to that point?

6. How do you feel peer reviews affected your understanding of the course?

7. What do you think are the learning aspects on having this exercise?

8. Did you learn anything from peer reviews?

C. Supervisor interview questions

1. How did the quality of the students work change over time?
2. Did you notice any changes in the need for clarity as a supervisor?
3. What did/do you think of the transition to peer-reviews from the previous method?
4. How has your view of the course changed?
5. Do you feel like the transition to peer reviews improved or haltered the learning?

IF YOU PLEASE, DRAW ME A RESILIENT CURRICULUM!

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ABSTRACT

The COVID-19 pandemic significantly impacted Higher Education as a whole, and the various educational institutions. It resulted in unexpected circumstances and unavoidable trade-offs to ensure that the curricula became more agile and flexible. Resiliency is also now a cornerstone, in order to navigate the disruptive change with the high levels of volatility, uncertainty, complexity and ambiguity. Ten universities in South-East Asia and three in Europe have since 2018 been engaged in a project aimed at improving the quality of their STEM programmes. In the context of this capacity building framework, this paper outlines a curriculum design workshop to stimulate curriculum transformations for VUCA contexts. The paper shares insights into facilitating international collaboration, which enabled different perspectives and representations of an original curriculum to emerge. The value of online tools as a way of promoting international collaboration and curriculum development is also discussed. The approach is based on a serious games model, to train curriculum designers to better embrace change, to collaborate and work across cultures. It is transferable to locally support the future transformation of programmes, by sharing and challenging ideas. Target participants are University programme leaders, deans, educational quality managers, accreditation bodies, curriculum heads and council stakeholders, as well as partners from industry, and even students. The main objectives and phases of the collaborative workshop are presented, followed by implications and recommendations aimed at developing a Resilient Curriculum framework.

KEYWORDS

Higher Education, Curriculum Design, Cooperation, VUCA, CDIO Standards: 3, 10, 12.

INTRODUCTION

In Science, Technology, Engineering and Mathematics (STEM) Higher Education (HE), Technical and Technological Universities are increasingly faced with the challenges and tensions of developing the competencies and employability of their graduates, which has been further exacerbated by the global pandemic (García-Morales, et al., 2021; Govindarajan & Srivastava, 2020; Mishra, et al., 2020). During the last decade, considerable emphasis has been placed on designing educational programmes and courses to develop the core and transversal skills as capabilities of future engineers and professionals, largely within a stable context. At a more systemic level, it is critical to identify international best practices regarding curriculum transformation processes in the context of a volatile, uncertain, complex and ambiguous (VUCA) world (Krishnamurthy, 2020).

Krishnamurthy (2020:2) argues that the "move to emergency remote teaching due to COVID-19 provides a discontinuous disruption to business-as-usual" and that it is critical to "unbundle and re-invent teaching, learning, assessment and certification". Unexpected disruptions may be particularly relevant for engineering education. For example, several CDIO standards refer to interpersonal skills that rely on direct interaction between students (e.g. Standard 4 on Introduction to Engineering or Standard 8 on Active Learning when considered experiential) and physical workspaces and laboratories (Standard 6 on Engineering Learning Workspaces). The quality levels of these standards, as examples, can easily be impacted due to a crisis, as the recent pandemic is one example, and hence the curriculum designers need to consider and develop a contingency plan for a more resilient educational program that might not be instantly apparent. Marinoni van't Land and Jensen (2020) in their study emphasised "the important degree of stress and constraint currently experienced by higher education institutions around the world. Almost all institutions that responded to the survey are affected in a way or another by the COVID-19 crisis and the crisis has affected all institutional activities… the incredible amount of pressure on higher education institutions to cope during the current crisis and at the same time their resilience and creativity." Taking into account the VUCA and multiple disruptions, STEM curricula in their structures are to become more adaptable, responsive, and resilient.

What could a resilient curriculum (RC) entail? Is it possible to reconcile HE stakeholders with cooperation design, in order to create a common understanding and develop hands-on methods? To address the question of curriculum resiliency, this paper proposes a process to facilitate STEM resiliency curriculum development with collaboration tools for curriculum design, which is largely based on a collaborative workshop, which was designed and run in 2021, with international programme designers, from diverse cultural backgrounds. As part of a European project, our aim was to bring together ad-hoc practices around agile thinking, with tools based on a serious game, from a playful and virtual perspective. The game also brings together sharing, conceptualization and collaboration, beyond the skills of the participants, around the design of agile and resilient curricula.

The proposed collaborative workshop can assist HE institutions to pave the way towards a Resilient Curriculum Framework (RCF), which can also help improve the quality and relevance of their curricula. With an international collaboration perspective, it is to facilitate innovative curriculum design activities, by exchanging or developing new practices and methods, and inspiring and learning from others. The proposed workshop is very much in line with the spirit of CDIO as reflected in its emphasis on integrated curriculum (Standard 3) where Faculty can play an active role in designing, as enhancement of faculty competence for effectively improving curriculum (Standard 10), by creating forums for sharing ideas and best practice.

CURRICULUM AGILITY AND RESILIENCY

Curriculum agility is important when relevant professional disciplines are developing rapidly, as in engineering (Brink et al., 2021). Brink et al. developed a shared vision on curriculum agility, where an agile curriculum is responsive and adaptable to changes in society and business, as well as student characteristics and needs, by having the capacity to change structures, learning outcomes, and learning activities in a timely manner. They introduced nine principles of curriculum agility, which defines or refines the concept of curriculum agility. Agility is perhaps now more than ever an unavoidable property of curricula to meet the transformational challenges of educational programmes in a more continuous manner, due to the various crises impacting the HE sector (García-Morales, et al., 2021; Govindarajan & Srivastava, 2020; Mishra, et al., 2020). In 2022, within the CDIO community, the development of self-assessment rubrics for the agility identified principles is underway for three clusters: Curriculum Vision & Strategy, Curriculum Quality & Provision, and Curriculum Design & Research principles. These rubrics are to support programme leaders in assessing the agility of their curricula to support the change processes in a common maturity scale (cf. CDIO standard 12).

The 2020 pandemic emphasised the need for curriculum flexibility and agility at all educational levels. There is also growing interest in system-level resilience within the 2030 Agenda for Sustainable Development[1]. According to IROWH (2016), the word "resilience" comes from the Latin verb "*risalire*", which means to rise again (to bounce back). A resilient community is able to cope with change, and retain its structures and functions after disturbances in order to keep up with continuous development. Resilience. Some HE programmes were particularly resilient for the pandemic, as for a University of Bristol programme which implemented a new curriculum in undergraduate Engineering (Berthoud et al., 2021). With a process of developing programme-level intended learning outcomes, followed by a process of linking the content and assessment of the programmes to focus on these learning outcomes, it resulted in a simplification of the structure of their programme along the pandemic. Flexibility and diversity of content delivery methods allowed teaching to large cohorts in a variety of situations due to changing restrictions thanks to the constructive alignment approach.

Curriculum development and collaboration in curriculum design require a change in mindset in VUCA contexts. HE curriculum designers and Faculty need to be able to embrace change, and be immersed in and able to cope with perturbations. It is important that they are more adaptable, cooperative, innovative, able to collaborate and work across cultures.

SOURCES OF INSPIRATION

The curriculum design workshop was mostly inspired by two sources. These are relevant examples of serious games, which facilitate stakeholder collaboration and cooperation to help identify alternative strategies and structural solutions. First, University of Utopia is a serious collaborative game intended for HE teachers (Laplanche and Escrig, 2019). It allows pedagogical concepts presented via concept cards to be transferred to teaching situations defined collectively in order to improve the quality of learning activities. The participants develop a mono and multidisciplinary educational activity project on a poster. Second, the Climate Fresk (CF) offers workshops to raise awareness of climate change issues (www.fresqueduclimat.org). It promotes individual and/or collective awareness and facilitates

[1] https://sdgs.un.org/2030agenda

a constructive discussion, creating a will to act in the face of the challenge of an ecological transition (cf. Figure 1.a).

Figure 1.a Climate Fresk sample in 2021 with students at IMT Atlantique,
and 1.b online with EASTEM curriculum designers

Background

Since 2018, ten universities in South East Asia and three European universities have been partners in a project aimed at improving the employability of students after graduation (www.eastemproject.eu) and industry collaborations (Rouvrais et al., 2020). This European project also aims to develop the skills of teachers, to promote the creation of networked educational services (cf. network of STEM centers[2]). The collaborative approach stimulates the sharing of good practices (Bennedsen & Rouvrais, 2016) and is a source of inspiration.

Cooperation kick-off

Some project members participated in a first workshop to stimulate and reinforce cooperation skills between partners involved in programme transformations. To commence with, as a cooperative design, participants first experienced an online CF on an international scale in 2021 (see Figure 1.b). It lasted approximately four hours, and was held online on Zoom in October 2021. Mural was used for the CF, and interaction was ensured through the use of Zoom breakout rooms, which facilitated group interactions. Eleven participants from diverse countries, including France, Iceland, Indonesia, South Africa, Vietnam and Thailand, participated. A qualitative and quantitative questionnaire allowed for analysis. The feedback primarily related to duration, group size, rhythm, STEM topic alignments, pros and cons, and the use of the Mural tool. Overall, it was found to be a pedagogically fruitful workshop to engage in systems thinking and intercultural cooperation. As a cooperative design, overall 60% of the participants liked the CF workshop (strongly agreed), 30% agreed, 20% neither agreed or disagreed (Likert scale). Twenty-five percent appreciated (strongly agreed) that collaboratively using cards in a design and system thinking workshop can be beneficial for a future RC workshop, 50% agreed, 12.5% neither agreed or disagreed, and 12,5% disagreed.

Best practices from the CF gameplay were further explored for the novel workshop. One RC workshop was then held online in November 2021 on Zoom, with five participants from different institutions, participants collectively exploring how first to design curricula.

[2] https://www.fsf.vu.lt/en/eastem-centers-platform

CURRICULUM DESIGN WORKSHOP

"When the mystery is too impressive, we dare not disobey… I took out of my pocket a sheet of paper and a pen. But then I remembered that I had mainly studied geography, history, arithmetic and grammar and I told the little guy (with a little bad humour) that I did not know how to draw" (Antoine de Saint Exupéry, The little prince, chapter 2, 1943).

The RC workshop was designed with the aim of developing collaboration between training managers, program directors, teachers, students and industry. In order to "get out of its own walls" and exchange in complete neutrality, the groups are to be mixed between stakeholders and institutional cultures to "draw" the main lines of an imaginary training program, resilient to the unforeseen. Under a serious game schema, and informally following some design thinking methods, the RC workshop stimulates a collaborative innovation in curriculum transformation with a view to analyse VUCA readiness of programmes.

In curriculum modelling, arrays including course blocks and semesters columns are often used, with learning pathway constraints between core, broadening or elective courses. It often takes very long to develop new programme architectures, and other challenges arise, such as deep managerial perspectives, resistance to change or administrative duties, which could limit the innovation and freedom for redesigning existing structures. A curriculum architecture representing a set of study program curricula of a faculty cluster helps to reach resilience principles when it already supports the basics of agility at more systemic levels. Participants reflected on the fact that there was a lot of paperwork, administration, and sometimes little freedom on structures, with respect to the university curriculum framework, accreditation standards and other requirements.

Six drawings were proposed, e.g. (i) curriculum architecture of all study programs in ITD (with four Faculty and three domains), (ii) a postgraduate diploma in Business Administration at UKZN with course structure, (iii) pillars and structure of a biomedical engineering BSc. at RU, (iv) an industrial design engineering bachelor with flexible choice-based curriculum.

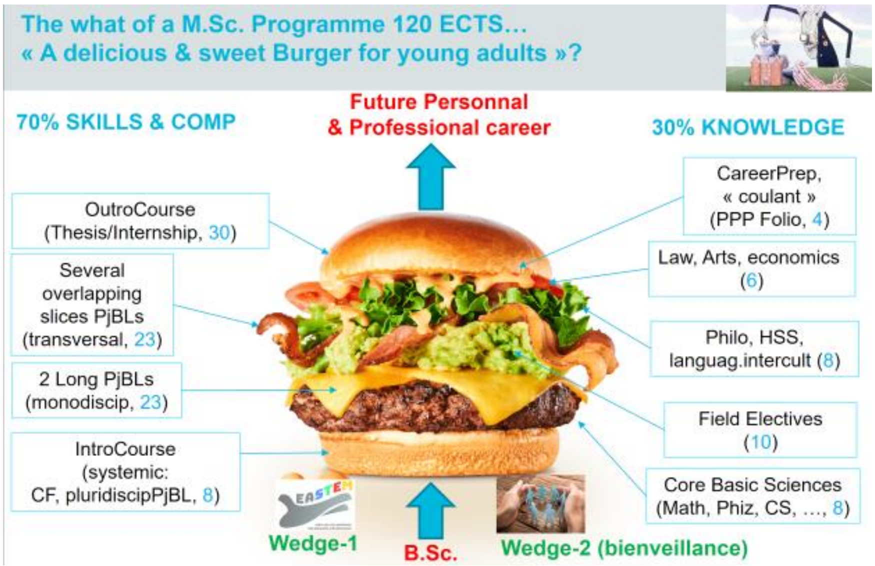

Figure 2. Curriculum drawing sample.

Among the six drawings, as an example, in Figure 2, the revamped burger-styled curriculum inspiration came from a meeting in Paris in June 2014 with members from UpCERG group from Uppsala University, Aalto University, and IMT Atlantique. It was recognized as attractive and flexible, but with few temporal links between too abstract courses. As a metaphor, it offers a kind of menu for curriculum blocks. The workshop highlighted how architectural representations of the curriculum suggested by the international participants varied considerably, both from a structural point of view and from the informal artefacts used. Five participants were asked to cooperatively sketch a resilient curriculum, echoing arbitrarily a BSc in cybersecurity. The participants however experienced challenges in designing a common understanding and reframing the problem in a human-centred and graphical way. They were questioning the main aim, problem, assumptions and implications. As a future activity, VUCA scenario could then be introduced to reflect on the resilience of the various participant's structures.

The RC workshop concluded with a short debriefing session and dialogue. Table 1 indicates preliminary elements of analysis, based on feedback.

Table 1. SWOT of the RC trial workshop.

Strengths	Weaknesses
• Collective work in favour of acting together • Based on plural and international experiences • Sharing good practices and enrichment • Serious playful games in accordance with motivational factors • Flexibility and freedom of graphic language for the design-thinking phase	• New approach with that needs appropriation of tools and techniques • No real concrete feedback yet quantitatively and qualitatively analyzed • No immediate post-workshop application under a concrete continuous improvement approach to programs
Opportunities	**Threats**
• Flexible and intuitive representation language • Transferable to other disciplines • Transferable to other universities or programs • Potential sharing of strategies, goals, action plans and quality indicators of the developed outlines • Agility and resilience analysis support at architectural level	• Modeling curriculums too restrictive when a too formal graphic language • Lack of support from decision-makers due to the variety of participants • Loss of motivation of partners with regard to repetitive serious games • Competitiveness between participants with regard to transparency

REFLECTIONS AND IMPLICATIONS

Intercultural encounter

The RC workshop allowed participants to identify many intercultural, professional and personal skills and aptitudes, which are mobilised by the participants. Problems of cross-cultural adaptation however remain. As noted by Kennedy et al. (2019), design and implementation of a programme may be influenced by cultural methods for conducting business and maintaining knowledge integrity, by taking interdisciplinary teams of academics on a journey towards 'curriculum reconciliation'.

As an example, for the Indonesian author, the "gotong royong" principle is anchored as related to its ideological basis. Gotong royong in literal meaning is "mutual assistance", a kind of collaboration with empathy, compassion in order to share burdens. During the 2019-pandemic, the Indonesian government encourage "gotong royong" to overcome the crisis. For the South African author, the African philosophy or concept of Ubuntu arose. This could be translated as "I am because we are" or "I am because you are", linked to Zulu, and in Xhosa, the meaning is also broadening to "the belief in a universal bond of sharing that connects all humanity". For the Icelandic author, “þetta reddast” is described as the country’s motto. Þetta reddast can be translated to “it will all work out okay”. Life could often be difficult in this barren, harsh country and over time Icelanders have developed a mentality which can sometimes seem a bit carefree. When faced with difficulties Icelanders always maintain a belief that things will work out in the end; no matter how big the problem, a solution will always present itself”[3].

Cooperation to stimulate thinking out of the box

It is important to note that the development of resilience takes time, especially in systems that are characterised by tight control and little room for risk-taking and innovation, as may be found in many HEIs. This workshop was thus exploratory in nature, with the purpose of primarily focusing on how best to support the development of resiliency and agility. It is important to bring together multiple, diverse stakeholders, who can journey through a process whereby their mindsets and traditional ways of working are challenged. The diversity of the group further led to participants being exposed to multiple perspectives and fresh thinking to attempt to address common problems plaguing HEIs.

It is important that members of HEIs, especially those on the ground, have the necessary skills and capabilities to drive change. The fixed organisational culture of HEIs which can be quite focused on policies and plans, can ensure efficiency, but can lead to staff being inhibited and unable to respond and recover quickly in the face of adversity. If the individuals in HEIs are unable to bounce back quickly, then how much more challenging is it going to be when examining the curriculum, especially when considering that it is the individuals in the system who are responsible for achieving outcomes. We thus argue that resilience-building of the curriculum is dependent on the extent to which individuals in the system themselves are capable of embracing change and being responsive and proactive.

Diversity of viewpoints

Participants highlighted the value of being able to hear the experiences of others, especially international perspectives. There was some value in the metaphors-direction, to help people think about curriculum as something other than just a timeline of courses planned over three or five years. The hamburger abstract design, in particular, was especially received well and led to the other participants thinking more creatively, as well during the second collaborative design from scratch phase; thus, emphasizing different characteristics of a curriculum. Increasingly, more and more criteria on HE programs are offered in quality procedures, sometimes even imposed by accreditation agencies.

To date, there is no global and unified framework for visualizing and discussing curriculum designs. The workshop presented was without any real constraints in terms of modeling, able to guide actors in HE to collaborate more effectively in their curriculum transformations. This informal and cooperative workshop makes it possible to start to act together in the construction of action plans in connection with strategies set by Universities, Ministries or accreditation systems. In our VUCA times, the present impact of the "turbulence" on the curriculum is being experienced worldwide.

[3]Iceland Magazine, by Sara McMahon, June 19/2014.
https://icelandmag.is/article/what-does-thetta-reddast-mean

Many HEs suffer because they have a rigid curriculum, with specific courses which are fixed. It is critical that the curriculum is both agile and resilient. As an example, in Indonesia, the Ministry of Education started to run the MBKM (Independent Learning-Independent Campus), formed at the beginning of 2020. Students of the 4-year Bachelor program are given the freedom to take the opportunity to spend one semester outside the study program and two semesters of carrying out learning activities outside the university. The credits of those semesters are taken into account in the academic transcript. It means that the curriculum must support a "big room" for MBKM activities and its credits. If the curriculum is not agile or is not resilient, it creates problems for the study programme. Students learn and gain experience from real world professionals, by doing the activities outside the university, especially through internships (in industry, government offices, research centres or in the community).

CONCLUSION

The main purpose of the RC workshop is to train curriculum designers to share a common understanding with intercultural colleagues and team members, to later transform (redesign/reform) their own curricula according to local challenges, traditions, culture, etc. What HE in VUCA times will entail, still remains a question for our future, even more in the context of international programme interoperability as to be seen in the ongoing European Universities movement. They are opportunities to allow organisations to increase the quality and relevance of curriculum design activities and to increase capacity to operate jointly at transnational level for programme interoperability. The RC workshop, held as a trial in Fall 2021, aims to identify alternative curriculum design strategies as curriculum solutions which may not be instantly apparent. It questions the problem and investigates whether it is possible to reconcile HE stakeholders with cooperative design, in order to create a common understanding and develop a collection of hands-on methods for curriculum transformation in VUCA contexts.

The workshop can assist curriculum developers and facilitate resilience of educational systems facing VUCA events. The tool paves the way to resilience investigations within a curriculum framework, to include models, methods, and processes transferable to local institutional contexts according to the local needs and challenges, for curriculum renewal, transformation and reconciliation. The tool challenges assumptions, strategies, alternatives, implications and foresight solutions. The RC workshop, which was presented in this paper, is a preliminary activity, to highlight why and how collaboration is needed between different stakeholders to open mindsets and innovation. On an international scale, the RC workshop demonstrated that collaboration of all stakeholders in curriculum design can be done effectively with serious games using various online tools. Sustaining all the CDIO standards during VUCA times is a challenge, for example because it relies on interpersonal skills, active learning and dedicated workspaces, all of which can easily be disrupted by unexpected VUCA events. An open minded cooperative workshop as outlined here may indeed be fruitful when developing strategies for more resilient and interoperable CDIO spirited engineering programs.

Globally, HE has to contemplate and start to develop resilient curricula, and this paper is a very first step in that direction. In 2022, in the context of reconfiguration of HE and the quality assurance landscape in Europe and worldwide, roles and challenges for STEM schools and accreditation bodies have been questioned. As a first recommendation, a RC Framework could be investigated, to include models, methods, processes and tools for guiding transformations of STEM programmes. As a starting point, graphic languages for the representation are now to be studied, maybe with a system modeling approach which makes sense to meet such challenges of exchange and interoperability (Rouvrais and Chiprianov, 2012). As a second recommendation, the RC workshop may be complemented with concept cards and strategic canvas to guide participants to identify more specific strategies and solutions under VUCA constraints.

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APPLYING ACTIVE LEARNING IN THE ELECTROMAGNETISM CLASS: A FIVE-YEAR ASSESSMENT

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ABSTRACT

The intrinsic difficulty of studying electromagnetism added to the ignorance of its implications and applications in our daily life has reduced the number of students who would probably work in this area at the end of their careers. Although it is an opportunity for them to learn and strengthen their professional profile, students usually perceive the electromagnetism class only as a degree requirement. To increase the interest of students in the study of electromagnetism and the utility value of its applications, as well as to improve the general perception and positive attitude of students towards this course, we have implemented and tested an active learning approach (Project-based learning –PBL-) since 2014. These changes were motivated by the adoption of a new CDIO-based curriculum in the electronic engineering program at the Javeriana University in Colombia. The purpose of this article is to illustrate the results obtained by five years of direct and indirect evaluation of students in electromagnetism classes, in terms of their learning graduality of key topics in the field, difficulty perception about learning them, and the general perception of the class. This evaluation was conducted over five years, comparing two different class sections each semester. A class section adopted PBL and active learning within the CDIO framework and the other section (which functioned as a control group) was taught using traditional methodology. In the class section taught with PBL and active learning, the results showed significant improvements in the general perception of the Electromagnetism class, in the learning of complex subjects, and the knowledge of the applications of electromagnetism. Likewise, the results show an increase in the interest of students to get involved in more projects related to electromagnetism later in their undergraduate studies.

KEYWORDS

Electromagnetism, Active learning, PBL, CDIO, Standards: 7, 8, 11.

INTRODUCTION

In recent years there has been a great increase in the demand for wireless technologies and this demand will continue to be sustained for a long time, not only due to the rise and implementation of 5G networks but also new paradigms the Internet of Things (IoT). This growth in demand increases the need for engineers with knowledge in all topics related with wireless communications, unfortunately, the perception of undergraduate students regarding these topics is that it is problematic and complicated. In fact, this has also been a case study of some authors like Sadiku (1986), Rosenbaum et al (1990), or Keltikangas et al (2010), and additionally the students do not find a relation to Maxwell's theoretical work nor do they visualize its application in wireless technologies, which requires that alternatives be created (Lim, 2014). These problems ask for a new teaching that not only motivates students to learn about these topics but also facilitates the appropriation of concepts and their applications.

These difficulties mentioned have impacted both students and teachers since the last decade. One example to illustrate this impact is that the number of conferences related with electromagnetism related topics has decreased, (MIT, 2019), (Berkely, 2019), (Stanford, 2019), which goes against technological trends and the need for engineers with effective knowledge and the ability to develop novel solutions in the field of electromagnetism and wireless communications. These fields, by nature, are a dynamic development area (Rosenbaum et al, 1990).

Electromagnetic theory topics and courses are part of the study plans of several universities in the world (Collier, 2017), (Sadiku, 2018), (Lim, 2014), (Lumori et al, 2010). Some of these courses have been approached with variations in their contents, reducing the depth of these and even with different perspectives, to try to solve the difficulties that students face (Lim, 2014), (Lumori et al, 2010). Innovations have been made using three-dimensional models (Huk, 2006), interactive learning environments such as Visual Electromagnetics (VEM) (Miller, E, et al, 1990), use of numerical approaches (Hoole, S et al, 1993), Computational Electromagnetism (CEM) (Trlep et al, 2006), Computer-aided instruction (CAI) (Vidal et al, 1997), (Crawley et al, 2014), incorporating applied software such as Matlab (Bertolo, J, et al, 2002), texts and experimental platforms with interactive multimedia interfaces (Liu et al, 2018) and even project-based learning (PBL) (Prince, 2004), (Jonassen, 2014), (Prince et al, 2006), (Spikol et al, 2018), which has shown an improvement in academic results (Macías-Guarasa et al, 2006). Our traditional course methodology has used some of these ideas, but the one we propose has had modifications that have been adapted to our own context, for example PBL.

One of the characteristics in the programs under the CDIO framework is the integration of learning experiences that lead to the acquisition of disciplinary knowledge and skills (CDIO), in our case, we use PBL and active learning [28], which involves students as active participants in their learning process (Bravo et al, 2016), (Crawley et al, 2014). So in this document we describe and analyze the implementation of an undergraduate course in electromagnetism under the CDIO framework with special emphasis on standard 8 (Active Learning), using group work experiences through projects focused on improving the concepts and their application over five years. The topics that we address in this document are the description of the electromagnetism course and its context, later the projects proposed under the CDIO framework, and the results obtained by the students will be described, then the analysis of the collected data will be done, quantitative and qualitative, finally the results obtained and future job prospects will be shown.

COURSE DESCRIPTION

The course is Electromagnetic Transmission. It is in the third year of the Electronic Engineering undergraduate program, which has three contact hours per week, for 16 weeks, and is offered each semester. The study plan divided by weeks can be seen in Table 1.

Traditionally, the methodology used in this course is based on theoretical lessons, with mathematical examples and exercises to do at home, the size of the groups does not exceed 30 people and usually, four to five groups are offered (at different times) in the year.

Given this situation of having different groups, in each semester there was a control group (traditional methodology) and one or two groups, with the methodological proposal presented in this document, which aims to integrate learning experiences in such a way that they facilitate the acquisition of lasting knowledge (basic concepts), using the project-based approach, as an active learning tool in which students are highly involved in their learning process. It is worth to note that although the course is project-based, it includes theoretical lessons oriented towards the development of the projects.

Table 1. Syllabus of the Project-Based Electromagnetic transmission course

Topic	Hours
1.1 Multivariable calculus and complex analysis review Course content description, a brief review of the theory of complex variable functions, an overview of multivariable calculus: orthonormal coordinate systems, vector differential and integral operators, vector and scalar fields properties (Sadiku, 2018), (Cheng, 1993).	3
1.2 Electrodynamics Review of the static Maxwell's equations, dynamics and Maxwell's vision, general boundary conditions, energy storage, power dissipation, transport and power guidance, radiation and introduction to fundamental propagation phenomena (reflection, transmission, scattering, and diffraction) (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	9
2.1 Electromagnetic wave's propagation in absence of sources Mathematical foundations of electromagnetic wave propagation from the Newtonian perspective of waves propagating in mechanical media. Helmholtz equation and solution for plane waves (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	3
2.2 Electromagnetic wave's characteristics Waves polarization, power density, group and phase velocity, phase distortion. Propagation in dispersive media, distortion effects (Jin, 2015), (Balanis, 2012), (Orfanidis, 2016).	3
2.3 Electromagnetic wave's reflection and refraction Reflection and refraction of electromagnetic waves in different media, normal and oblique incidence, Snell's law, and phase matching. Propagation in multiple media. Design example of antenna radome with the Smith chart (Jin, 2015), (Orfanidis, 2016).	3
2.4 Electromagnetic wave's diffraction Doppler effect, scattering, and simplified models of diffraction (Balanis, 2016),.	3
3.1 Electromagnetic wave's propagation in presence of sources Vector potentials formulation, the extinction surface equivalence theorem. Wire and rectangular aperture radiation (Jin, 2015).	3
3.2 Antenna's parameters Antenna's definition and parameters: gain, directivity, radiation pattern, radiated field, effective area effective height, polarization, bandwidth, antenna matching (Balanis, 2016).	3
3.3 Antennas case studies Rectangular horn antenna, infinitesimal and Hertzian dipole (Balanis, 2016).	3
4.1 Computational Electromagnetics (CEM) - Frequency methods Introduction to fundamentals of computational electromagnetics methods, microwave, and RF systems applications. Frequency methods in 1D: Method of Moments (MoM), Finite Element Method (FEM) (Jin, 2014), (Balanis, 2016).	3
4.2 Computational Electromagnetics (CEM) - MoM simulation An MoM algorithm for a wire antenna simulation, electric current distribution, and far-field calculation (Gibson, 2021), (Harrington, 1993).	6
4.3 Computational Electromagnetics (CEM) - Time methods Time methods in 1D and 2D: Finite Difference Time Domain Method (FDTD) in pulse-based techniques simulations for ground-penetrating radar (GPR) (Warnick, 2020).	6

Difficult topics in Electromagnetism

The Electromagnetic Transmission class has been famous among students for being very difficult, not only about the subject being worked on, but additionally, they must have very good concepts from previous courses, such as physics and vector calculus, topics that have historically been difficult for them.

The students were asked using a survey about their perceptions about the difficulty of the course (at the beginning and the end). Table 2 shows that there is a preconception with low favourability about the difficulty of this class, which improved at the end of the class.

Table 2. Survey scores in 2015 and 2018 about the perception of class difficulty

Item	**2015**	**2018**
What was your perception of difficulty in the Electromagnetic Transmission course before starting it?	4.17/5.0	4.35/5.0

The perception of difficulty among the students who are going to start the class is quite high.

Additionally, based on the historical results of the evaluations, the three themes that generate the greatest difficulty in the students' learning process and some of their possible causes have been identified:

• Electrodynamics from the perspective of Maxwell's equations, which results in students thinking that Maxwell's equations are just equations, in which one must learn about mathematical vector operators, but no information is obtained about how the energy through an electromagnetic field, students consider electric and magnetic fields to be static.

• The dielectric properties of materials, since the students, still have a Newtonian vision of the physical world and in this way, the permeability, permittivity, and conductance do not fit into the model they brought.

• The perspective, utility, and applicability of electromagnetism in your professional life.

PROPOSAL USING THE CDIO FRAMEWORK

From the diagnosis made, we considered ways to improve and facilitate student learning in the subjects and the application perspective of electromagnetism. To meet these objectives, we developed a course methodology based on the CDIO framework, with active learning through PBL. Table 3 describes the four stages of the CDIO framework used to develop the projects proposed in this course; depending on each project, different stages were addressed.

Table 3. Stages of the CDIO framework used to develop the projects in this course

Stage	Description
Conception	The teacher shows the relationship between the project, the related concepts, and the expected learning outcome in the development of the project. By engaging students in thinking about concepts, new knowledge, and the need for open response, students enhance not only their learning process but also their deep understanding of what and how they learn (Crawley, et al, 2014)
Design	This stage is carried out in working groups and with the teacher's guidance, students must define the components and tools that are involved, develop the plans and algorithms for the project, and design the result of the project.
Implementation	In this stage, the students materialize the proposed design (hardware, software, testing), validate the accomplishment of the given restrictions, and evaluate the degree of compliance with the requirements indicated in the conception and design stages.
Operation	This stage involves demonstrations of the prototype (software or hardware). It allows students to understand their prototype working in the real world. Additionally, they can obtain feedback from users (other students) and an expert (teacher). As part of the final evaluation, they must present a written technical report in IEEE format.

With the CDIO framework, students develop their projects in such a way that, by acquiring knowledge and putting it into practice, they improve their team work skills, develop their critical thinking and strengthen their written and oral communication skills (Crawley et al, 2014), (Bravo et al, 2018).

PROJECTS DESIGNED FOR STUDENTS

Given that three topics generate the most learning difficulties, we created one project for each. Table 4 describes the three projects:

Table 4. Description of the projects

Project	Description
Vector Analysis of electromagnetic fields.	The motivation of this project is directly related to the abstraction of how a dynamic electromagnetic field propagates energy in a dielectric media as a wave. The students, as part of their active learning, (Standard 8), are asked to use Matlab as a visualization tool with an initial question on how an electromagnetic vector field can visually being represented with a proposed SteadyState Electric field expression. With the proposed expression students must obtain the magnetic field component by using Maxwell's equations. Having both field expressions, they are asked to include time dependence and propose a visualization method to show and explain intuitively the energy propagation phenomena. Then, students are asked to set up an additional propagating wave changing from a cartesian to the cylindrical or spherical coordinate system.
Dielectric-properties measurement system	The motivation of this project is to show the importance of knowing the dielectric properties of materials where electromagnetic waves propagate. Into the given context, students must acquire in-depth insights about the meaning itself of the permittivity, permeability, and conductivity of materials, besides how these concepts can be applied in radio waves propagation, materials characterization for diverse purposes. In this project the students must: 1. Designing, modeling, simulating, and implementing the selected method, including the excitation coupling. 2. Measuring the implemented method to validate the theoretical and simulated results. 3. Once validated, using the implemented method obtaining the dielectric properties of a liquid, solid or semi-solid load. Integrated learning experiences (Standard 7). 4. Comparing the obtained dielectric properties of the load with a valid dataset.
Impulse-based Ground Penetrating Radar (GPR) simulation for landmine detection	The main motivation of the project is to show students how the main concepts taught during the course can be applied in a real scenario. The problem exposed in the project has a direct impact on the national context since Colombia is one of the countries most affected by mines in the world with more than 11 000 registered victims since 1990. During the project development, students address important course concepts such as wave propagation in different media, reflection, and refraction of electromagnetic waves, wave velocity and time of arrival, electromagnetic computational time-domain methods, space domain discretization, and microwave imaging concepts. Students are asked to implement and simulate a 1D FDTD method by setting up the distance of the space domain, the grid points, the grid parameter, the excitation signal, and the boundary condition. In this fashion, they need to adapt the simulation set up with different landmine scenarios considering the air-soil discontinuity and the presence or absence of the explosive artifact.

DATA COLLECTION AND RESULTS

Data collection occurred over five years (since 2015). Two types of data were collected. The first was the final grade and GPA on a scale of 0.0 to 5.0 (the passing grade is 3.0). These data were collected in 2015 and 2018 for all 323 students. Measurements of central tendency and variability were found using descriptive statistics. After t-test was performed, there were no statistically significant differences between the GPA of students registered for the traditional class (3.83/5.0) and students registered for the PBL course (3.81/5.0).

The results of the students in later courses were also investigated, without obtaining any statistically significant difference. The results also indicate that student participation in the PBL class did not affect the percentage of students who failed the next electromagnetism course (Antennas). 21% of the students enrolled in the PBL course failed the Antenna course later, while 20% of the students enrolled in the traditional course failed the Antenna course later.

Nonetheless, there was a slight difference (although not statistically significant) of the percentage of students whose grades were above 4.0 in the Antennas course: 20 % of the students registered in the PBL class and 17 % for students registered in the traditional methodology class had a final grade above 4.0.

The second dataset was collected with a survey distributed in 2015 and 2018 (N=323, response rate=95 %). The survey has three parts. The first part asks students for their perceptions about the difficulty of the course at the beginning and the end of the course. The second part asks about the effectiveness and acceptance of the instructional strategy used. Finally, the third part of the survey inquiries about students' perception of learning in some specific concepts of the course. To reduce bias, these surveys were conducted before the students knew their final grades.

The four most relevant positive results in both surveys are mentioned in Table 5.

Table 5. Survey highest scores in 2015 and 2018

Item	2015	2018
What is the perception of the difficulty of the Electromagnetic Transmission course, when the course is ending?	3.57	3.36
Did you learn the concept of propagation of incident, reflected, and transmitted electromagnetic waves?	4.17	3.98
Did you learn the concept of dielectric characteristics of materials?	3.98	3.93
Did you learn the concept of Maxwell's equations and their use?	4.04	3.93

Additionally, other results have been obtained in terms of the perceived learning about the subjects of the course. These have remained at the same level except for Maxwell's Equations that lowered their rating. More than 80% of the students said that the teacher has been decisive in the perception of the course. Regarding the evaluation of the learning obtained by the students, more than 82% of them rated their learning process about electromagnetic wave propagation concepts over 4.0. A similar grade was obtained on Maxwell's equations and their use. In addition, more than 75% of the total students scored with 4.0 or higher in their learning process about the dielectric characteristics of the concepts of the materials.

Likewise, the three most notorious results that should be improved in our course are:

- After having completed three-quarters of the course, only 35% of the students thought they would pass the course.
- About 25% of the students scored with 2.0 or less the benefit-cost value of the class.
- About 30% of the students, gave a grade of 2.0 or less their learning and clarification of concepts about computational numerical methods in electromagnetism, including the utility of the project about the measurement of dielectric properties of materials through a resonant cavity.

In the same way that the highest scores were maintained between the two surveys, the three lowest scores are also maintained in both surveys and correspond to the learning of computational methods. As shown in Table 6.

Table 6. Survey lowest scores in 2015 and 2018

Item	2015	2018
How effective was it for learning the concept of numerical computational methods in electromagnetism?	3.04	3.09
How effective was it for the CLARIFICATION of the concept of numerical computational methods in electromagnetism?	3.02	3.00
Did you learn the concept of computational numerical methods in electromagnetism?	3.09	3.13

The positive effects perceived in students registered in the PBL class compared to the traditional class was also validated since its implementation in 2015, the number of capstone projects related to the area of electromagnetic transmission has increased more than 40%, as well as the number of students (more than 50%) in the elective classes related to these topics (optical transport networks and wireless communications). Also, after 2014, due to the greater interest generated in the students in the area of electromagnetism, students participated in external events and competitions of this area with very good results, among these achievements, the first place obtained in the design, implementation, and operation of an antenna for the reception of environmental images from the National Oceanic Atmospheric Administration (NOAA) satellites stands out.

DISCUSSION AND FUTURE WORK

The results show that there are no significant differences between the academic performance in the Electromagnetism course or the subsequent Antennas courses, between the students who took the course with the traditional methodology or those who took it in the course with PBL. What has been presented has been an increase in the number of degree work related to the subject of electromagnetism. This could indicate that there are no great differences between the learning of the students who were in the traditional methodology and those who applied PBL, however, it does show that there is much greater interest in continuing to work on the subject of electromagnetism in the students who had to carry out the different projects.

Despite the perceived difficulty of the subject, when students develop the projects proposed under the CDIO work methodology and show both the application and development of the concepts discussed in class, improvements in their attitude and learning are evident, thus the course has greater acceptance and thanks to the projects the learning has been more enjoyable according to their own opinions.

On the other hand, although the applied methodology has been essential to reduce the perception of difficulty. However, resonant cavity project needs to be evaluated in detail, either by changing its approach or the evaluation methods. Nonetheless, the course structure aligns very well with the CDIO approach implemented in the electronics engineering program.

Beyond maintaining the high results on the perceptions of difficulty, effectiveness, and acceptance of the instructional and learning strategy of the students, the data shows an increase in the participation in workshops and competitions of electromagnetism applied outside the university, even obtaining awards and recognition for projects related to electromagnetism. Therefore, continuous work should be promoted and maintained in the creation, design, and implementation of more projects related to the applied electromagnetic course and even previous courses, which help to demonstrate the application of electromagnetic theory, motivate students and reduce your perception of highly complex problems.

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ALIGNING STAKEHOLDER NEEDS WITH PROGRAM REQUIREMENTS USING A MULTI-STAKEHOLDER SURVEY

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ABSTRACT

From the 2020/21, the School of Engineering at the University of Navarra joined the CDIO network. This paper describes the first step of the process of adapting the programs to the CDIO paradigm: the extent of compliance of the implemented programs with the key components of the CDIO syllabus as well as the extent to which these programs provide graduates with skills specified in the CDIO syllabus. Multiple approaches to data collection were used. The skills and competencies of the different engineering programs were mapped against the components of the CDIO syllabus. This was followed by a questionnaire survey for employers of past graduates. The core of this questionnaire consisted of their opinions of the importance of the various components of the CDIO syllabus and an assessment of the level of proficiency of these skills and competencies in our graduates who work in their companies. A second survey, a tracer study of engineering alumni, also consisted of their opinions on the extent to which the engineering programs provided them with the skills and competencies specified in the CDIO syllabus. Finally, a third survey was conducted among the School's teachers on the importance of a subset of these competencies and the possibility of developing them in their courses. The mapping exercise confirmed the presence of the competencies in the syllabuses; however, the employer survey revealed gaps in the required proficiency levels of the most important skills. The results of alumni and teachers also provided information on the quality of the degree programs and are useful in validating employers' opinions. In addition, information was obtained from the teacher's survey in order to draw up the map of competencies for each program.

KEYWORDS

CDIO syllabus, program assessment, stakeholders, employers, alumni, CDIO Standards: 2, 12.

INTRODUCTION

Training an engineer requires multiple competencies that must be used simultaneously. However, a common problem in engineering education has been the lack of alignment between graduate attributes and the skill as well as competency requirements of stakeholders such as employers, professional and other regulatory entities (see, for example Prados, Peterson and Aberle, 2001; Crawley et al, 2007; Lover at al, 2011; Kolmos and Holgaard, 2019). Some primary consequences of this lack of alignment include graduate unemployment, difficulty in attaining professional certification and the necessity of employers to invest in additional training to make their graduate employees able to discharge their functions. Responsive programmes around the world have attempted to remedy this problem by using the results of stakeholder consultation as a way of either validating the programme learning outcomes of engineering degrees (May and Strong, 2006; Khoo, Zegwaard and Adam, 2020).

The CDIO syllabus provides a not only a framework for specifying the skills and competencies required of engineering graduates. Standard 2 of the syllabus requires a CDIO compliant engineering programme to have, as learning outcomes, a detailed specification of the personal, interpersonal, product and system building skills that have been validated through a process of stakeholder consultation (Malmqvist, Edstrom, Gunnarson, Ostlund, 2005).

Edwards, Sanchez-Ruiz and Sanchez-Diaz (2009) observed that Spain lagged other countries in adopting an explicit competence-based approach to curriculum design. Fuentes Del Burgo and Navarro Astor (2016) used a qualitative study of 34 Spanish building engineers to identify gaps between graduate attributes and employer requirements in building engineering. To the best of our knowledge, no study has investigated the views of multiple stakeholders across different engineering disciplines in Spain.

Standard 12 address the need of "a system that evaluates programs against the twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement". The goal of this study was to conduct an initial assessment of the alignment between the learning outcomes of the different engineering programs at the University of Navarra against the CDIO syllabus. The objective of this assessment is to identify competence gaps that can be addressed through programme improvements in order to meet the expectations of not just the employers but also alumni and internal stakeholders such as faculty members. This study is important in providing a cross-disciplinary snapshot of the desired skills by employers and graduates in engineering. It will be the basis for decisions made about the programs and continuous improvement plans. The study also provides evidence on which curriculum adjustments can be made by other engineering education providers in Spain.

The rest of the paper is structured as follows. A brief description of the CDIO syllabus which formed the basis of the competencies that were evaluated are presented. This is followed by a literature review which places this study within the context of other stakeholder studies in engineering education, followed by a description of the methodology employed in this study. In the results section we summarize the main findings obtained from the surveys followed by a brief discussion of the results and conclusions derived from the study.

THE CDIO SYLLABUS

The conceive-design-implement-operate (CDIO) was developed in the late 1990s to address the gap between engineering education and professional practice (Crawley, 2001). It sought to answer the question of what the full set of knowledge, skills, and attitudes of engineering graduates must be (Edstrom and Kolmos, 2014). These answers formed the basis for a curriculum development process that sought to produce graduates proficient in technical knowledge and reasoning, with the personal and professional skills and attributes required of an engineer. This graduate is a team worker with strong communication skills, who is also able to conceive, design, implement, and operate engineering systems (Crawley, 2001; Crawley, Malmqvist, Ostlund, and Brodeur, 2007; Crawley et al., 2014).

The components of the syllabus are the result of a systematic process of soliciting and harmonizing multiple stakeholder inputs of both the educational process and outcomes. The graduate competency descriptions that are created from a synthesis of the stakeholder inputs become the purpose of the degree program, resulting in an education process and outcomes that are responsive to stakeholder needs

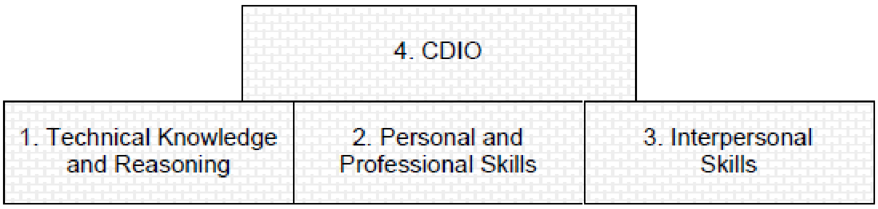

Figure 1. Components of the CDIO syllabus. Source: Crawley, 2001

Figure 1 shows the components of the CDIO syllabus which can be decomposed into different levels of detail.

ENGINEERING STAKEHOLDER STUDIES

The CDIO process was an attempt to address the gap that was identified between engineering curricula structure and the needs of stakeholders such as employers, accreditation agencies, the universities and alumni. The outcomes of the process, the CDIO syllabus described above, was the result of the codification of industry requirements, validated by a multiple stakeholder study (Crawley, 2001). Several other authors have also performed stakeholder studies for engineering education.

Khoo, Zegwaard and Adam (2020) used focus group discussions and surveys to explore employer and academic staff views of engineering graduate competencies in New Zealand at the time of the study and in in ten years. They found teamwork, written communication, problem solving, oral communication, and interpersonal relationships currently important for employers. May and Strong (2006) focused on the gap between employer needs and Canadian graduate attributes in engineering design as the latest contribution to years of similar studies in North America. They compared incoming and exit interviews of engineering students in engineering capstone courses in order to assess if any changes occur in knowledge, skills and attitudes as a result of the final design capstone course. In addition, alumni and industry representatives were surveyed on similar items concerning the engineering design skills of Canadian students of multiple engineering disciplines. Employers complained about the absence of problem solving, communication, business and teamwork skills. Grant and Dickson

(2006) compared recent graduates´ self-assessment of their proficiency in specific personal skills with their ranking of the importance of the same skills at work: teamworking; problem solving; numeracy and IT skills; self-learning. Not surprisingly, skill deficits were identified, necessitating curriculum modification recommendations for the chemical engineering degree in the University of Strathclyde in Scotland.

In Spain, a similar study was undertaken by Fuentes Del Burgo and Navarro Astor (2016). However, it covered only 34 building engineers working as site managers in a particular region of Spain. This study found a gap between a Spanish engineering curriculum dominated by abstract engineering principles with few applications and employer requirements. Prior to that, Edwards, Sanchez Ruiz and Sanchez Diaz (2009) discussed the importance of competence-based education as the basis of engineering education design. Key competencies identified by employers for this purpose include problem solving, decision making, as well as planning, coordination and organizing. However, this study was also restricted to one program – electronic engineering. Nevertheless, the argued for future multi-stakeholder studies involving academics, students, alumni and employers.

The existing Spanish studies either cover a single engineering discipline, or a single set of professionals in a specific activity, i.e., building site management. The rest of engineering practice and the various engineering disciplines have been omitted. It was therefore important to pursue a broader stakeholder study covering a multiplicity of engineering skills contained in the CDIO syllabus to serve as a guide for engineering educators in Spain. The key research question therefore is: what is the relative importance of the core and optional competencies contained in the CDIO syllabus?

METHODOLOGY

To address this question, a multi-stakeholder study was implemented using questionnaires addressed to employers, alumni, and teachers as units of analysis. Pinsonneault and Kraemer (1993) characterised survey research as designed to produce quantitative descriptions/analyses of target populations, through structured questions the answers to which constitute the data to be analysed. As it is usually impractical to collect data about the entire population, surveys are designed to collect information about a subset of the population in a way that allows the analyses to be generalisable. For these reasons, the authors chose to employ a questionnaire survey as the primary means of data collection.

26 competencies were chosen based on a combination of items from the CDIO syllabus and additional skills that were being taught at Tecnun for years through a personal coaching program (Lleo, A. et al., 2018). A brief description of each competence was included in the surveys. Table 1 shows the competencies assessed in the questionnaire, grouped in six categories for employers, alumni and faculty.

Table 1. Skills covered for employers, alumni and faculty

		Employers and alumni	Faculty
1. Technical skills			
1.1	Technical knowledge.	x	
1.2	Problem solving	x	x
1.3	Conducting experiments and research	x	
1.4	Global vision	x	x
2. Personal skills			
2.1	Decision making	x	x
2.2	Emotional balance	x	x
2.3	Self-knowledge	x	x
2.4	Motivation and enthusiasm	x	x
2.5	Effort capacity	x	x
2.6	Time management	x	x
3. Interpersonal skills			
3.1	Social skills	x	x
3.2	Communication	x	x
3.3	Communications in English	x	x
3.4	Conflict management	x	x
3.5	Teamwork	x	x
4. Business vision and entrepreneurial initiative			
4.1	Creativity	x	
4.2	Initiative	x	x
4.3	Opportunities identification	x	
4.4	Business vision	x	x
5. Social responsibility and global perspective			
5.1	Integrity	x	x
5.2	Professional behavior	x	x
5.3	Sustainability	x	
6. Orientation to results			
6.1	Requirements and planning	x	
6.2	Technical design	x	
6.3	Implementation	x	
6.4	Operation	x	

Employers survey

Tecnun has an Advisory Board made up of 32 companies and institutions with which it maintains collaboration agreements to review, in a joint and structured way, the quality of engineering training in order to improve the competency profile of graduates and its adaptation to the labour market. A total of 51 companies were chosen based on several criteria: all those on the Advisory Board had to be included, they had to cover a wide range of sectors, and all of them had to include a representative number of Tecnun graduates. It was also decided to include some consulting firms even though they were not on the Advisory Board because they hire Tecnun students.

The survey had two parts. In the first part the employees were asked to grade with a five-point Likert scale the importance given to these competencies in the profile of an engineer (1 represented "not important" and 5 represented "very important").

In the second part, the respondents had to evaluate Tecnun engineers in these competencies. The NIH Proficiency Scale[1] (National Institutes of Health, 2019) was used, which is an instrument to measure one's ability to demonstrate a competency on the job. The scale ranges from proficiency levels 1-5. Each level in the proficiency scale had a detailed description to help identify the employee's level of proficiency.

1. Fundamental Awareness (basic knowledge - understanding of basic concepts and techniques)
2. Novice (limited experience - level of experience acquired in a classroom and / or experimental settings or as an apprentice on the job)
3. Intermediate (practical application - able to successfully complete the tasks of this competence as requested. Expert help may be required from time to time, but you can usually perform the skill independently)
4. Advanced (can perform the actions associated with this competence without help)
5. Expert (recognized authority - can provide guidance, troubleshoot, and answer questions related to this area of expertise and the field in which the skill is used)

Alumni survey

The questionnaire sent to the alumni dealt with the same competencies as that of the companies. They were asked to rank the level of competence achieved throughout their undergraduate studies. As in the second part of the employer's survey, the NIH Proficiency Scale was used. The questionnaire was sent to 387 alumni that finished his degree between 2016 and 2020.

Faculty survey

Once the evaluation of the employers and alumni were collected, the committee analysed the data in order to specify improvements and define the next steps to be taken. We selected those competencies in which there was a greater gap between the importance given by the companies and how our students were doing in those competencies (either because the companies or the Alumni themselves thought so). Therefore, out of the 26 initial competencies, 17 were selected to continue with the analysis (Table 1).

Since faculty were going to be one of the main agents in achieving the objectives that were set, the committee thought it would be important to listen to their opinion. Moreover, although all members of the School of Engineering were aware of Tecnun's recent incorporation to the CDIO, the professors were not yet familiar with it, so it was a good opportunity to start getting to know this approach.

Teachers conducted a two-part survey. In the first part, as in the case of companies, they were asked to rate with a five-point Likert scale the importance of each competence in the professional life of an engineer. In the second part, they were asked to indicate whether

[1] https://hr.nih.gov/working-nih/competencies/competencies-proficiency-scale

learning outcomes related to these competencies could be included in the subjects they teach. In this way we collected practical information for the establishment of objectives for the improvement of the programmes. In this work, we do not analyse the results of the second part of faculty survey.

RESULTS

The results obtained from the three surveys are summarized in Table 2. It shows the mean value (and standard deviation) for each skill and survey.

Table 2. Responses of Employers, Alumni and Faculty Teachers.

Skill		Importance of skill		Level of proficiency	
		Employer	**Faculty**	**Employer**	**Alumni**
1. Technical skills					
1.1	Technical knowledge.	4,105 (0,658)		4,105 (0,567)	3,800 (0,806)
1.2	Problem solving	4,789 (0,419)	4,838 (0,406)	3,947 (0,524)	4,100 (0,664)
1.3	Conducting experiments and research	3,737 (0,991)		3,421 (0,507)	3,600 (0,907)
1.4	Global vision	4,579 (0,507)	4,426 (0,577)	3,421 (1,071)	3,971 (0,751)
2. Personal skills					
2.1	Decision making	4,632 (0,496)	4,441 (0,627)	3,421 (0,902)	3,929 (0,773)
2.2	Emotional balance	4,211 (0,631)	4,044 (0,848)	3,316 (0,582)	3,943 (0,887)
2.3	Self-knowledge	4,000 (0,745)	4,044 (0,775)	3,105 (0,737)	3,843 (0,844)
2.4	Motivation and enthusiasm	4,368 (0,597)	4,176 (0,640)	3,895 (0,875)	4,114 (0,924)
2.5	Effort capacity	4,526 (0,697)	4,471 (0,581)	4,000 (0,745)	4,443 (0,744)
2.6	Time management	4,421 (0,607)	4,603 (0,572)	3,947 (0,621)	4,029 (0,878)
3. Interpersonal skills					
3.1	Social skills	4,158 (0,602)	3,912 (0,702)	3,368 (0,831)	4,043 (0,853)
3.2	Communication	4,263 (0,872)	4,353 (0,681)	3,368 (0,761)	3,886 (0,878)
3.3	Communications in English	4,579 (0,607)	4,250 (0,672)	3,737 (0,806)	3,843 (1,013)
3.4	Conflict management	4,158 (0,765)	4,162 (0,699)	3,316 (0,885)	3,886 (0,793)
3.5	Teamwork	4,579 (0,507)	4,529 (0,629)	3,842 (0,898)	4,357 (0,663)

4. Business vision and entrepreneurial initiative					
4.1	Creativity	3,895 (0,809)		3,474 (0,697)	3,557 (0,924)
4.2	Initiative	4,158 (0,765)	3,750 (0,930)	3,421 (0,692)	3,757 (0,885)
4.3	Opportunities identification	3,895 (0,809)		3,474 (0,905)	3,729 (0,922)
4.4	Business vision	4,053 (0,970)	3,574 (0,880)	3,211 (0,918)	3,514 (1,067)
5. Social responsibility and global perspective					
5.1	Integrity	4,684 (0,478)	4,735 (0,559)	4,263 (0,562)	4,457 (0,801)
5.2	Professional behavior	4,368 (0,597)	4,412 (0,647)	4,000 (0,745)	4,443 (0,704)
5.3	Sustainability	3,684 (0,820)		3,474 (0,612)	3,971 (0,841)
6. Orientation to results					
6.1	Requirements and planning	4,105 (0,809)		3,737 (0,806)	3,971 (0,874)
6.2	Technical design	3,526 (0,697)		3,842 (0,688)	3,757 (0,901)
6.3	Implementation	3,842 (0,602)		3,632 (0,496)	3,743 (0,838)
6.4	Operation	3,737 (0,733)		3,684 (0,582)	3,771 (0,778)

A total of 20 employers responded to the survey, a response rate of 39 percent. Of the 20 companies, 9 were industrial companies, 6 were consulting firms, 2 were research centres: one technological and the other health, 1 was an engineering company, 1 was a business group and 1 was a foundation. From these survey responses we observe that:

- The respondent companies consider all the competencies included and described in the questionnaires to be important: only seven of them are rated below 4 with the average lowest rating being 3.526.
- Regarding the observed level of proficiency of the skills of our graduates, all of them reach a score bigger than 3.0 meaning employers believe TECNUN graduates to be capable of practical application of not just engineering tools and concepts but also all the other skills.
- The skills that companies consider most important (with a score higher than 4.5) were found to be Problem solving, Integrity, Decision making, Global vision, Communication in English, Teamwork and Effort capacity. In these competencies our graduates are rated above 3.4, although only in Integrity and Effort reach a score greater than or equal to 4.0.
- Our graduates are rated with an average greater than or equal to 4.0 in four competencies: Integrity, Technical knowledge, Effort capacity and Professional behavior. The worst ratings are in Self-knowledge, Business vision, Conflict management, Emotional balance, Social skills and Communication, all with a score between 3.0 and 3.4. There is no overlap between the latter and those considered most important by the companies.

For the survey conducted administered on our graduates, the number of responses was 71, a response rate of 18 percent.

The distribution of respondents' year of completion of studies was as follows: 8 in 2016, 14 in 2017, 21 in 2018, 14 in 2019 and 14 in 2020. Table 3 shows the distribution of the alumni who responded to the survey according to degrees. Respondents were working in the following sectors: Industry (automotive, railway, energy solutions, construction, etc.) (28), Medical or pharmaceutical industry (9), Consultancy (12), Software developers (4), University (9), Research (2), others (7).

Table 3. Degree of Alumni Respondents

Degree	**Number of respondents**
Industrial Technologies Engineering	28
Mechanical Engineering	13
Electrical Engineering	1
Industrial Design Engineering and Product Development	2
Industrial Management Engineering	8
Telecommunication Systems Engineering	6
Biomedical Engineering	13
Total	71

In this case it can be seen that

- The evaluation of the competencies ranges between 3.4 and 4.5 which suggests that in general the alumni value themselves higher than their employers do: while in employers' survey the number of skills with a level of competence with a mean score greater than 4.0 is four, for graduates' survey that number is eight.
- The graduates' self-evaluation matches the companies' evaluation in the areas of Integrity, Capacity for effort and Professional behavior as strengths. However, in the case of Technical knowledge, which the employers value with 4.105, the graduates do not feel so confident and value their level of competence of this skill a bit lower, with an average of 3.8.

Regarding the survey conducted by faculty, a total of 68 teachers responded to the survey, a response rate of 46 percent. Faculty, viewed Problem solving, Integrity, Time management and Teamwork as the most important competencies for engineering graduates (score higher or equal than 4.5). All of them coincide with those most highly rated by companies, except for Time Management, which, although not among them, had a good score (4.421).

In view of the results, four competences were selected which are very important for companies and teachers and yet our students do not reach the desired levels. These competences are Problem solving, Decision making, Global vision and Teamwork.

CONCLUSIONS

In this paper we assessed the alignment between the learning outcomes of the different engineering programs at the Engineering School of the University of Navarra against the CDIO syllabus using a multi-stakeholder survey. Data from different stakeholders were collected to assess the relative importance of competencies outlined in the modified CDIO syllabus, the level of competence our graduates reach upon completing their undergraduate studies, as well as alumni self-evaluation of their own proficiency level with respect to the same skills and competencies.

Even though the employer and alumni surveys confirmed the presence of competencies in the study programs, in general, graduates have not attained the best ratings in terms of the level of proficiency in the skills considered most important by employers. This is consistent with findings by Fuentes Del Burgo and Navarro Astor (2016), May and Strong (2006), Grant and Dickson (2006). This points to the need for changes in the programs, provides guidance on the direction in which further work needs to be done and helps to set concrete targets for improvement in the teaching-learning process of these competencies.

A surprising finding is the relative importance of English language as necessary skill by Spanish employers. A possible explanation could be the international scope of activities by Spanish engineering employers as well as the dominance of the English language in international business.

The fact that companies and teachers agree on the competencies they consider most important is a positive factor. Changes to be made to programs can be proposed by the commission in charge of the CDIO implementation process, but teachers should also be involved to some extent in the process of defining improvements, as they will ultimately be the ones who will have to implement them in the teaching of their subjects.

Our findings provide valuable feedback on the skill requirements of multiple stakeholders across multiple engineering subdisciplines. This should be useful for other universities across Spain. At the same time, the number of respondent companies and alumni may not be representative of the entire engineering sector in Spain. Further studies involving a larger employer and alumni list across different universities could improve the validity of findings from a similar study.

LIMITATIONS

Some of the findings could be complemented with follow-up qualitative studies. Although valuable results were obtained from the alumni survey, the response rate was low (18%). The number of companies interviewed was not high (20 companies). The main reason was that the companies interviewed needed to get to know Tecnun alumni closely enough to be able to assess their proficiency in the specified skills and competences. Future research could separate the two parts of this survey, expanding both the sample of companies in the part corresponding to the assessment of the importance of the competences and engineering alumni from other universities.

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ANALYSIS OF STUDENTS' PERFORMANCE IN CAPSTONE PROJECTS

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ABSTRACT

After 10 years of having implemented the design-build project courses path according to the CDIO standard 5 at the ICT Engineering School of UPC in Barcelona, we have carried out an analysis of the students' performance in the 12 ECTS capstone project course performed in the 4th year of the bachelor and in which most of the challenges are set by external companies and institutions. In these 10 years, 1440 students have participated in 138 different projects. The course is called Advanced Engineering Project (AEP). This conference communication presents the results of the analysis of the individual students' performance according to different project features. We have considered the challenge source, (internal/external), the promoter type, the promoter involvement, for external promoters, the contact person profile, the result type, the degree of finalization, the size of the team and the term (Fall /Spring). The chosen performance index used for this study is the individual assessment result, which is quite integrative. About the Internal/External character of the promoters, there is a significant difference ($p<0.001$) in the AEP average of the individual marks of 0.42 points between projects with external promoters (8.68) and projects with internal promoters (8.26). Considering the type of promoters' significant differences ($p<0.05$) are found between projects proposed by companies and both the internal projects proposed by teachers and by research groups. The projects in which the main component was ideation or more ideation than technical performed better than the mostly technical projects (up to 0.92 points in a scale of 10, $p<0.001$). We have not found any significant differences due to the team size or academic term (Fall or Spring). The reasons for the observed differences are probably due to a different degree of motivation and also to a higher pressure when an external stakeholder is involved, although the differences are smaller than 1 point in a 10 points scale in all cases.

KEYWORDS

Capstone Project, Industry Involvement, Stakeholders, Performance, Standards: 5, 11.

INTRODUCTION

The demands for future engineers' competences have been highlighted since de past decades, both from industry and institutions like ABET (2017), CDIO initiative (Crawley et al., 2011, 2014), NAE (2004) and ENAEE–EUR-ACE® (European Network for Accreditation of Engineering Education, 2020), among others. What is expected from future graduates is far more than technical skills or "hard" engineering knowledge. Even though this is fundamental, it is not enough. Pippola et al., 2012 state that beyond having engineering core skills (which is a critical factor), it is needed to develop competences like creativity, communication, uncertainty management and business skills among others. This need of competences' development has widely been addressed from the academia by creating capstone design courses where final year students, as described by Dym et al. (2005), develop "real" project using their theoretical knowledge on a system level.

Following the CDIO framework (Conceive-Design-Implement-Operate), since 2012 at Telecos-BCN, the ICT Engineering School of UPC at Barcelona there were introduced capstone project courses named Advanced Engineering Projects (Bragós et al., 2010, 2012). It was observed that this notably improved some of the competences required by the industry (i.e.: problem solving, teamwork, project management, critical thinking, communication, among others). Beyond generic competences, it was also identified that specifically innovation related competences were also very relevant and demanded by industry and society (Lehman et al 2008) and needed to be further developed. With the aim of further developing innovation competences, in 2014, the Telecom Engineering School at UPC co-created with ESADE and IED the CBI (Challenge Based Innovation) Course, which students from UPC can take as an alternative to the "standard" capstone project (Hassi et al. 2016), working in multidisciplinary teams (engineering, design & business) to tackle complex societal challenges. and using CERN technologies. NESTA, as described by Chell & Athayde (2009) demands innovation skills like Creativity, Energy, Leadership, Self-efficacy and Risk propensity. These and other innovation competences can be developed through project-based learning and challenge-based learning (Charosky et al., 2021, Charosky & Bragós, 2021). Working with a clear project-based approach, inherently experiential (Kolb, 1984) tackling real life industry challenges or broader societal challenges, can help better equip engineering students with the skills and innovation competences demanded by the society.

It could be said that capstone projects became the standard in the past decades. They have evolved from "invented by faculty members" project topics to real industry challenges sponsored by companies or institutions (Dym et al., 2005). By working with Project-Based Learning in engineering higher education, with an active learning process and learning by doing approach (Johnson, 1999), students learn from real situations (Cazorla & De los Ríos, 1996). Cazorla et al. (2007), after 20 years of applying project-based learning in higher engineering education describe it as "the most adequate educational methodology for the development of competences, linking teaching with the professional sphere". Typically, these student projects in engineering education focus on solving a technical problem, working in non-multidisciplinary teams and following a "classical" product development approach described by Ulrich-Eppinger (2008). More recently, Challenge-based Learning has appeared as an alternative methodology to involve the real-world context in the project courses which focuses on identifying, analyzing and designing a solution to a sociotechnical problem going beyond the purely technical result. Typically, is approached in multidisciplinary teams and aims to reach "a collaboratively developed solution, which is environmentally, socially and economically sustainable" (Malmqvist et al., 2015).

There is a long tradition on capstone projects according to industry specifications and having external institutions as projects' stakeholders in the CDIO community. Design-Build projects (CDIO standard 5) are one of the most acknowledged ways of promoting the learning of skills of groups 2, 3 and 4 of CDIO syllabus. From the very beginning of the Initiative, there have been papers describing the cooperation between academia and industry. In the 1st annual CDIO Conference, Surgenor (2005), already described the involvement of industry in capstone projects at Queen's University in Kingston, Canada. Berglund (2007) also describes a 4th year multidisciplinary capstone project with industry involvement carried out at Chalmers. Thomson (2012) compares two projects performed at Aston University with different openness degree in the starting brief and project follow-up. Hallin (2012) discusses the role of customers of both the industry and the students, which have a different time-perspective. Metjoft (2015) discusses about the double role of Industry as an enabler and receiver. Tornqvist (2015) and Einarson (2015) describe the experience at their respective universities with project courses enabled by an external organization, Demola, which facilitates co-creation projects between university students and companies, either locally or internationally. More recent references describe the initiative to involve stakeholders at program level at DTU (Nordfalk, 2018) or the review of university-Industry collaboration in Europe and Asia (Rouvrais, 2020).

In this article, we analyzed the different capstone projects developed by the students in the last 10 years, since 2012, either project-based or challenge-based and studied the results of the teams and individual students' performance according to different project features. The main research question is if the challenges involving external agents would provide better students' performance and if there are other project features which would affect this performance.

STUDY FRAMEWORK

The implementation of the design-build project courses path, according to the CDIO standard 5, was completed 10 years ago in our School. Three courses were created: Introduction to ICT Engineering (2nd year, 6 ECTS), Basic Engineering Project (3rd year, 6 ECTS) and Advanced Engineering Project (AEP, 4th year, 12 ECTS). In the first two subjects, students work in small teams (3-5 students) on challenges of increasing complexity proposed by teachers and acquire the necessary methodology to undertake the challenges of the third one, AEP, object of this study. It can be assimilated to a Product Development Project (PDP) model. In this course, bigger working groups (8-12 students) undertake the design of a complete product or service, including its business model. The requirements and specifications of the product or service are generated, the block structure and the work packages are defined and then distributed among the subgroups of 2-3 students. They must design, implement and test the subsystems, integrate them, define a business model based on the product or service and perform the sustainability analysis. In the first years (2011-2014) the challenges of the AEP projects were proposed by the teaching staff. Since then, and building in the reported results and conclusions of the work of several CDIO institutions, cited in the last by one paragraph of the introduction, external agents were gradually incorporated (Figure 1) and currently, 7 out of 10 challenges are proposed by companies, hospitals, foundations or NGOs. Some challenges are reserved each semester for strategic projects such as Formula Student Driverless, nanosatellites or 5G research. This subject is compulsory and 1440 students have passed through it who have worked in 138 different projects, being 81 of them proposed by external agents.

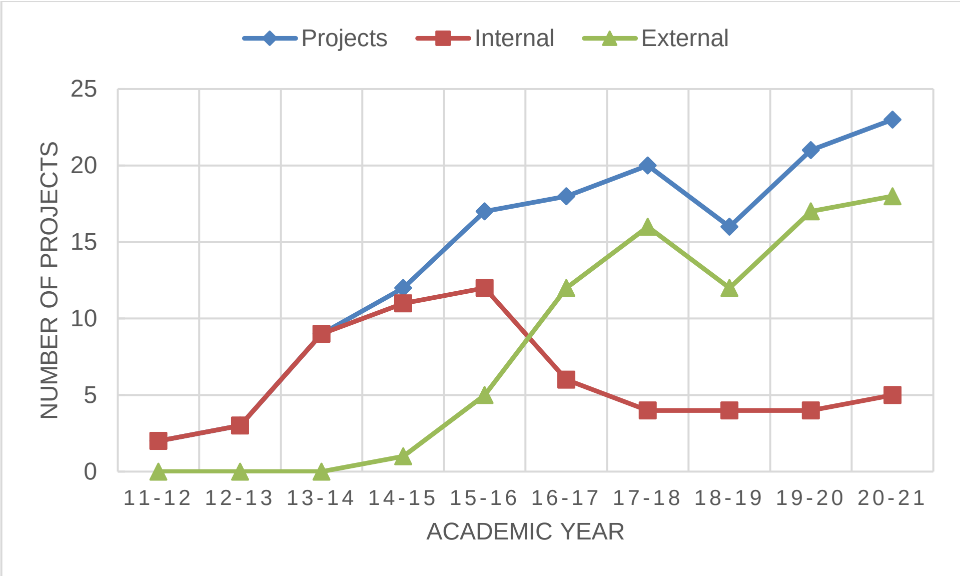

Figure 1. Time evolution of the EP capstone projects along 10 academic years (2011-2012 to 2020-2021) and type of promoters (internal/external)

Some examples of project challenges are: image processing software for rehabilitation of facial paralysis due to facial nerve injury, human-machine interface techniques for car cockpit, development of sensors for 3D printers, blockchain-based payment distribution system in the music industry or low-cost IoT sensor system for detection of irregular discharges in wastewater.

METHODS

The object of the study is the performance in the AEP capstone course project of the 1440 students that have participated in 138 different projects in the 10 years since the first implementation of AEP (academic years 2011-2012 to 2020-2021). The average team size is 9.2 students, with a minimum of 4 and a maximum of 20 but only 12 out of 161 have been smaller than 7 or bigger than 14. There are more teams than different projects because in some cases, two teams have performed two replicas of the same project. The course takes 15 weeks and is performed every term, so twice per academic year, except in the first two years.

The learning outcomes of the course are mostly the ones of the involved generic skills, most of them related with the CDIO syllabus skills group 4 (Innovation and Entrepreneurship, Societal and Environmental Context, Ability to Conceive, Design, Implement and Operate Complex Systems in the ICT Context) but also Oral and Written Communication and Teamwork. Although the individual final grade is not the only valid metric to assess the performance in the course, we have chosen it as performance index for this study because of its integrative character. According to the learning outcomes of the course, the project supervisors assign a team mark, which reflects the assessment of the process (50%) (Preliminary and Critical Design Review, team dynamics) and the final result (50%) (Solution Technical Performance, Business Idea, Final Report, Final Presentation and Video). The individual marks are obtained from this team mark after applying a triple modulation (30% max): The Supervisors' Assessment of the individual performance, the Team Leader assessment (batch of points) and the Peer Assessment using a 10 criteria rubric. Therefore, the final individual marks are quite integrative of several aspects. The average of the individual marks is 8.44 in a scale of 10, with a standard deviation of 1.17.

The features and categories which have been taken into consideration to classify the projects are displayed in Table 1:

Table 1. Project features and categories

Features	Categories and ranges
Promoter type	Internal / External
Promoter type (detailed)	Teacher / Research Group / NGO / Hospital / Company /Institution (e.g. CERN, City Council)
Promoter involvement	Sponsor/Stakeholder
Contact type	Management/Technical/User/Teacher)
Result type	ideation (1) to pure technical (5)
Degree of finalization	Incomplete , functional test, test with users (1-5)
Size of the team	4-20
Term	Fall / Spring

About the promoter type, a higher-level category (Internal/External) has been added. The two kind of promoters which belong to the University staff (Internal) are Teachers and Research Groups. The difference among them is that Research Groups propose challenges that are coherent with their research activity. They are limited to topics that are considered strategic by the School (Nanosatellites, 5G, Autonomous Vehicle, Biorobotics) as fields in which there is interest in promoting specific skills for the graduate students. On the other hand, the category "Teachers" includes projects whose challenge was defined by the teaching staff but not as a part of their research activity but trying to define real world challenges according to their technology transfer experience. This modality was mainly used in the first years, before having enough external institutions engaged. In addition to the internal/external character, other differences can be induced by the type of contact person (technical or closer to the management or a final user) or the term (semester) or the team size. The difference between sponsor and stakeholder is that the first one is more involved while the second one may just behave as an external observer.

For the statistical analysis, the hypothesis that the marks in the different feature categories are different has been tested using the t-test for comparisons between two categories and the Anova test for comparisons between more than two categories. Depending on the statistics of the data (gaussian or not gaussian, equal variance or not), the suitable kind of test (standard t-test, Welch, Mann-Whitney) was applied. In the boxplot graphs depicted in the results section, the grey box contains the 50% of the values and an inner line shows the median. Then the upper and lower tails represent the range of the 95% of the values and the outliers are marked as individual symbols. The tool used for the analysis was SigmaPlot (Systat Software Inc, UK).

RESULTS AND DISCUSSION

In this section, the results of the more representative cases are displayed and the statistically relevant differences are highlighted, discussing the possible causes when there is an identified background.

The differences among AEP marks between the two terms (Fall and Spring) are very small (0.01 points), and not significant ($p=0.157$). Considering that the students that follow the progress of their cohort perform AEP in the Fall term, we expected a higher difference. Nevertheless, the delay in the progression of students can take more than one semester and there would be diffusion in the composition of the actual cohorts.

About the possible incidence of the team size, the correlation analysis shown no correlation among the team size and the individual marks. We were expecting a kind of optimal size for the teams to generate the better results (up to the extent that the results are reflected in the mark) but apparently there is no correlation at all.

About the promoter type (Internal/External), there is a significant difference ($p<0.001$) of AEP average of the individual marks of 0.42 points between projects with external promoters (8.68) and projects with internal promoters (8.26). If we consider the detail in the type of promoters (Figure 3), the significant differences ($p<0.05$) are found between projects proposed by companies and both the internal projects proposed by teachers and by research groups. This can be due to a higher motivation in the first ones but also to a different kind of expected results. The motivational character of having external stakeholders is consistently mentioned in the reflection document that is included in the projects' final report and in the oral feedback received by the supervisors. We didn't perform, however, a systematic analysis of these reports looking for a confirmation of this hypothesis and, therefore, this conclusion can be considered speculative.

Among the external promoters, the ones that show more differences with the internal project results are the industrial or services companies. The projects for NGOs show lower results but there have been few of them and the interaction has not been as good as with other stakeholders. It has been observed that NGOs, foundations and some small companies have different expectatives than regular companies with a higher degree of professionalization. These last ones understand clearly what they can expect from a capstone project performed by 4^{th} year students and play their stakeholder role collaborating with the educative function of the course. They are more interested in having students with the suitable learning outcomes and in having more chances to hire some of them than in the project outcome. On the other hand, and despite our efforts in managing expectatives, NGOs, foundations and some small companies, even hospital departments are more interested in having a result as close to a final product as possible and this affects the interaction with the students and their motivation and commitment.

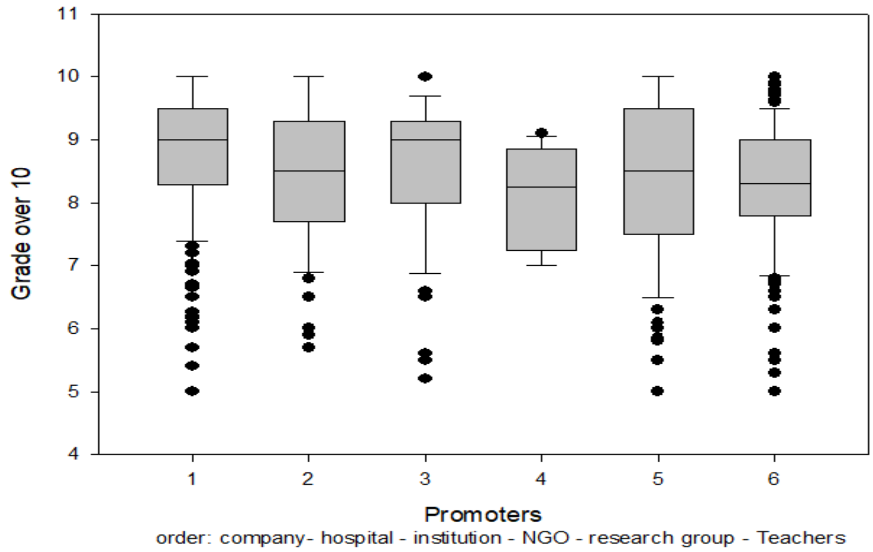

Figure 2. Boxplot of the individual AEP marks according to the challenge promoter type.

If we consider the type of results, it can be seen in Figure 3 how the more abstract projects obtain higher average marks than the purely technical ones. The categories “only ideation” (9.26) and “more ideation than technical” (9.09) provide significant higher marks than “more technical than ideation” (8.80) and “purely technical” (8.34). The projects which include some kind of creative phase at the beginning or which have more degrees of freedom obtain better marks than the projects that are purely technical, which start from requirements and specifications already set. Very likely, if the students feel themselves as owners of the solution, the motivation would be higher.

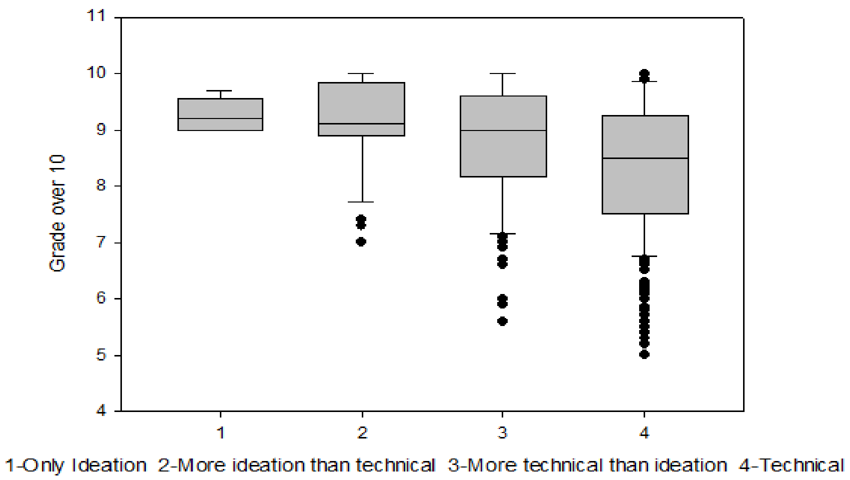

Figure 3. Boxplot of the individual AEP marks according to the type of project results

Even if the promoter is an external institution, the contact person or persons are in some cases engineers (technical) and in some others managers and even users. There are significant differences among some of them (Figure 4). The cases in which the contact person was a pure manager, the marks have been lower than the others although the high dispersion in this category limits the statistical significance of the differences. The combination of management/user (typical of hospitals) shows to be significantly higher (9.1 points) than most of the others and, as it could be expected, the results when external technical staff are involved (8.7), are significantly higher than when the stakeholder is a teacher (8.3) ($p<0.001$). Again, having an external stakeholder is a key factor.

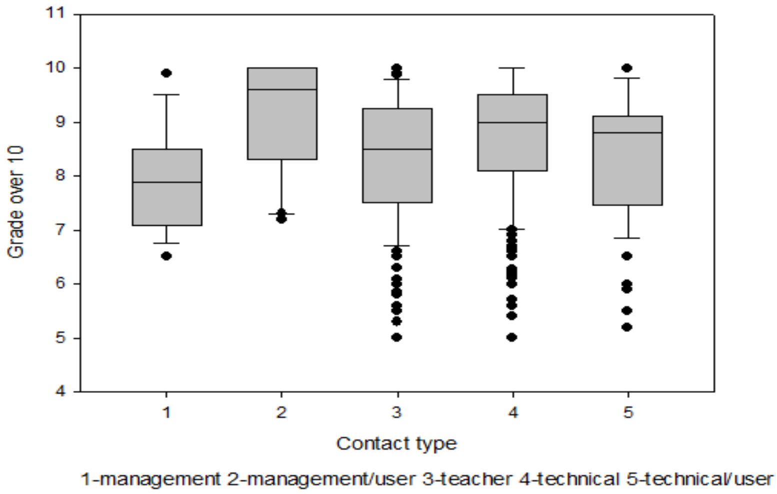

Figure 4. Boxplot of the individual AEP marks according to the contact person type

About the finalization degree (Figure 5), from the few projects that have not been able of integrating the parts to projects tested with real users, the average marks show an ascending progression with significant differences ($p<0.05$) in all cases.

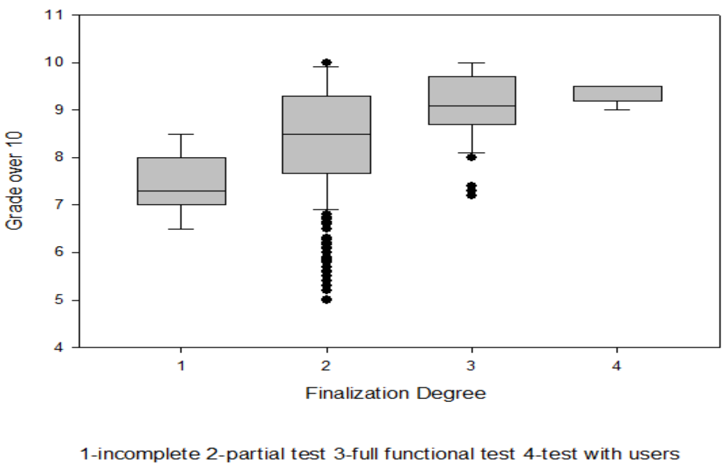

Figure 5. Boxplot of the individual AEP marks according to the project finalization degree.

The finalization degree can be due to incidences or to projects that start at a different readiness level and then are expected to reach different finalization degrees. We acknowledge that the Finalization Degree cannot be considered an independent variable but we found that the projects which are able to provide full functional tests and even tests with users generate a more comprehensive experience which would drive to better results, again probably due to a higher motivation than the projects that design and build a system or service which is not complete.

In courses such as these, the team supervisor may play a substantial role in the team's results, both because his/her ability to motivate the students' team and also because of his/her personal role as evaluator. There are more than 25 supervisors involved in this course, among the two terms. They work in pairs (each project has two supervisors) and, at least one of them has been involved in internal projects before supervising projects with external stakeholders. Therefore, they may appreciate the differences and take them into account for the assessment. Every term, before publishing the final assessment, there is a coordination activity to discuss the marks assigned to each team/project in order to justify the fairness of the mark differences among them.

CONCLUSIONS

The more significant differences between PAE marks according to the PAE project features are that there is a difference of 0.42 points between projects with external promoters and with internal promoters probably due to a higher motivation in the first ones, being the industrial or services companies the external institutions which provide better results. The projects which have more degrees of freedom obtain better marks than the projects that are purely technical, which start from requirements and specifications already set. Also, the projects which are able to generate a testable result and in which the interaction with the students is done by professionals with a technical/user profile or management/user profile obtain better results also probably due to a higher motivation and engagement. Nevertheless, these differences are not really big, less than one point on a scale of 10 in all cases, which would mean that the internal projects are also playing a good role as learning experience.

According to the students' feedback, the reasons for the observed differences are probably due to a different degree of motivation and also to a higher pressure when an external stakeholder is involved, although the few internal projects are carefully chosen and the topics are quite appealing.

The AEP course was the first capstone project course we implemented in our curricula, more than 10 years ago. Therefore, it has been a field for prototyping and testing active teaching and learning modalities. In the last three years, we started new bachelors (Data Sciences and Engineering and Electronics Engineering) and a Master (Urban Mobility) and we introduced that kind of courses in them, with external stakeholders from the very beginning as a requirement.

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ACADEMIC DEVELOPMENT SUPPORT FOR IMPLEMENTING CDIO

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ABSTRACT

Inducing changes in the management of education can be challenging, especially in the field of engineering. In the School of Engineering in Tallinn University of Technology (TalTech) being a member of the International Society for Engineering Pedagogy (IGIP) and CDIO, the Centre for Learning Excellence was established recently to provide academic staff with more support in teaching and learning development. In the last decade, the IGIP curriculum for engineering educators has been available for all teaching staff.

Therefore, in this paper, it is evaluated how the newly updated IGIP curriculum covers basic pedagogical knowledge used in the CDIO framework. A survey was conducted for teachers of the Product Development and Robotics programme, to evaluate the current state before starting to implement CDIO principles. One teacher from the programme shared his vision of support needed from a teacher who is planning to implement CDIO. The aim of this paper is to analyse what is the current situation in teacher training in TalTech and what kind of specific support is needed by the teachers who start implementing the CDIO framework in their courses. Three different analysis methods pointed out various aspects that should be considered in planning how to support teachers in the process of implementing CDIO.

KEYWORDS

IGIP curriculum, Faculty Development, Course Development, CDIO implementation, Standards: 3, 7, 8 and 10

INTRODUCTION

Graduates of Tallinn University of Technology (TalTech) are valued highly for their professional knowledge. The industry expects more independence in analysing and solving real engineering problems. Therefore, TalTech's School of Engineering sought for experiences and solutions of making engineering education more connected with real life. The CDIO Initiative has created a framework that provides students with an education that sets fundamentals of engineering to the context of Conceiving - Designing - Implementing - Operating real-world systems and products. The CDIO Network is a worldwide community with knowledge and a wide variety of well-working examples in engineering education. The first study programme with interest and readiness to start using CDIO principles in TalTech was bachelor´s programme Product Development and Robotics. The programme director initiated collaboration with Estonian Centre for Engineering Pedagogy (ECEP) to provide teachers with needed help when implementing the framework. ECEP, with International Society for Engineering Pedagogy (IGIP) accreditation since 2003, has been the prime provider of pedagogical training in TalTech for years. In the last decade, the IGIP curriculum for engineering educators has been available for all teaching staff.

Up to 2020, pedagogical training in TalTech has been provided centrally through the personnel department. Changes in determining the role of the University in society has led to understanding that there is a need for a field-specific approach for course development. According to the Strategic Plan 2021-2025, TalTech launched school-based didactics and pedagogy centres to enhance and improve the quality of teaching. The School of Engineering established the Centre for Teaching and Learning Excellence, where teachers get support with analysing and developing their courses, inspiration from colleagues, and the latest studies of engineering education. The School of Engineering sees great potential in implementing the CDIO framework to provide students with real-life engineering experiences. The Centre for Teaching and Learning Excellence should become a beneficial collaborator for teachers and program directors who start engaging CDIO principles in their courses and programs.

Dirksen (2015) in her book "Design for how people learn" empathizes the need to understand the gap between learners' current knowledge level and the expected level in order to professionally succeed. Most training programs start to solve the knowledge gap, but there may also be a gap in motivation, skills, habits, and/or environment. Felder and Brent (2016) have brought out the problem that sometimes teachers have to teach skills they haven't learned nor experienced and are not sure in their competencies in those skills. Especially integrating professional skills in core courses may be a problem accompanied by the fear of using new instructional methods that may take too much time away from the main subject.

Collaborators of CDIO Network have suggested methods on how to support teachers starting to implement CDIO principles in their courses. Usage of the mentoring approach has been proved to work successfully as a teaching competence enhancement model (Loyer & Maureira, 2014); (Papadopoulou, Bhadani, Hulthén, Malmqvist, & Edström, 2019). Teacher training programs should take a holistic approach with CDIO case studies, active engagement, and direct usefulness to get teachers to know and use active learning methods (Papadopoulou, Bhadani, Hulthén, Malmqvist, & Edström, 2019); (Kontio, 2009). Using a learning-centered approach in training programs may help teachers to overcome uncertainty and provide new viewpoints for the role of a teacher and tools for assessment with active teaching and learning (Kontio, 2009).

Therefore, a compliance analysis of IGIP curriculum and CDIO standards was performed to understand how the IGIP curriculum covers the pedagogical competencies that support implementing CDIO principles in TalTech. A survey was conducted among teachers of the Product Development and Robotics program, to map how teachers evaluate their courses before starting to implement CDIO principles. Most of the teachers in the program have participated in one or two CDIO workshops. One teacher conducted an analysis of his challenges (described in detail in Case-study section) with starting to implement CDIO principles in his course and what kind of support teachers may need when developing their courses. He has participated in CDIO workshops and several courses from the previous IGIP curriculum. Based on the results, the current situation was identified and will be used for planning specific training and individual support.

The aim of this paper is to understand the current baseline and potential gaps in teacher training in TalTech and the specific support needed by the teachers who start implementing the CDIO framework in their courses.

COMPLIANCE ANALYSIS OF IGIP CURRICULUM AND CDIO STANDARDS

International Society for Engineering Pedagogy (IGIP) was established in 1972 in Austria. IGIP aims to develop practice-based curricula, engineering pedagogical competencies, contemporary methods for teaching and assessment for engineering education. IGIP accredits training centres for engineering pedagogy at institutions delivering courses conforming with the IGIP prototype curriculum with a minimum amount of 20 ECTS credits. In 2021 IGIP reaccredited TalTech updated in-service micro-credentials program for engineering faculty continuing education in engineering pedagogy (24 ECTS). IGIP maintains a list of accredited individual engineering educators who are awarded the title „International Engineering Educator" certifying IGIP's required level of engineering pedagogical competencies for effective teaching engineering. (International Society for Engineering Pedagogy, 2022)

Engineering educators who redesign their courses for the implementation of CDIO principles need pedagogical competencies and students participating in newly redesigned CDIO courses need supervision and support in reflection and self-regulation. The newly updated program gives the needed competencies for engineering faculty for effective teaching and supervision.

In the framework of the present research, a compliance analysis was carried out to analyse whether the updated pedagogical program meets the CDIO standards (CDIO Standards 3.0, 2022), thus supporting the smoother implementation of CDIO principles. In Appendix 1 the structure of the updated TalTech engineering-pedagogical curriculum is presented.

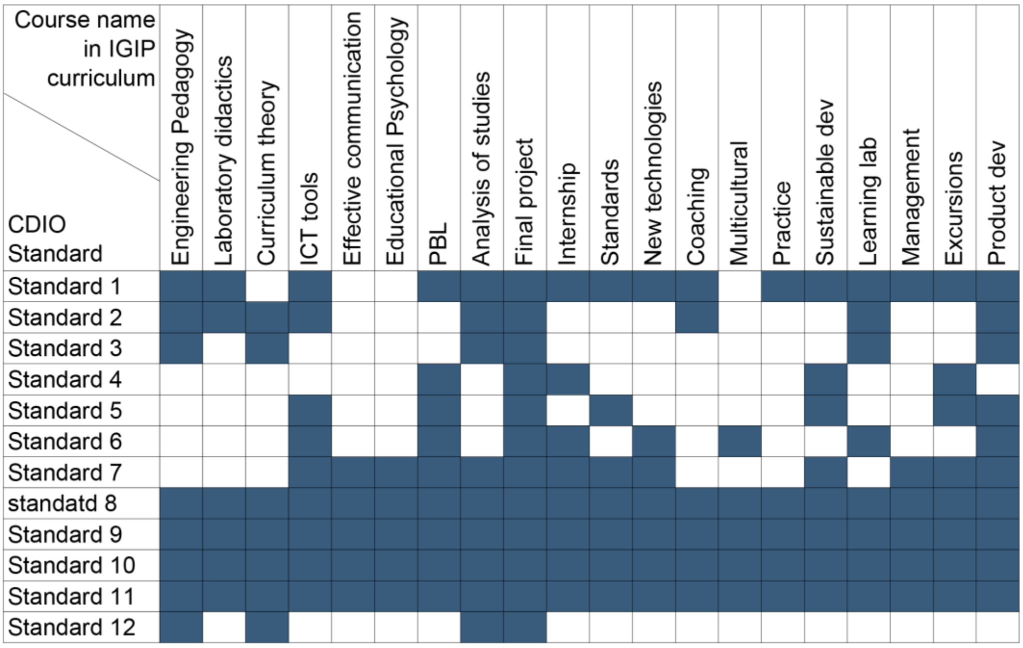

Figure 1. Results of compliance analysis of IGIP curriculum courses that include guiding principles of CDIO Standards

According to the compliance analysis presented in Figure 1, all modules of the engineering-pedagogical program support the implementation of *CDIO Standard 1 "The Context"*, Standard 8 - "Active Learning", Standard 9 - "Enhancement of Faculty Competence", Standard 10 - "Enhancement of Faculty Teaching Competence", Standard 11 - "Learning Assessment" are guaranteed by all subjects of the curriculum.

CDIO Standard 2 "Learning Outcomes" is ensured by following courses of the curriculum: "Engineering Pedagogy", "Laboratory Didactics", and "Curriculum Theory and Practice", "ICT tools supporting interactive e-learning", "Analysis of the study process. Ethical problems in education", "Final Project", "Coaching and Mentoring", "Learning Lab" and "Product Development and Innovation".

CDIO Standard 3 "Integrated Curriculum" is covered by courses "Engineering Pedagogy", Curriculum Theory and Practice", "Analysis of the study process. Ethical problems in education", "Final Project", "Learning Lab" and "Product Development and Innovation".

Principles of the *CDIO Standard 4 "Introduction to Engineering"* are covered by the learning outcomes of courses "Final Project", "Internship in a company. Cooperation projects with partners", "Problem-based and meaningful learning ", "Sustainable development", and "Excursions to Companies", "Product Development and Innovation".

CDIO Standard 5 "Design-Implement Experiences" is implemented in courses "Problem-based and meaningful learning ", "Final Project", "Standards and Quality", "Sustainable Development", "Excursions to Companies", and "Product Development and Innovation".

CDIO Standard 6 "Engineering Learning Workspaces" is ensured by learning outcomes of the courses "ICT tools supporting interactive e-learning", "Problem-based and meaningful learning", "Final Project", "Internship in a company. Cooperation projects with partners", “Standards and Quality”, “Multicultural Learning Environment”, “Product Development and Innovation” for engineering educators and “Learning Lab” for engineering students.

CDIO Standard 7 “Integrated Learning Experiences is afforded by integration learning outcomes of the courses “ICT tools supporting interactive e-learning”, “Educational Psychology and sociology”, “Effective Communication”, “Analysis of the study process. Ethical problems in education”, “Problem-based and meaningful learning”, “Final Project”, “Internship in a company. Cooperation projects with partners”, “Standards and Quality”, “New Technologies”, “Sustainable Development”, “Management”, “Product Development and Innovation”, and “Excursions to Companies”.

Standard 12: Program Evaluation is guaranteed by the courses “Engineering Pedagogy”, “Curriculum Theory and Practice”, “Final Project”, “Analysis of the study process. Ethical problems in education”.

Results of the compliance analysis of IGIP curriculum and CDIO standards present solid proof that IGIP engineering-pedagogical curriculum ensures and contributes to the effective implementation of CDIO principles by supporting engineering faculty members with needed pedagogical competencies.

SURVEY

A survey among teachers of the Product Development and Robotics programme was conducted, to map how teachers evaluate their courses before starting to implement CDIO principles.

Method

The survey consisted of 16 statements and 2 background questions. 16 statements were based on the 12 standards of CDIO. There were 2 statements for Standards 2, 6, 8 and 11, that consider several different aspects. Using separate statements allowed responders to answer according to each aspect. All statements were answered on the Likert scale, where 1 meant “disagree,” 5 meant “agree” and 0 meant “don´t know.” One question was about respondents role in the course (main teacher or assistant) and one was for comments. The survey was anonymous and conducted in Estonian. Translated survey questions can be found in Appendix 2. The online survey was sent out to 41 teachers of the Product Development and Robotics program.

Results

The self-evaluation survey was conducted by 18 (44%) teachers. All respondents marked themselves as main teachers.

Figure 2. gives an overview of the results. Standards 11, 6, 2 were evaluated highest. For Standard 2 there were two statements about learning outcomes: consistent work with learning outcomes (average 4,35) and considering feedback from stakeholders (average 4,12). Standard 6 consisted of two statements: there is a physical engineering workspace where students can evolve their knowledge through hands-on activities (average 3,78); digital learning materials are available to students all time (average 4,94). The highest rating for the second statement of Standard 6 is related to the e-support project in TalTech, where the minimum level of e-learning should be ensured in compulsory courses in I and II levels by the year 2021 (TalTech E-Learning, 2022) For Standard 11 there were two statements about

learning assessment: whether professional skills are developed during course (average 4,33) and learning outcomes are specified and understandable for students (average 4,53).

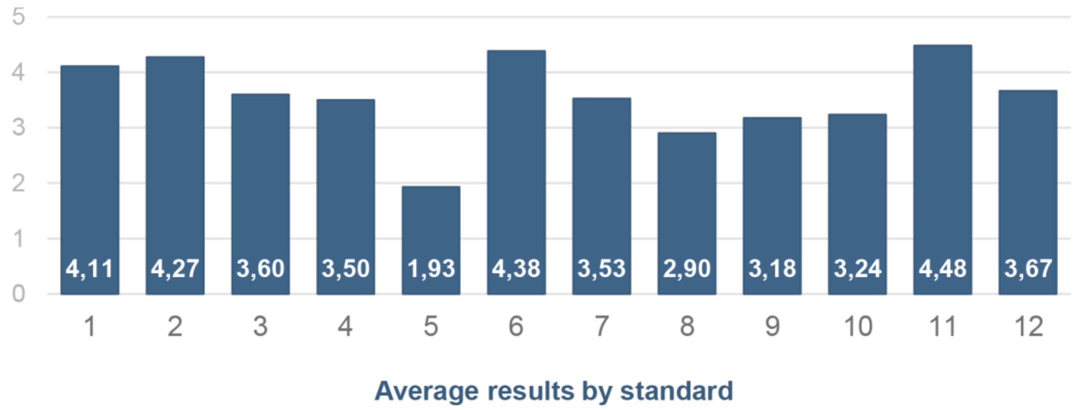

Figure 2. Overview of the survey results

Standards 5, 8, 9, 10 were evaluated lowest. In Figure 3 it is illustrated how responses were divided for each statement. Standard 5 stated that design-implement experiences are used in the course (average 1,93). It is important to take into account, that all respondents were not teachers of engineering subjects. Standard 8 (average 2,90) consisted of two statements about active learning: using active learning methods in lessons (Statement 1, average 3,40) and using peer assessment to evolve professional skills (Statement 2, average 2,40). Standard 9 stated that the enhancement of disciplinary knowledge and professional skills are well supported by the university (average 3,14). Standard 10 stated that the enhancement of teaching skills are well supported by the university (average 3,24).

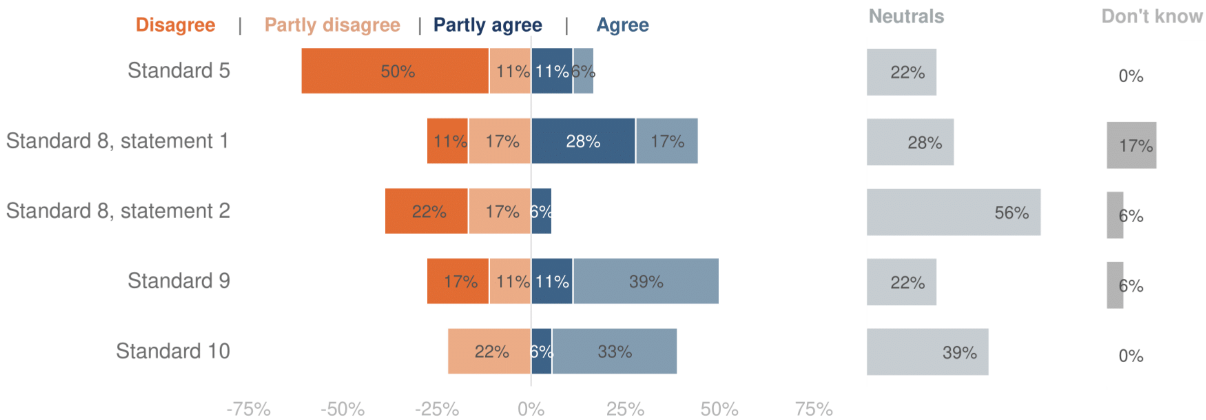

Figure 3. Distribution of answers for statements with lowest average rate

Four respondents added comments to their self-evaluation. One stated that the course is not engineering-subject and supports evolving transferable competencies. One respondent brought up the problem that the level of students' (especially international students) for knowledge and skills is uneven, some students are not able to understand the essentials needed to pass the course. Based on the CDIO Standard 6 one possible solution would be to use digital content repositories from prerequisite courses to enable students to acquire needed knowledge.

One comment was about Standard 3: "At the moment there is no collaboration nor integration with other courses, every teacher works by themselves. Hopefully, program directors see the big picture." The average rate for the statement about Standard 3 was 3,60: 22,2 % answered "agree", 33,3% "partly agree", 16,7% "didn't know", 5,6% were neutral, 16,7% "partly disagree" and 5,6% "disagree". The survey was sent out to all teachers of the program but there were no questions about whether they teach speciality subjects or general courses. Teachers of speciality subjects may have rated this statement higher as they may have a better overview of how their course is related to other courses.

The last comment was a proposal for improving the used survey with comments for all statements to clarify the meaning of the statement or CDIO standard.

Conclusions of survey results

The results of the survey pointed out Standards 5 (Design- Implement experiences) and 8 (Active learning) that need more attention. Also, Standard 3 should be one focal point for supporting the implementation of CDIO. Answers for the statements about Standard 9 (Enhancement of Faculty Competence) and Standard 10 (Enhancement of Faculty Teaching Competence) refer that both need a new approach. To get a more adequate view of compliance of the programme to CDIO standards, it should be distinguished between teachers of general and speciality studies.

CASE-STUDY AND DISCUSSION

This section describes the need for support on a university level to implement CDIO aspects to a course in TalTech. The needs are listed from a teacher's point of view who has some prior knowledge of CDIO but has not yet implemented these principles in a course. The teacher also participated in the survey and his answers were consistent with overall results with one major difference – the lowest score in self-evaluation was for Standard 5 Design-Implement but for this course it was evaluated much higher as it's project-based course.

CDIO methods will be implemented in a course for 5th semester Bachelor engineering students in Product development and robotics curriculum. The course title is Integrated Product Development, and its workload is 6 ECTS credits. It's a project-based course where students develop a new product, often resulting in a physical prototype. About 60 students are taking the course each semester and projects are done in groups. The maximum limit of students per group is 5, but it's recommended to have groups of 3 as this keeps the vagueness of responsibility in check. Each group has an individual project topic that has been confirmed with the teacher. The course ends with an exam (30% of final grade) and submitting the project documentation (70% of final grade). The exam is in written form, with multiple-choice questions and individual so that every student's knowledge of the course materials can be checked. The project documentation grade is communal.

The problem lies in the individual project topics and the amount of documentation created that needs to be checked and given feedback. On average the group size is 3 which means about 20 projects. Each project documentation is about 50 and sometimes up to 90 pages long. That means about 1000 pages to read, process, and give feedback to. The amount of work is somewhat mitigated by discussion and questions from the students throughout the semester, so the teacher already knows the project quite well but usually, these are projects from the more active students who make more effort to pass the course with a good grade.

To solve this problem a principle from CDIO can be implemented – including the students in the review and feedback process. This is related to Standard 8 Active learning and the fact that this approach hasn't been implemented before is consistent with the survey results described in the previous section. The survey shows that the self-assessment score for this standard is one of the lowest.
The feedback is organized in the middle of the semester (8th week) and it's a pre-requisite for attending the exam and getting the final grade. The following is a description of the support required at the university level.

The solution will be implemented in an e-learning environment Moodle. This affects some of the decisions how the feedback process is set up.

The main benefit of this approach is the increase in learning quality and quantity. Reviewing other students' projects will give perspective on how well they themselves are doing, what can they improve, add or do differently.

Support before implementation
Don't fix what's not broken. On a teacher level it is often argued why should one change something if the majority of students are happy, they pass the course, they learn the required material and the feedback is positive? Everything new is always daunting, especially if the amount of work required is unknown and the usefulness questionable.

From the teacher's perspective the support before implementation of CDIO methodology should focus on helping teachers understand the benefits of improving their courses. This can be done by using examples of successful changes in other courses. The examples must be similar to the course in question. If a math course teacher is shown examples of a biology course, then the potential impact might not be reached as the teaching methodologies are different and not transferrable.

The second support aspect before implementation is to show mathematically how the invested work hours by the teacher pay off in the long run. By spending x number of hours, one will reduce the amount of work at the end of the semester by y. A simple multiplication should demonstrate the benefits from the teacher's point of view. Time saved was one really important factor in the Integrated product development course because it significantly reduces the amount of complicated and lengthy feedback for groups that are not active during the semester. Reviewing good projects is easy and quick, 80% of the time giving feedback is spent on low-quality projects.

The third aspect where the university can offer support is where to start from. If the teacher is unfamiliar and inexperienced then starting from nowhere can be difficult. Most of the academic staff just need a nudge in the right direction and everything else will follow naturally. The establishment of Centres for Teaching and Learning Excellence in TalTech is expected to provide such support in the coming years.

Support during implementation
There is a need for technical support during the implementation of CDIO methods. In the analysed case, the peer review is to be added to the Integrated product development course.

The exact set-up is not defined yet but because all activities related to learning should be in one location, a learning management system (Moodle) is to be used.

The first aspect that requires support is not knowing the technical possibilities of the Moodle. The teacher in the course is well versed in computers but not knowing that a specific functionality exists will result in inefficient solutions. For example, the peer review could be organized in a standard forum, but this would create a lot of confusion and extra work for the teachers. The second option is to use “Group self-selection” which allows the groups to work together, keep their files in the same place, and give access to other groups for peer review. But this solution has the same problems as using a forum. The third option is to use the special activity “Workshop” where peer review is organized into four phases. The “Workshop” activity is rarely used and may be hard to find.

The second aspect of technical support is setting up the CDIO activities themselves. There are 11 different categories that all have several options on how to set up the peer review. The support provided does not have to go into details with every option, but some basic recommendations would reduce the amount of time required from the teacher. Also, it’s not visible how the projects for reviews will be distributed and how to avoid getting your project for reviewing (randomly getting your own group members' project).

The third aspect is the best practices. To avoid just learning from mistakes there could be recommendations on what usually works best. One of the concerns for Integrated product development was whether to use anonymous feedback. Being able to be brutally honest vs. knowing how seriously to take the feedback based on the person making the comments. The second concern was the number of reviews per student. Are 2 reviews enough to get a comprehensive overview or would 3 be better? Also, how many reviews per student would be too much work? This kind of support would also mean that the teachers can talk to somebody about the course and brainstorm for ideas. For example, the “compliment sandwich” was proposed to be used in the review method where it starts with a compliment, then things that can be improved and finish with something positive.

Support after implementation

The support from the university after implementation should focus on measuring the results and improvements based on the experience. Measuring the effects of implementing peer review can be challenging because there is not an objective baseline to compare it to. Students and their skills vary each year and just a comparison to the previous year's results/grades might give a biased result. Proposing suitable KPIs would increase the teachers’ morale if it is shown how the students’ learning experience and inquired competences have improved. Or in case of negative feedback what can be done differently in the future.

At the end of the course, teachers should always conduct self-evaluation to recognize positive and negative aspects of used methods. It is recommended to create a tool for the self-evaluation to make the practice more convenient. It could be a list of important aspects to think through or an evaluation form that can be saved for comparison for the following years.

CONCLUSIONS

Three instruments used in the present research pointed out various aspects that should be considered in planning teacher training and support for implementing CDIO principles.

Compliance analyses of the IGIP curriculum and CDIO Standards proved that the IGIP curriculum can be used as the base of pedagogical training for engineering teachers implementing CDIO approaches. To introduce CDIO principles and get more effect out of training programs, suitable CDIO principles should be used in training programs. Design-implement experiences and Active learning should be considered as the first topics for training. The case study pointed out the need to collect use cases of implementing CDIO principles, spread the inspiration and learn from best practices. Mentoring could be used for providing support for those who are starting to implement CDIO principles. The method of covision is also suitable for group mentoring teachers with similar challenges in close fields. The second point that came out from the case study was the technical support needed with Moodle. Finding the best possible solution for the learning process should be worked out in collaboration with teachers and specialists from the Centres for Teaching Excellence. Support on how to set up activities in Moodle is provided by the Educational Technology Centre at TalTech.

To support the sustainability of implementing CDIO principles in courses, the tool for self-evaluation should be developed and researched. Training programs should be modified using the CDIO approach to give teachers experience in active learning and impact their teaching. In contemporary education, students can give us valuable input to enhance the impact on faculty and course development.

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APPENDIX 1: STRUCTURE OF TALTECH MICRO-CREDENTIAL PROGRAM OF ENGINEERING PEDAGOGY

Module	Subjects/ECTS
Compulsory Module 1 – „*Course Design*“ 6 ECTS	1.1 Engineering Pedagogy (2 ECTS)
	1.2 Laboratory didactics (2 ECTS)
	1.3 Curriculum theory and practice (2 ECTS)
Compulsory Module 2 – „*Design of Learning Process*“ 6 ECTS	2.1 ICT tools supporting interactive e-learning (2 ECTS)
	2.2 Effective communication (2 ECTS)
	2.3 Educational Psychology and sociology (2 ECTS)
Compulsory Module 3 – „Analysis of Learning Process“ 6 ECTS	3.1 Problem-based and meaningful learning (2 ECTS)
	3.2 Analysis of the study process. Ethical problems in education (2 ECTS)
	3.3 Final project. Portfolio design (2 ECTS)
Elective Module - Minimum 6 ECTS to be elected	4.1 Internship in a company. Cooperation projects with partners (2 ECTS)
	4.2 Standards and quality (1 ECTS)
	4.3 New technologies (1 ECTS)
	4.4 Coaching and mentoring (1 ECTS)
	4.5 Multicultural learning environment (1 ECTS)
	4.6 Teaching practice (2 ECTS)
	4.7 Sustainable development (1 ECTS)
	4.8 Learning Lab (1 ECTS)
	4.9 Management (1 ECTS)
	4.10 Excursions to companies (1 ECTS)
	4.11 Product development and innovation (2 ECTS)
Total	**24 ECTS**

APPENDIX 2: TRANSLATED SURVEY QUESTIONS

Standard	Question
	1. I´m : a. Main teacher b. Assistant (teaching in practicum, laboratory, exercise)
1: The Context	2. Students work with real-life problems or conceive, design and analyze the lifecycle of different products, processes or systems.
2: Learning Outcomes	3. I consistently work with / develop/ review learning outcomes of my course 4. The feedback from key stakeholders (program manager, colleagues, students, and Industry) is considered during the process of developing course learning outcomes and content
3: Integrated Curriculum	5. I know how my course content aligns with skills and knowledge taught in other courses in the same program
4: Introduction to Engineering	6. In the first lesson of the semester, I explain to students, how the course is related to other courses in this program or engineering in general
5: Design-Implement Experiences	7. My course follows a design-implement approach - students develop products, processes, systems or services
6: Engineering Learning Workspaces	8. There is a learning environment that supports and encourages hands-on learning 9. Digital learning materials are available for students all the time
7: Integrated Learning Experiences	10. In my course, professional competencies like personal and interpersonal skills are developed as well as disciplinary knowledge
8: Active Learning	11. There is active learning in my lessons, for example, group work, discussion, case analysis, etc 12. I think that peer assessment is a valuable experience for students, and I use it in my teaching
9: Enhancement of Faculty Competence	13. The enhancement of my disciplinary and professional competencies is well supported by the university
10: Enhancement of Faculty Teaching Competence	14. The enhancement of my teaching competencies (integrated, active, and experimental learning methods, assessment) is well supported by the university
11: Learning Assessment	15. I think that it is essential to enhance student disciplinary knowledge and skills as well as professional competencies (communication, leadership, analyzing, motivation, time management, critical thinking etc) 16. Learning outcomes for my course are written in a way that students can understand what they need to be able to do and how it is assessed
12: Program Evaluation	17. My course is continuously evaluated in the context of the program, and results are introduced to key stakeholders
	18. Comments (other ideas in connection with the CDIO framework)

EVALUATION OF STUDENTS' PERFORMANCE IN CDIO PROJECTS THROUGH BLENDED LEARNING

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ABSTRACT

Current engineering job sectors do not only demand theoretical technical knowledge but also hands-on skills and critical thinking to ensure that engineering graduates are adaptive to the evolving and innovative world. Hence, several engineering modules at Canterbury Christ Church University have incorporated CDIO projects to integrate professional skills into the course. Following the UK government COVID-19 lockdown guidelines in 2020, traditional on-campus face-to-face learning was restricted at UK universities and colleges; therefore, students faced several challenges from academic and wellbeing perspectives. To overcome the challenges and enhance those professional skills through CDIO projects whilst following COVID-19 restrictions, blended learning was implemented via reconfiguring the delivery and implementation of the CDIO projects through an optimal arrangement of online and on-campus sessions. Online CDIO practical sessions were dedicated to students for transforming their ideas into feasible designs and solutions whereas students developed the hardware prototype during the face-to-face sessions. The learning framework was inclusive with additional support for disabled students with accessible learning materials and supportive technical and professional training. The above strategy also helped students to complete their online assessment to achieve the required professional attributes and manage online/blended group-based tasks appropriately. Their outcome of the CDIO project was impressive and the quality of those projects is comparable to final-year projects. The performance of the students was also encouraging as the first-time overall pass rate is relatively high (86%) for a cohort of 75 students where average marks are around 59.6 and standard deviation is around 18.5. The high success rate was achieved in all areas of the cohort, for example the pass rate in BAME students was 93.75%, in female students it was 98.43%, and in disabled students it was 98.43%. A survey on students' experience shows that they benefited highly from the sessions related to the CDIO project.

KEYWORDS

Blended learning, CDIO project implementation, Inclusive learning, Professional skills, CDIO Standards 3.0

INTRODUCTION

The advancement of technology has changed the required skills of engineering job sectors where applicants should have up-to-date technical and professional skills and have the ability to adjust with the current trend (Pusca, Bowers, & Northwood, 2017). The present engineering trend supports Industry 4.0 (Diez-Olivan, Del Ser, Galar, & Sierra, 2019) which refers to the fourth industrial revolution in the manufacturing and industrial sector. It includes the application of advanced robotics, smart sensors, Internet of Things and advanced automation. Therefore, it is required to include more project-oriented skills in the curriculum as it enhances several competencies in students so that they would come up with innovative ideas through critical thinking, have the ability to solve problems, improve their competency in hands-on skills, engage in teamwork, and improve project writing skills, strategic competence and future vision. Recent qualitative research suggests (Llorens, Berbegal-Mirabent, & Llinàs-Audet, 2017) that aligning professional skills in active learning methods can establish a satisfactory engineering skillset. Critical thinking (Pee & Leong, 2005) is one of the essential skills that encourage students to choose the best alternative solutions for a specific problem. Other important professional skills for engineering students are teamwork and communication skills that would help them to resolve the conflict between individual contribution and provide the best solution (Ercan & Khan, 2017). Along with these skills, writing a project business report (Zainuddin, Pillai, Dumanig, & Phillip, 2019) is required for standard documentation in the industry. In the UK, for engineering students, hands-on skills are identified as one of the important learning outcomes in most of the modules and they must be developed within the higher education curricula by the UK engineering council and accreditation bodies (Engineering Council, 2014). Nevertheless, the lack of an innovative learning framework in engineering education especially in STEM areas leaves several employability skills unaddressed such as critical thinking, statistics, computing ability and so on (Siregar, Rachmadtullah, Pohan, & Zulela, 2019).

To overcome those problems, engineering modules are integrated with CDIO projects to embed better professional skills in the curriculum at Canterbury Christ Church University (CCCU) (Manna, Nortcliffe, & Sheikholeslami, 2020). Each of the CDIO Standards is intended to be fully integrated into engineering programmes by corresponding teaching and learning facilities at CCCU (CDIO, 2020), shown in Figure 1. CDIO (Chuchalin, 2020) framework builds an interactive platform for students where they conceive an idea, design and develop a feasible and useful solution to implement that idea, operate the system/solution to evaluate its working function for its improvement.

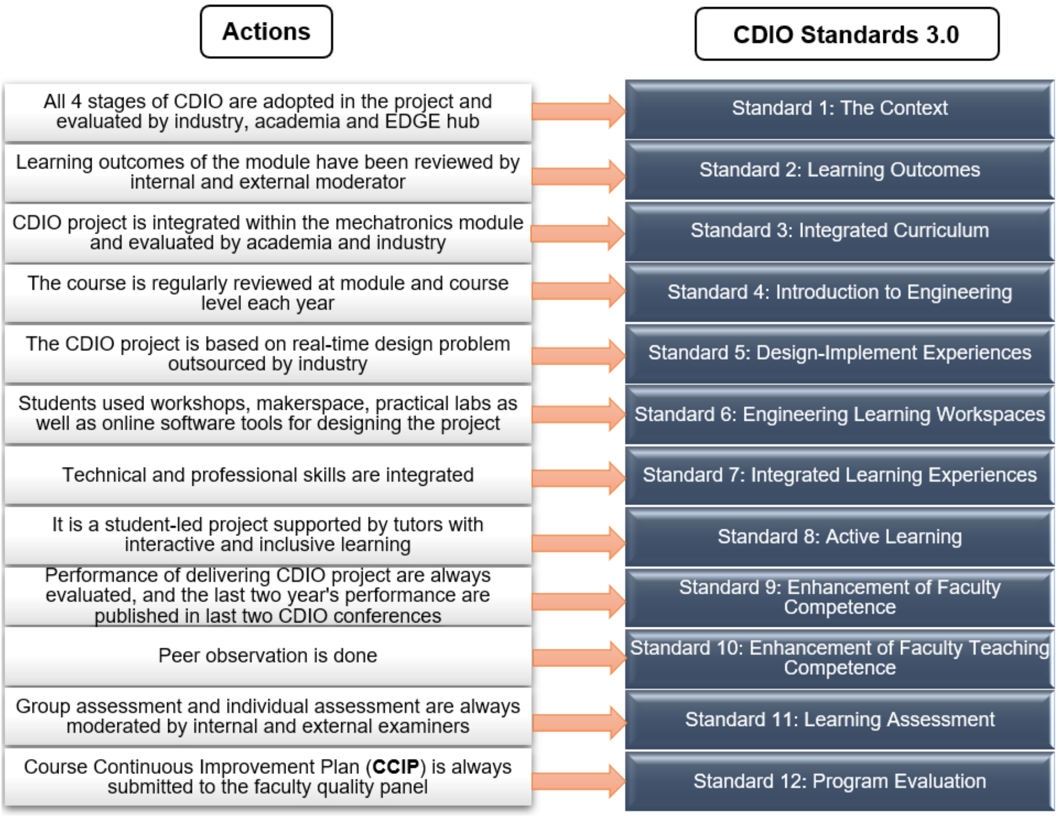


Figure 1. Mapping of actions with CDIO standard 3.0

We have been teaching one such CDIO project-oriented module ‘Professional Engineering Project (with Mechatronics) in the last academic year for the Level 4 (first year) students. The CDIO project was outsourced by a local company Barton Marine, designers and manufacturers of products for sailing boats. The task was focused on resolving an existing real-world problem in the sailing industry. Therefore, students require technical knowledge to come up with innovative ideas through critical thinking. However, they also need competency in hands-on skills, engagement in teamwork and project writing skills to document the final project for making it presentable in front of the industrial partner.

Due to the new COVID-19 guidelines in the UK higher education sector, a hybrid learning platform where a combination of online and campus-based learning has been adopted in all higher education institutions (Peimani & Kamalipour, 2021). Along with other universities, courses in CCCU have been shifted to a blended learning platform. In the blended learning approach (Lapitan Jr, Tiangco, Sumalinog, Sabarillo, & Diaz, 2021), both online and face-to-face sessions have been implemented in the teaching and learning framework for lecture and practical sessions respectively. Due to a large cohort of students, lecture sessions were scheduled during online sessions whereas students were divided into a small group of 15-20 students to attend the practical sessions in-person with tutors and technical staff on campus. Based on the following learning and teaching strategies, an optimal arrangement of blended learning approach facilitated the CDIO project effectively: online lectures and practical sessions for 8 weeks until Easter holiday, face-to-face practical sessions on campus for two weeks after Easter (6 hours a day and continued for four days per week). The schedule of the online and face-to-face sessions was organised in a way so that allotted time could be utilised appropriately and learning outcomes will be met whilst maintaining COVID-19 restrictions. Lecture classes had been delivered in two different sessions: in technical lecture session, students were taught about different technical knowledge and skills related to mechatronics for developing the CDIO project whereas in professional lecture session, students were taught about professional attributes such as teamwork, ethics, sustainability, health and safety, project planning, report writing etc. for supporting the CDIO project. Also, separate one-to-one session was provided to individual students for clearing doubts and project guidance.

Online practical sessions were mainly planned for students to develop their solution of the CDIO project. During this time, students came up with innovative solutions for the CDIO problem and designed them using different software tools. Face-to-face practical sessions were then delivered after Easter so that students could manufacture the components and develop the prototype. To build the hardware model of their CDIO project, students have used several pieces of mechanical equipment during face-to-face sessions. They had also undergone health and safety training for handling equipment and operating these safely. Hence, the arrangement of blended learning (Figure 2) has not only maintained the CDIO projects in flow with COVID-19 restrictions but also improved the hands-on skill, critical thinking and teamwork ability of students. In this module, all student groups were encouraged to come up with their individual innovative ideas to design and develop the CDIO project. Following the strategy, conceive and design part of the CDIO project were completed during online sessions whereas the project was implemented and operated during the face-to-face sessions. During the conceive stage, students defined the aims and objectives of the CDIO project based on their proposed solution. After that, students performed a thorough investigation (literature review) on the existing projects (relevant to the CDIO problem) to know more about their advantages and limitations and drew their conclusion to identity the required properties needed to be incorporated in their proposed solution. In the next stage, the overall methodology of the project was proposed and described by each group with the required product design specification sheet (Stoll, 1999), technical and commercial attributes. As a part of literature research, students accumulated the specifications of the CDIO project with ideal value, target and achieved values where ideal value was determined from the research on existing projects, target values were decided by the cost, time and several other factors whereas achieved values were recorded after developing and testing the prototype. All these processes were completed during online sessions.

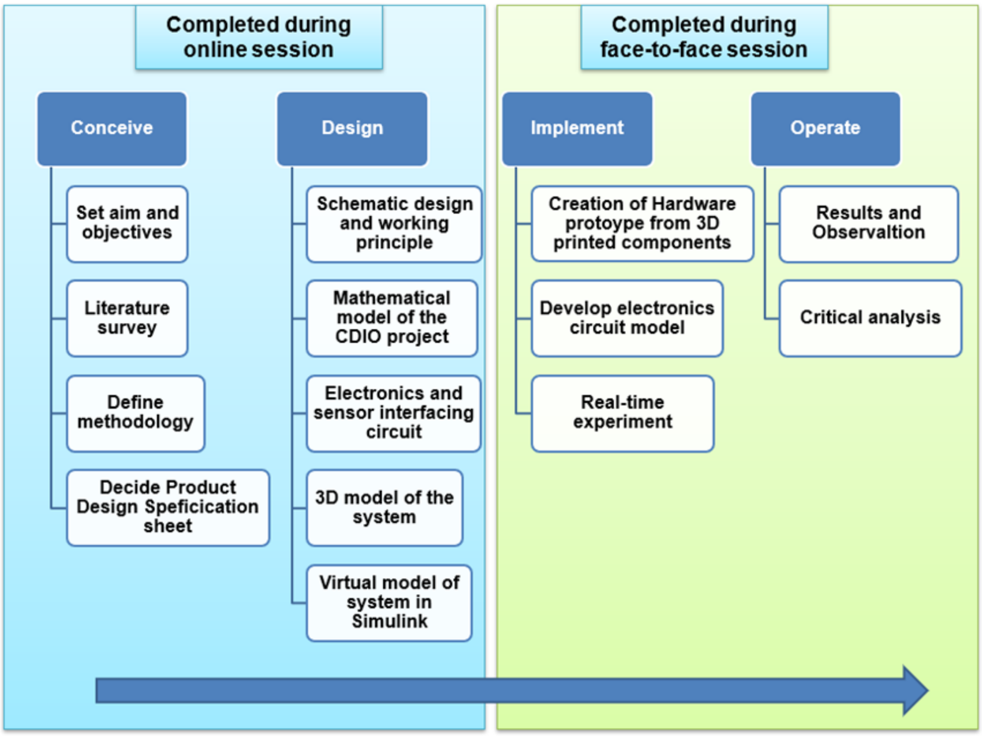


Figure 2. Pathway of implementing the CDIO project

During the design stage, students developed the design framework of the CDIO project and its associated outputs from a technical perspective such as schematic design, mathematical model, 3D model, electronics circuit, sensor interfacing circuit, virtual model. A Gantt chart with an appropriate timeline was provided to students. Different types of software were used to develop those models such as Fusion360 for creating 3D models, Tinkercad for designing the electronics circuit and sensor interfacing circuit, Arduino studio for embedding code in Arduino board, MATLAB and Simulink for creating a mathematical and virtual model of the proposed solution. The advantage of using these software tools was that students could furnish those tasks online, evaluate the model virtually before finalizing the hardware. Besides, learning these software tools made their portfolio stronger for a career goal.

For implementing the CDIO project, face-to-face sessions were arranged so that students could manufacture the hardware parts of the CDIO project. During operate stage, a comparative analysis was drawn by students between the real-world results, simulation results and theoretical results. Finally, all students submitted their CDIO project report (mentioning individual contribution in the project work) and presented as a group.

GROUP PROJECT SESSIONS

The CDIO project was based on a group-based task where 3 to 4 students were involved per group in providing an innovative solution to a real-world engineering problem. Although it is a group project, students found it difficult to manage teamwork during online sessions for several reasons such as technical, physiological and mental wellbeing issues (Savage et al., 2020). Several students suffered from COVID-19, therefore they could not attend several sessions and missed important discussions of the project work. Staying at home and disengagement with peers and friends in person have made the majority of students mentally not well. Students with prolonged medical illness (legionnaires disease and mental health issues) and learning disability (dyslexia, AHDD, and autism) were sometimes unable to convey their opinion properly during online sessions and a miscommunication gap occurred. It should be noted that 20% of the cohort have learning support plans, typically for a learning disability (dyslexia, AHDD or autistic). Furthermore, we are aware of a number of students not yet formally diagnosed. Students not in University accommodation in Canterbury, surrounding area or countryside locations faced challenges with internet connectivity (as Kent is poorly broadband served). Therefore, the communication was often interrupted during the group sessions. In addition, students' hardware mic and camera would function with MS Teams, but not with Blackboard Collaborate, however chat functions were operable. Another important issue was the lack of IT equipment among the students from low economic backgrounds, preventing them to attend the scheduled online sessions with other students.

In order to incorporate the seed of teamwork among the students during online sessions, breakout groups were created in Blackboard Collaborate platform for facilitating teamwork, nurturing constructive discussion and generating critical thinking. Even disabled students had been treated in the same way (with extra support from tutors) as they joined a usual group and participated in the group task. Constructive criticism of ideas was always helpful for a group project. A discussion room was created in Blackboard for sharing weekly progress and doubts, and tutors reviewed those reports by providing constructive comments to improve them further. The whole task was divided into several sub-tasks and distributed among the group members so that each team member in the group had the responsibility to complete a specific part of the project and shared the outcome with others. For example, the person who did the 3D modelling of the project during online sessions, will manufacture the components using 3D printer and assemble them to develop the prototype during face-to-face sessions. Although the subtasks were assigned to each person in a group, they could seek assistance from team members while doing their part of the job, enhancing their ability to pursue teamwork and partnership in the project. To support the students with physical and mental health issues, the student-wellbeing team functioned efficiently and provided the required help. Students also benefited from the CCCU hardship fund to buy IT equipment for learning.

ONLINE ASSESSMENT STRATEGY

The assessments associated with the CDIO project were designed to judge their technical skills as well as several professional attributes such as critical thinking, hands-on skill etc. In the end of the CDIO project, students submitted a group poster where they described the aims, methodology, design, manufacturing, and testing results of the CDIO project. All team members in a group contributed to designing the poster and presented it in front of a panel. Due to COVID-19 restrictions, the poster presentation was organised online. Finally, students also submitted an individual CDIO project report on producing their novel idea to overcome the issues raised by the industry. The project report included the design model, test, and results in detail.

CDIO PROJECT OUTCOME AND PERFORMANCE OF STUDENTS

The project was based on designing and developing a digital, portable and affordable solution for measuring tensile strength. The project ideas (Figure 3) pursued by the students were brilliant, innovative and diverse consisting of spring based linear displacement to transform tensile strength into digital scale, ultrasonic sensor displacement in terms of measuring continuous tensile force, encoder based angular displacement due to tensile force, strain gauge-based solution for measuring tensile strength, force sensor-based solution for measuring tensile strength etc along with different types of mechanism. Their outcome of those CDIO project was satisfactory as per the quality and standard.

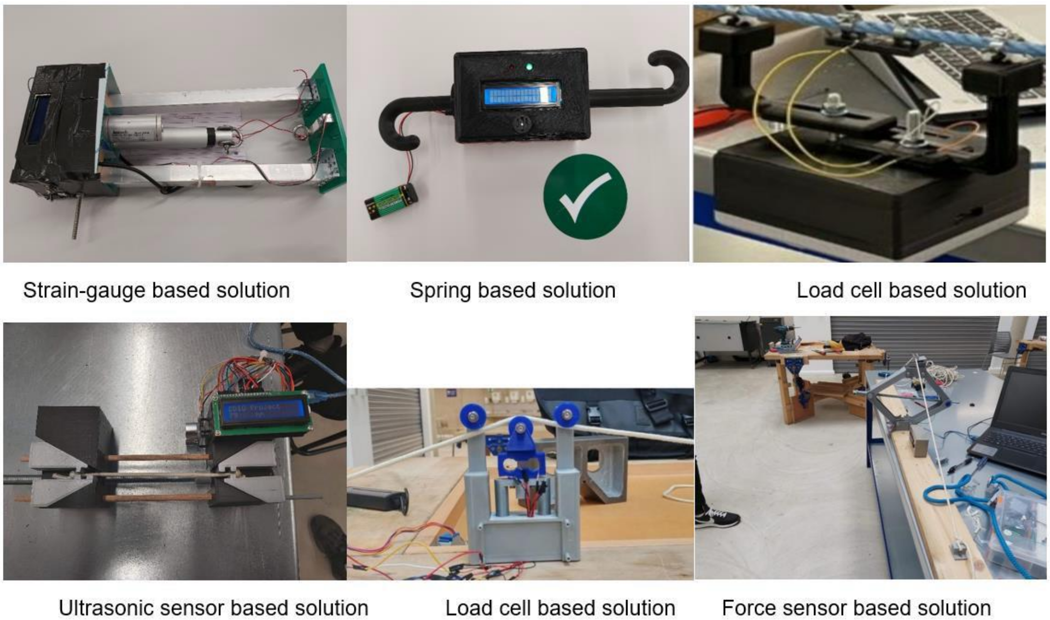
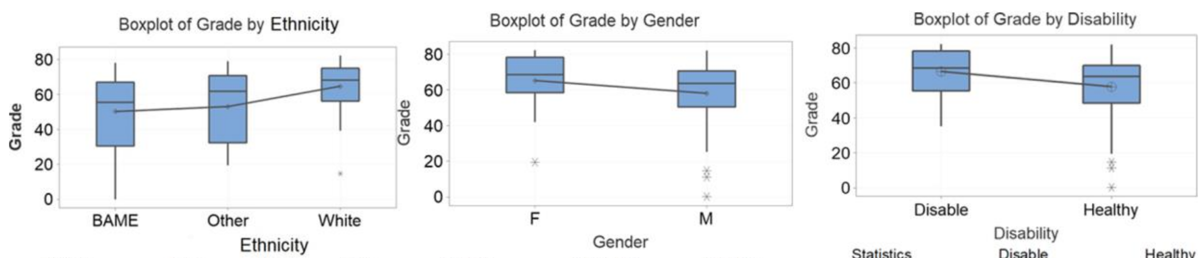


Figure 3. Innovative solutions proposed by students

Along with the outcome of the prototype, both group poster and individual CDIO project report of the students were assessed for evaluating their performance and grades. The student grades have been analysed through Minitab® (statistical software). There were 72 students enrolled in the module, however, 8 students did not engage in the module and their marks are excluded. Hence, we have only considered the marks of 64 students for the analysis. The first-time overall pass rate is relatively high (86%). The average grade of the module is 59.66 (excluding missing marks) and the standard deviation is 18.51 which is a satisfactory outcome.



Statistics	BAME	Other	White
N	15	9	40
Mean	50.2	53.056	64.688
Standard Deviation	24.265	21.156	13.417
Minimum	0	19.5	14.75
Maximum	78	79	82.25

(a)

Statistics	F (Female)	M (Male)
N	14	50
Mean	65.214	58.1
Standard Deviation	17.659	18.617
Minimum	19.5	0
Maximum	82.25	82

(b)

Statistics	Disable	Healthy
N	13	51
Mean	66.596	57.887
Standard Deviation	14.068	19.199
Minimum	35.25	0
Maximum	82.25	82

(c)

Figure 4. Performance analysis of students based on several factors

The grades of the students have been investigated further based on ethnicity (Figure 4a), Gender (Figure 4b) and disability (Figure 4c) using box plots. Figure 4a shows that the average grade of the white students is 64.69 which is comparatively higher than that of BAME (black, Asian and minority ethnic, 50.2) and students of other ethnicities (53.06). Also, the grades of white students are distributed close to the mean value whereas the spread of grades for BAME and students of other ethnicities is larger.

The grades achieved by female students (mean value: 65.21) are on average higher than male students (mean value: 58.1), as shown in Figure 4b. Due to the inclusive learning framework, disabled students have performed well in the CDIO project, the average grade of disabled students is 66.59.

A high pass rate of students has been reflected in all types of student cohorts, for example, the pass rate of female students is 98.43%, for BAME students is 93.75% and for other ethnic students is 95.31%. The overall pass rate of disabled students is also 98.43%. The performance of students has been further investigated using box plot of groups where student cohorts have been divided into disabled and healthy around gender, and ethnicity around gender. Figure 5a shows that disabled students of both male and female gender have achieved higher grades compared to health students. Similarly, male and female white students have achieved higher grades compared to other ethnicities and BAME students (Figure 5b). It also shows that female BAME students actually performed well and achieved good grades, however, male BAME students faced difficulties and need support (Figure 5b).

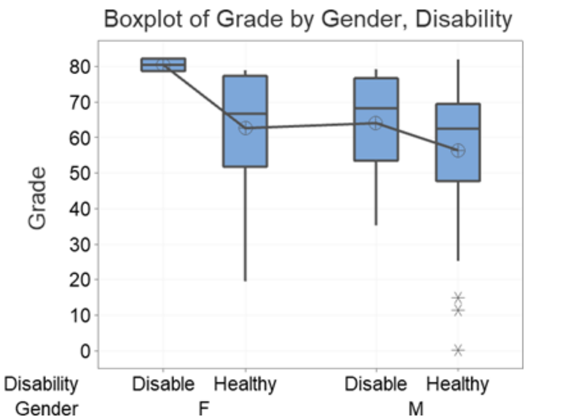


Figure 5a. Performance of disabled students based on gender

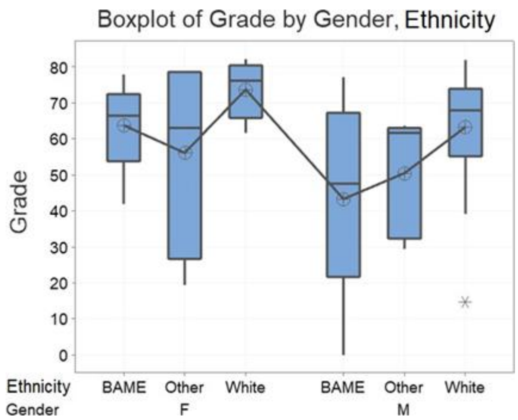


Figure 5b. Performance of different ethnicity students based on gender

The students' grades have been distributed by students' age and shown in the main effect plot (Figure 6). It shows that students within the age group (> 25 years and < 20 years) have achieved comparatively performed well. On the other hand, the amount of variation in the grades for 20 – 25 years students are significantly higher compared to other age groups.

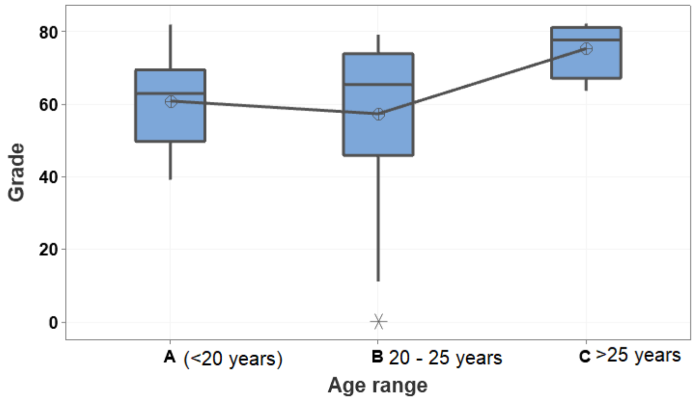


Figure 6. Distribution of grade over the age group of students

A survey with a qualitative questionnaire was conducted among the students to capture their experience in the module and how the project helped to grow their professional and technical skills. The survey also included the future recommendations from the students related to the engagement of employability skills using CDIO projects. The overall experience was above the satisfactory level from students' perspectives. Feedback from students was positive, helpful and informative. The arrangement of CDIO project sessions was efficient in terms of fulfilling students' expectations and it was also reflected in their final assessment. There are a few improvements required in several areas such as time allocation for completing the project, industrial engagement, engagement of disabled students in group work, blended learning approach, conflict of interest in a group project, enhancing outreach and networking. We have also received positive feedback from Barton Marine regarding the outcome and the standard of the project.

CONCLUSION

The main aim of introducing the CDIO project in this module was to enhance the critical thinking, hands-on skills, teamwork and report writing skills of students. Most of the aims have been already achieved through optimal use of blended learning, arrangement of supporting workshops, problem-based learning and so on. Several areas for improvement have been identified, including enhancing the engagement of students with learning disability, improving the industrial engagement and allowing sufficient time for practical work. The survey outcomes consisting of students' feedback on their involvement and experience (innovative ideas development, way of completion, level of outcome, project planning) in finishing the CDIO project were satisfactory and have supported the plans for the future delivery of this CDIO project module. In this CDIO project, students have also implemented previously gained knowledge that was taught in previous modules, as per CDIO Standard 3. For example, students learned Fusion360 and Tinkercad in the previous semester. However, they used Fusion360 for designing the 3D model of the CDIO project and Tinkercad for designing its electronics model. Due to the involvement of industry, it did not merely appear as an academic project as students were engaged to the industrial platform, talked to industrialists, and created an understanding of the outside engineering world. Working in a multidisciplinary CDIO project, students became familiar with the overall structure of a system and its associated components and their functions. This helped to incorporate the problem-solving skills so that students could resolve real-life engineering problems using their mechatronics knowledge.

Several future action plans have been considered in the reflecting stage in order to overcome the current limitations. For example, the CDIO project can be divided into two segments between two levels (Foundation year and Level 4) where basic parts will be designed and developed by foundation year students and Level 4 students will work at the advanced level of the project. The students from both levels will be working together to present the project, in a way that Level 4 students can supervise the foundation year students and thus enhancing teamwork and leadership capability. Due to COVID-19 restrictions, it was not possible to keep face-to-face interaction with the industry. When the situation will become normal, an industrial visit will be planned for students to enhance their engagement. It is always difficult to integrate disabled students in a group project due to their communication issues with other group members. The best practice will be to provide extra support for them so that they would not fall apart and lag behind other team's members. Students will be encouraged to unite irrespective of their abilities and disabilities in order to manage the group work. In the last academic year, we had to keep block face to face practical sessions to maintain a certain number of students in a lab.

To improve the students' learning experience, weekly practical sessions will be arranged for students as students can follow weekly lectures with relevant practical sessions rather than doing it after five to six weeks. Besides, all the academic support, more individual support should be provided to students suffering from mental and physical wellbeing. Although several learning support arrangements are already in place for disabled students, the university should still provide extra student-support such that students will be more confident during their studies.

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BIOGRAPHICAL INFORMATION

Dr Soumya Kanti Manna is currently a Lecturer and Course Director (Biomedical Engineering) at the School of Engineering Technology and Design, Canterbury Christ Church University, UK. Soumya completed his master in Mechatronics and PhD in Medical Robotics. Soumya's research interest primarily lies in the areas of designing assistive devices and healthcare products, sensor deployment for gait analysis and and IoT based biomedical applications. He is also interested in engineering education-based research using CDIO based project curriculum to explore new pedagogy approaches.

Dr Najah Battikh is currently a Lecturer and Course Director for Chemical Engineering at the School of Engineering Technology and Design, Canterbury Christ Church University, UK. Najah has a degree in Chemical Engineering, MSc in Embedded Systems Engineering and PhD in Chemical Engineering. Najah's main research interests include the use of optical techniques in characterising the crystallisation process as also how this can be utilised in combination with rapid heating and cooling to control the crystallisation process in chemical and pharmaceutical industries as well as water treatment, desalination, and the removal of microplastics from water. She is also interested in Engineering Education Research and CDIO based project activities.

Dr Anne Nortcliffe is Head of the School of Engineering, Design and Technology, Canterbury Christ Church University, UK. Anne has a degree in Chemistry, MSc in Control Engineering, PhD in Process Control Engineering, industrial experience in artificial intelligence and software engineering for the Chemical Engineering Industry. Anne has been an academic in several institutions teaching, leading in areas of automation, manufacturing, computer networks, aerospace/aeronautical, software engineering, software entrepreneurship, mechanical and materials engineering. Anne is an active engineering education researcher with an international reputation in engineering employability development, learning technology to support computing and engineering education, and engineering education pedagogical approaches.

Dr Joseph Camm is currently a Lecturer at Department of Mechanical, Materials and Aerospace Engineering, University of Liverpool, UK. He was a former Lecturer at the School of Engineering Technology and Design, Canterbury Christ Church University, UK. His doctorate research focused on reducing harmful exhaust emissions in the car industry, and has now been adapted to study greener alternatives for asthma inhalers. He also contributed towards developing the CDIO project and its implementation at CCCU.

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NORDIC COURSE DEVELOPMENT COOPERATION IN AN EMERGING FIELD OF ENGINEERING

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ABSTRACT

Four decades ago, a specific engineering BSc study program in Fire Safety Engineering was formed at Lund University, Sweden, and several Nordic universities have since included courses on such subjects in their own BSc og MSc programmes. The field of fire safety engineering encompasses topics from a wide range of engineering disciplines, including mathematics, physics, chemistry and advanced engineering courses such as heat transfer, thermodynamics and fluid dynamics. It is not immediately obvious how to balance the need for knowledge from fundamental, applied and specific courses to be taught within the discipline of fire safety engineering. Long standing cooperation across 12 Nordic universities and research institutions has made this distinction clearer and most recently this network secured Nordic funding for three years for a specific cooperation program in education, including PhD exchange programs and the development of a summer school for students of engineering, focusing on fire safety and energy. Specifically, four of these universities, through the authors of this paper, have been cooperating for a number of years within one of the key courses called „Enclosure Fire Dynamics“, the study of how a fire develops in a building and how engineering methods based on classical physics and chemistry can be used to simulate the environment due to fire, allowing engineers and designers to test and compare various possible design solutions regarding building fire safety. This has required careful development of educational material in close cooperation between Nordic universities, following the CDIO principles. The fruitful cooperation has resulted in the production of comprehensive educational material such as textbooks, homework assignments, laboratory instructions and computer labs, to name a few examples of results. Most of the material is free of charge and available on the internet. This paper provides an example of how this has been achieved by a cross-Nordic collaboration on providing and developing educational material in an emerging engineering discipline.

KEYWORDS

Fire Safety Engineering (FSE), Fire Protection Engineering (FPE), Performance-based Codes, Prescriptive Codes, Fire Safety Engineering Education, Fire Safety Engineering Design, CDIO Standards 1, 3, 4, 5, 6, 7.

INTRODUCTION AND RELEVANCE TO CDIO

In this section we shall discuss the emergence of the discipline of fire safety engineering (sometimes termed fire protection engineering) and how the CDIO standards and principles have, in recent years, been helpful in further developing educational programmes in the field. A brief overview of this paper will be presented.

The emergence of fire safety design as a new engineering discipline

Fire safety regulations can have a major impact on many aspects of the overall design of a building, including layout, aesthetics, function, and cost. Rapid developments in modern building technology in the last decades often have resulted in unconventional structures and design solutions. The physical size of buildings increases continually; there is a tendency to build large underground car parks, warehouses, and shopping complexes. The interior design of many buildings - with large light shafts, patios, and covered atriums within buildings connected to horizontal corridors or malls - introduces new risk factors concerning spread of smoke and fire. Past experiences or historical precedents (which form the basis of current prescriptive building codes and regulations) rarely provide the guidance necessary to deal with fire hazards in new or unusual buildings.

At the same time there have been great strides in the understanding of fire processes and their interrelationship with humans and buildings. Advancement has been particularly rapid in the area of analytical fire modeling. Several different types of such models, with varying degrees of sophistication, have been developed and are used by engineers in the building design process internationally.

As a result, there is a worldwide movement to replace prescriptive building codes with ones based on performance. Instead of prescribing exactly which protective measures are required (such as prescribing a number of exits for evacuation purposes), the performance of the overall system is presented against a specified set of design objectives (such as stating that satisfactory escape should be effected in the event of fire). Fire modeling and evacuation modeling can often be used to assess the effectiveness of the protective measures proposed. The need to take advantage of the new emerging technology, both with regard to design and regulatory purposes, is obvious. The increased complexity of the technological solutions, however, requires higher levels of academic training for professionals in fire safety engineering and a higher level of continuing education during their careers. The CDIO principles have been an excellent guide when academians in the Nordic countries have cooperated on developing programmes and individual courses for fire safety engineers.

The CDIO principles and standards

The CDIO Initiative was launched in the year 2000, with the aim of providing students with an education that stresses engineering fundamentals set in the context of Conceiving, Designing, Implementing and Operating engineering activities. The four phases are an abbreviation of the word CDIO (Crawley et al, 2011).

Further, the four phases encompass (Zabalawi, 2018):
Conceive phase: Defining customer needs; considering technology, enterprise strategy, and regulations; developing concepts, techniques and business plans.
Design phase: Creating the design; plans, drawings, and algorithms that describe what will be implemented.
Implement phase: Transforming the design into the product, including manufacturing, coding, testing and validation.
Operate phase: Using the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

Due to the great advancement in knowledge in the field of fire safety engineering in the last few decades, particularly with respect to fire modeling and evacuation modeling, engineers can now use methods based on fundamental physics and chemistry to simulate the evolvement of a fire in a building and can thus compare various possible design solutions regarding building fire safety. But in order to apply this new knowledge, the building regulatory system must be performance-based, to allow such methods of verification. Older regulatory systems are often based on prescriptive rules, certain rules-of-thumb based on old experience or given values and numbers that often have little to do with fundamental physics and chemistry. It can be difficult to apply new engineering methods based on the advancing knowledge in the field in countries where regulatory systems are dominated by older prescriptive rules.

In this paper we shall therefore discuss Performance-based regulatory systems and how fire safety design based on fundamental engineering knowledge can be applied to complex situations, where the older prescriptive rules can not be applied. We shall briefly describe a Core Curriculum for fire safety engineering and, as an example, one specific fundamental course within the curriculum, called Enclosure Fire Dynamics. We shall then give examples of educational programmes in fire safety engineering offered at a number of Nordic universities and discuss how the close cooperation between Nordic academemians in the field has allowed a sound development of the fire safety courses and programs, in line with the CDIO principles and standards.

PERFORMANCE-BASED BUILDING CODES

Variations of performance-based regulation regimes have been adopted in many developed countries around the world for regulating such aspects as building and fire safety, air and water quality, consumer product safety, energy efficiency, food safety and many other fields. With regard to building and fire safety, there has been a worldwide tendency in recent decades to facilitate a transition from prescribed to performance-based building regulations.

It has been argued that the main purpose of building regulations is to serve as a legal tool to provide minimum social needs with regard to the built environment, without causing excessive costs to society. This objective can be achieved by regulations composed of a mixture of prescriptive and performance requirements. To clarify the terms further, a prescriptive rule would typically be of the type: “Escape routes shall not exceed 30 meters in length”, while the corresponding performance-based rule could typically be of the type “An escape route shall be designed in such a way that the occupants may exit the building safely in case of fire”. The prescribed rule presents an exact measure and can be easily verified, but is inflexible, while the performance-based rule states a goal, allows flexibility and various different design solutions, but verifying the fulfillment of the goal can be a challenge.

In many parts of the world an effort has been made to move from prescriptive demands in building regulations toward an increased use of performance-based demands. In many countries the shift has been gradual and careful, while other countries have opted to make comprehensive changes to their building codes in a single step, as described by Meacham (2010). The Society of Fire Protection Engineers (SFPE, 2015) has published guidelines on performance based codes and international entities such as the the International Standards Organization (ISO) and the International Code Council (ICC) have produced guidelines, standards and codes on this subject.

In the 1970s regulatory agencies of all types began to reconsider the traditional prescriptive approach to regulations, seeking ways to clarify the intent of regulation, reduce regulatory burden, and encourage innovation without compromising the level(s) of performance delivered. This gave rise to consideration of functional, objective-based or performance-based approaches to regulation. In the building regulatory environment, the hierarchy outlined by the Nordic Committee on Building Regulation (NKB, 1978) became a widely adopted model. Figure 1 shows an outline of the NKB hierarchy of demands.

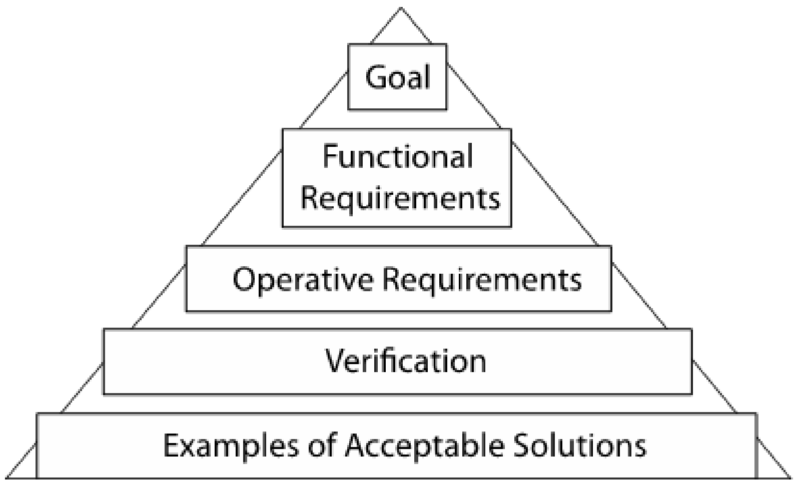

Figure1. The NKB hierarchy of demands.

In the NKB model the regulatory provisions are based on a set of broad societal goals, at the top of the pyramid. Through increasing levels of detail, functional requirements and operational requirements for buildings are described. Instead of prescribing a single set of design specifications for compliance, the approach outlines the need for instructions or guidelines for verification of compliance, in the next level. This could include engineering analyses, test methods, etc, and would be used to demonstrate compliance with the operative requirements. Finally, at the bottom of the pyramid one finds “Examples of Acceptable Solutions”. These are supplements to the regulations with examples of solutions deemed to satisfy the requirements, which may be prescriptive. The NKB model is attractive because it places the focus on societal (policy-level) goals and allows for a variety of forms of regulatory provisions to provide the detail required to demonstrate compliance.

Any regulatory regime must find a balance between how tight controls should be in promoting consistency and accountability versus how much discretion should be granted in promoting flexibility and innovation. The prescriptive approach emphasizes control and accountability. The performance-based approach desires to promote flexibility with accountability for results.

Some of the potential benefits of moving toward a performance-based regulatory regime are that this may lead to greater effectiveness in reaching specific regulatory objectives, greater flexibility in means of adhering to the regulation and increased incentive for innovation, resulting in buildings that are to a greater extent designed for the intended use.

However, the performance-based approach demands professional designers with a deep knowledge of the technical fundamentals, such as mathematics, physics, chemistry, thermodynamics to name only a few engineering disciplines. When developing the context, learning outcomes and curriculum of any fire safety engineering programme or courses, the CDIO standards form an excellent bases to build on.

In the next section we shall give a brief description of the fire safety engineering design process and how performance-based demands are typically presented in building codes. Such design methods must often include verification that certain design limits are met, which frequently requires the use of fire safety engineering calculations or modeling.

Further, we shall give an example of how a core curriculum for fire safety engineering education has been developed and give an example of how one of the fundamental courses in that curriculum was set up, providing simple engineering relations for solving engineering problems in performance-based fire engineering design.

THE FIRE SAFETY ENGINEERING DESIGN PROCESS AND CODE DEMANDS

Various sets of rules, procedures and guidelines on how to use fire safety engineering methods in building design have been developed over the last few decades. For example, it is known that humans can tolerate a limited amount of heat and a limited amount of toxic gases for a short time and some minimum visibility must be guaranteed if building occupants are to evacuate a smoke filled environment effectively.

A general consensus on a number of such limiting values has been established and published in standards, guidelines and a large number of national building regulations. The limiting values can vary somewhat between countries, but the performance based demands are essentially similar. For example, when the design goal regards the safety of building occupants, a demand is made that smoke does not hinder safe evacuation. This entails that the smoke level never reaches further than roughly 2 m above floor level, or that the concentration of carbon monoxide in the smoke is below 2000 ppm. A good description of the fire safety engineering design process and limiting design values is for example given in the Nordic Standard *INSTA 950 – Fire Safety Engineering – Comparative method to verify the safety design in buildings* (INSTA, 2014). The INSTA 950 Standard is valid in all the Nordic countries: Norway, Sweden, Denmark, Finland and Iceland. Several other standards and guidelines are available to the reader, such as the *SFPE Guide to Performance-Based Fire Safety Design (2015).*

The prescribed and the performance-based approach to design

When preparing a trial fire safety engineering design for a building an engineer will often base the initial design on pre-scribed demands in the building code, or pre-accepted solutions, as discussed in the previous section and presented as the lowest pier in the triangle depicted in Figure 1. For simplicity and expediency, it is thus quite common that buildings are initially designed against the threat of fire using only prescriptive demands or pre-accepted solutions, However, a deviation from one or more of these solutions may be in the interest of the buildier. For example, the fire safety design of a simple two-storey school building may easily be based on prescriptive demands or pre-accepted solutions, but when the owner decides that the stairway between the floors must be open, allowing smoke to travel between the floors, the designer may greatly benefit from utilizing calculations and fire models to design heat and smoke extraction of some kind, thus fulfilling the performance-based demand of a smoke free escape environment.

Figure 2 shows some examples of how design solutions can be verified when using prescriptive and performance-based fire safety engineering design methods, or a combination of both. Thus, compliance with fire safety regulations can be demonstrated by constructing the building in accordance with prescribed or pre-accepted solutions as defined by national building authorities. Alternatively, given that the national building authority in question allows and has set performance-based demands, a design solution can be based on fire safety engineering methods as a means of proving that the fire safety is satisfactory. This, however, demands that the designer has a fundamental understanding of the subject "enclosure fire dynamics", the study of how the outbreak of a fire in a compartment causes changes in the environment of the enclosure.

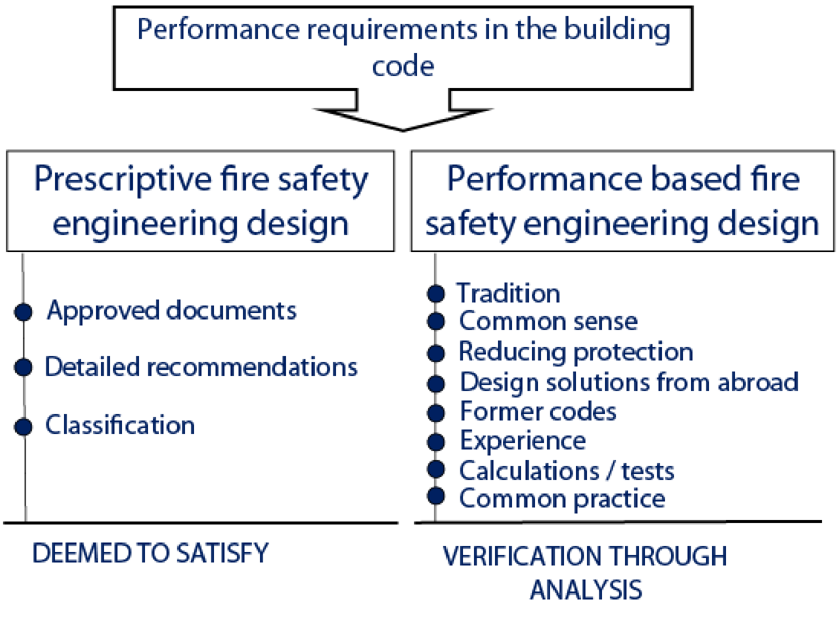

Figure 2. Examples of ways to verify compliance to demands presented in building codes using either prescriptive or performance-based fire safety engineering methods, or a combination of both.

In fire safety engineering design the engineer can use various tools to verify that the proposed design fulfills certain fire safety objectives, or design goals, and results in safety levels that are acceptable to society. The design goals can for example be safe evacuation of people, preventing building collapse, protecting valuables, ensuring safety of rescue teams in case of fire, to name some of the most common design objectives. In the process of verifying that design goals are met, the designer can use rational argumentation, traditional solutions, laboratory tests, common sense, and many other tools. When using calculations and models, these predominantly have a basis in classical physics, chemistry and thermodynamics, derived from scientific principles, empirical calculations and laboratory test results. The modeling techniques and calculational methods used for this purpose are the main focus when studying enclosure fire dynamics.

CORE CURRICULUM IN FIRE SAFETY ENGINEERING

The field of fire safety engineering encompasses topics from a wide range of engineering disciplines as well as material of unique interest to fire safety engineering. It is not immediately obvious which of these topics of interest should be addressed in courses for fire safety engineering students.

When developing courses for fire safety engineering students the authors were greatly assisted by the publication *A Proposal for a Model Curriculum in Fire Safety Engineering*, by Magnusson et al. (1995), which identifies the contents of the background, fundamental, and applied courses that may be taught within the discipline of fire safety engineering. The Society of Fire Protection Engineers (SFPE 2010 and 2013) has expanded on the curriculum in recent years for both bachelor's and master's programs, but the description below is based on the work of Magnusson et al. The fundamental courses listed by Magnusson et al are divided into five modules:

- Fire fundamentals
- Enclosure fire dynamics
- Active fire protection
- Passive fire protection
- Interaction between fire and people

These modules are interlinked to a considerable extent, and it is often a question of preference where to include borderline topics and where to present a summarized background. Also, it is not obvious where to strike the balance between material presented in the fundamental modules and material assumed to be prerequisite knowledge from basic courses in physics, chemistry, fluid mechanics, etc. We assume that the student has a basic knowledge of mathematics, physics, and chemistry.

The course Enclosure Fire Dynamics

As an example, one of the fundamental courses listed above will be further discussed here; Enclosure Fire Dynamics, the study of how the outbreak of fire in a compartment, causes changes in the environment of the enclosure. In many of the Nordic universities where fire safety engineering is taught, the textbook Enclosure Fire Dynamics by Karlsson and Quintiere (1999) is used as main literature. The textbook does not attempt to provide an in-depth study of all the phenomena involved, but rather to present the most dominating mechanisms controlling an enclosure fire and to derive some simple analytical relationships that can be used in practice. In view of the increased use of calculational procedures and computer models in building fire safety engineering design, the main purpose of this textbook is to:

- provide an introductory, basic understanding of the phenomena of interest and present some examples where these can be used in practice;
- derive the equations from first principles in order to give the student a true sense of the validity of the procedures in each design situation; and
- compare the derived equations with experimental data to provide a sense of confidence in the analytical results.

Additionally, laboratory experiments, computer labs, design exercises are discussed and described in the textbook.

EXAMPLES OF PROGRAMMES AND COURSES IN FIRE SAFETY ENGINEERING

At several Nordic universities, fire safety engineering courses are presented in a great variety of ways. Some universities teach one or two fire related courses as a part of a BSc or MSc engineering degree, other universities provide full BSc fire safety engineering programmes and some provide a full MSc fire safety engineering degree on top of any BSc degree in engineering.

To mention a few examples, Lund University, Sweden, offers an extended BSc degree in Fire Protection Engineering, a 3,5 year programme with around 50 students per year and Lulea Technical University, Sweden, offers a similar BSc programme. Lund University also offers an International Erasmus Mundus Master in Fire Safety Engineering (IMFSE), which they run together with Ghent University and The University of Edinburgh. This is a 2 year program with around 20 students/year, where the students spend 1/3 of the time at each of the three universities.

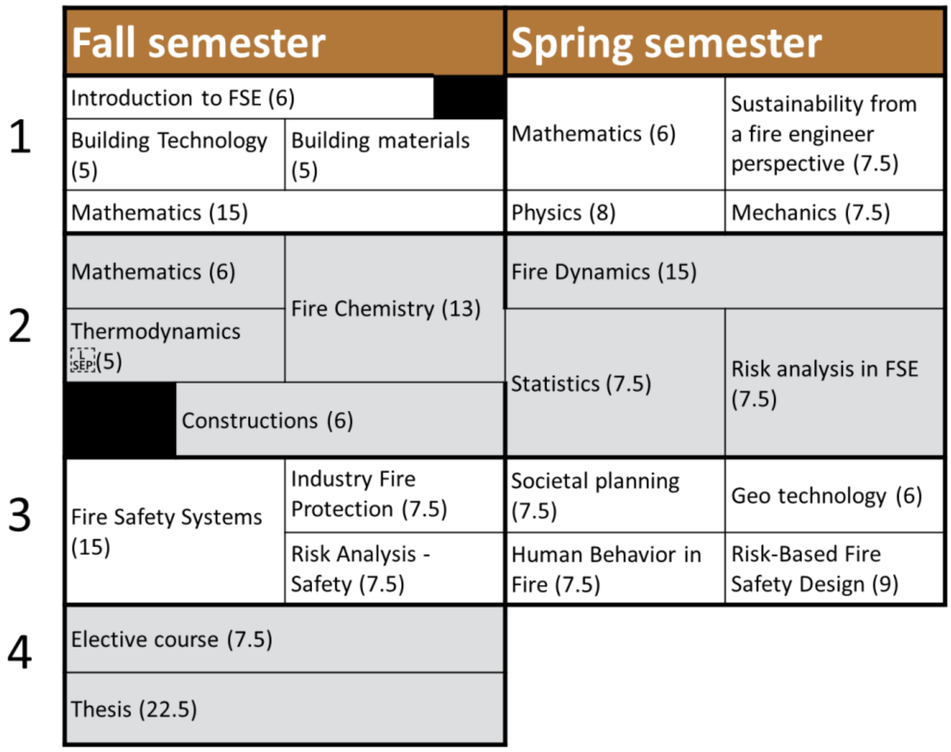

Figure 3. A schematic of the 3,5 year extended BSc programme in Fire Protection Engineering offered at Lund University, Sweden.

As an example of these and other programs, Figure 3 shows a schematic of the 3,5 year extended BSc Fire Protection Engineering programme offered at Lund University where the numbers on the left hand side represent the years of study.

Graduates from these educational programmes have been very much appreciated by employers, such as industry, government and local authorities and there has been no unemployment registered for Fire Safety Engineers (or Fire Protection Engineers) in Sweden in the last decades. The graduates from these programmes have on average higher salaries than graduates from other engineering programmes, such as Civil Engineering and Mechanical Engineering. Applications to enter the programmes have been far greater in numbers than the intake over many years. In view of these facts it can be clearly stated that the Fire Safety Engineering (or Fire Protection Engineering) programmes in Sweden have been very successful in general.

When examining the course descriptions for these programmes, it is clear that the courses, and the educational programmes in general, fulfill to a high degree the relevant CDIO Standards. This is especially so for Standard 2 – Learning Outcomes, Standard 3 – Integrated Curriculum, Standard 4 – Introduction to Engineering (see top of Figure 3), Standard 5 -Design-Implement Experiences, Standard 6 – Engineering Workspaces and Standard 7 – Integrated Learning Experiences.

COLLABORATION OF NORDIC ACADEMICS IN FIRE SAFETY ENGINEERING

In addition to the programmes offered at Lund University and Lulea Technical University described above, various additional degree programs and/or single courses on fire safety engineering are provided at several other Nordic universities, such as Denmark Technical University (DTU), Aalto University, Finland, Norwegian University of Science and Technology (NTNU), Norway, Western Norway University, Haugesund, Norway, and University of Iceland, to name only a few. The academics at these educational establishments, involved in fire safety engineering education, have been collaborating for the last many years on course development and production of educational material, as well as organizing conferences and collaborating in research.

This informal cooperation through the years was formalized in the year 2015, when a core group of Nordic fire safety engineering educators and researchers started the organisation Nordic Fire and Safety Days (NFSD). The main activity was to hold annual conferences on fire safety engineering issues in the Nordics and enhance Nordic collaboration in the field. Since then this platform has grown and the conference has become a meeting point for educators, researchers, students and professionals interested in fire protection and safety issues in general.

A further step was taken in the year 2020, when this network of educators and researchers in the field applied for and received funding from Nordic Energy (a funding organization linked to the Nordic Council of Ministers) to focus on fire safety and risk management of buildings and energy infrastructure. The network has now organized summer schools, webinars and educational opportunities for professionals, in line with the CDIO emphasis on continuing education.

Additionally, the authors of this paper have been collaborating on educational material for some of the fundamental courses in the fire safety engineering programmes, specifically the course Enclosure Fire Dynamics. Three of the authors have received four grants from Erasmus+ Staff mobility for teaching. Two of the authors have now prepared a second edition of the textbook by Karlsson and Quintiere (1999) and other authors have contributed towards teaching material, such as Power Point slides, homework assignments, description of laboratory experiments, reading instructions for students, detailed suggestions for certain problem solutions and descriptions of computer labs for simulating fires and evacuation. All this educational material, which the authors and others have collaborated on developing, is available for free at the website of the International Association for Fire Safety Science, www.iafss.org.

CONCLUDING REMARKS

The CDIO Call for Paper September 2021 states that „The CDIO collaborators recognize that engineering education is acquired through programs of varying lengths and stages in a variety of institutions and that educators in all parts of this spectrum can learn from practice elsewhere". This paper provides an example of how this has been achieved by a cross-Nordic collaboration on providing and developing educational material in an emerging engineering discipline, Fire Safety Engineering.

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RECYCLING PROGRAMS FROM ENGINEERING FOR STUDENTS AND THEIR FAMILIES

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ABSTRACT

In today's world, the need to take care of our environment and reduce our footprint on it is increasingly essential. Although the universities have recycling programs inside the campus, including collection sites, in our country, Colombia, there are no programs from the university aimed at motivating the work of recycling by students and their families inside their homes. To create awareness in each student and involve their family members, the recycling program at home was created, which has academic recognition through additional voluntary evaluations. Our project is based on three types of activities, which are supported by programs by private companies, unfavorably these programs have not been widely disseminated nor are they remembered among people as would be desired. Therefore, many of our students who start the program were unaware of the existence of these programs and the potential for action that they could have in their environment. The three recycling programs are plastic bottles filled with single-use plastic (“botella de amor” = “bottle of love”) to create furniture with recycled material for use in schools, plastic caps (“tapitas para sanar” = “caps to heal”) for a foundation that makes treatment of children with cancer, and recycling of used cooking oil (“manos verdes” = “green hands”) for the manufacture of soaps and candles. This document shows the process of conception, creation, and implementation of the campaign, the results obtained both from the students and within the families, together with the satisfaction, involvement, and participation of the students. Also, the project promotes the development of communication skills for engineers.

KEYWORDS

Recycling, Sustainability, Engaging students, Engineering education, Communication skills, CDIO Standards: 7, 11. CDIO Optional Standard 1 (V 3.0)

INTRODUCTION

> Toward the end of January, the sea was growing harsh, it was beginning to dump its heavy garbage on the town, and a few weeks later everything was contaminated with its unbearable mood. From that time on the world wasn’t worth living in, at least until

> the following December, so no one stayed awake after eight o'clock. (García Márquez, 1999, p. 226)

Sometimes life consists of diving into the waters of reality; sometimes it consists of immersing yourself in something like a chapter of a magical realist or science fiction story. At the beginning of The Sea of Lost Time story, Gabriel García Márquez brings us closer to the paradoxes of development and the dreams of humanity. As in the story of the Nobel Prize in Literature, contemporary reality is debated and presents questionable aspects. Entering the 21st century, many corners of the planetary geography continue to suffer the irruptions of the modernizing project. Capurganá, a tourist center on the Pacific Ocean in Colombia, is part of the Darién region, an area of global importance for the conservation of biodiversity. Migrating birds and other animals found in this corridor a crucial point in their journeys through Latin American territory. It is also part of the world's migrant route. However, the maritime and jungle landscape of Capurganá is drowning in 200 tons of garbage (Osorio, 2022; El Tiempo, 2022). Despite the seriousness of the previous news, the fact did not transcend the world news agenda. However, Colombia is the country with the greatest biological wealth per square kilometer: 14% of the planet's biodiversity. But its biodiversity and titles are in danger: the first place globally for the number of species of birds and orchids; the second in plants, amphibians, butterflies, and freshwater fish; third place in palms and reptiles; and the fourth in mammals. According to the Humboldt Institute (2021), the serious deterioration of biodiversity is putting life in the country at risk.

The United Nations (UN) leads several initiatives related to the preservation of the environment and other issues related to sustainable development in the world. Due to the growth of the world population, it is expected that by 2050 global solid waste ("trash") is expected to increase from 2.01 billion tons to 3.40 billion tons per year. According to UNESCO (2021) "if we continue to live the way we do now, the equivalent of almost three planets would be needed to provide the natural resources" (p.3). As for plastic waste, if consumption patterns and waste management practices do not begin to change, it is estimated that by 2050 there would be 12,000 million tons of plastic waste in landfills and in the environment. With this scenario, the Ministry of Environment and Sustainable Development of Colombia (2022) projects that the rate of recycling and use of solid waste by 2022 will increase to 14.22%.

In the joint work on environmental issues and the formulation of proposals that involve the perspective of sustainable development, sustainability, environmental education, among others, various actors of society are participating (United Nations, 2021). Institutions related to university education for example: UNESCO 2021, Futures of Education initiative, and the CDIO initiative are leading projects to integrate these issues into university education processes (Wedel et al, 2019; Cheah et al, 2012; Cheah, 2014; Malmqvist et al, 2020a; Malmqvist et al, 2020b). Finally, a study (Rosén, A, et al, 2019) showed that "enhanced integration of sustainable development will contribute to improving the relevance and future compliance of engineering educations and could also contribute to students' and teachers' motivation" (p. 74).

ENGINEERING EDUCATION FOR LOCAL AND GLOBAL CHANGES

Pope Francis (2015) in the Encyclical Letter *Laudato Si* said:

> The urgent challenge to protect our common home includes a concern to bring the whole human family together to seek a sustainable and integral development, for we

> know that things can change. Humanity still has the ability to work together in building our common home (p. 12).

In affinity with this call from Pope Francis, the Pontificia Universidad Javeriana in Bogotá, Colombia, leads a waste reduction and recycling management program that aspires to have positive effects on the academic, professional, and personal lives of the people involved. This program, aimed initially at students of the basic cycle of the Electronic Engineering career, has the purpose of encouraging care for the environment based on the following general objectives:

First, strengthen local and global cooperation to form "citizens of the world", as proposed by Martha C. Nussbaum in tune with education:

> We live in a world in which people face one another across gulfs of geography, language, and nationality. More than at any time in the past, we all depend on people we have never seen, and they depend on us. Nor do any of us stand outside this global interdependency. The global economy has tied all of us to distant lives. Our simplest decisions as consumers affect the living standard of people in distant nations who are involved in the production of products we use. Our daily lives put pressure on the global environment. Education, then, should equip us all to function effectively in such discussions, seeing ourselves as "citizens of the world" (Nussbaum, 2012, pp. 79-80).

Second, to contribute to awareness based on the recognition of our "Earth-Home" and teach the "Earth identity". The concepts "Earth-Home" and "Earth identity" come from the *Seven complex lessons in education for future* (Morin, 1999); UNESCO recognizes the validity and necessity of this knowledge in the 21st century for education throughout life:

> *Development conceived exclusively as techno-economic progress, including durable development, is in the long term unsustainable. We need a more rich and complex notion of development which is not only material but also intellectual, emotional, moral*…. *The education of the future should teach an ethics of planetary understanding* [author's emphasis] (UNESCO, 2021, pp. 34, 39).

The above approach is valid by virtue of the environmental situation in the world, but also given the seriousness of the problem in the Colombian context, since in Colombia 12 million tons of garbage are produced per year, of which it is recycled on average 17%.

The Pontificia Universidad Javeriana created its ecological and environmental policy in 2015 and participates in the *UI Green Metric World University Ranking*, an initiative of Universitas Indonesia (UI Green Metric, 2022). Although the incorporation of the ecological and environmental dimension has its origins in the seventies, the programs designed in the training courses with a perspective of a holistic approach to the issues of environment and sustainable development are contributing to training students who can act as agents exchange.

The project, which combines the conceptual perspective and real problems such as those indicated, was also implemented considering the principles of CDIO, as described below. Keeping in mind the greater purpose (to encourage care for the environment), activities were designed to point in this direction with the conviction that engineering learning and teaching well admit a holistic and transdisciplinary vision. In this direction, Jamison from Aalborg University proposed the term *hybrid learning* for engineering education that includes aspects considered for this project:

> In the transformative learning experience, grand challenges such as sustainability are not fixed; they are continuously constructed and reconstructed, and the students are to be prepared not only to enter but also to set the scene for the change of discourses, institutions, and practices (Jamison, 2014, p. 268).

It has been mentioned that the knowledge coming from relevant experiences of CDIO in other universities was searched, mainly, regarding sustainability or sustainable development: Cheah (2014) describes a model curriculum for Education for Sustainable Development (ESD). Binder et al (2017) show a possible implementation of Sustainability aspects in Mining Engineering education. Finally, Uruburu et al, (2018) expose results and reflections on teaching-learning methodology to incorporate sustainability aspects in engineering projects.

In another sense, the actions of the CDIO network were consulted in the review and update of the Standards and Syllabus about sustainable development, competencies for sustainability, and CDIO optional standards 3.0.

PROGRAM AND EXPERIENCE

The need to include an agenda on environmental issues in the syllabus of the subjects of the first two years has been identified. Thus, students were proposed to carry out an optional activity on the declared purpose of caring for the common home. This activity could integrate both the students and their family nucleus and/or the people with whom they shared a home. The optional activity sought to confront the habits and practices of consumption and recycling of students and their families to motivate thinking that would allow them to understand their relationships with the environment in a more sustainable, responsible, cooperative, and ethical way.

The participation of students and their families in the programs of non-profit organizations that were selected for this project because they deal with waste management and recycling. Generating other types of interactions from their actions to solve community problems.

As additional motivation, students are offered the opportunity to earn an additional quiz score of 5.0 (highest possible score) for participating in each of the following three recycling programs.

- Program of Bottles of love ("*Botellas de amor*", in Spanish) transforms plastic waste through the action of filling plastic bottles with all kinds of flexible plastic packaging (Botellas de Amor, 2019). They would seem small or insignificant actions, but with this material (Recycled Plastic Lumber), they are building homes and furniture to improve the lives of vulnerable communities (Teleantioquia, 2017). The limitation is that it only works in six sites in the country.
- Program of C aps to heal ("*Tapitas para sanar*", in Spanish) promotes the recycling of plastic bottle caps (Sanar, 2022). Collection points have been increasing in places such as shopping centers, educational institutions, and companies. The strategy for 2022 is to promote the acquisition of mini collectors that are more functional for small spaces. In addition, they facilitate a better work of communication, promotion, and environmental education. The resources of this program are aimed at supporting children and adolescents with cancer.
- Program of Green Hands ("*manos verdes*", in Spanish) was born in 2016, from the idea of a citizen who decided to contribute to the environment by recycling used cooking oil

and converting it into biofuel (Manos Verdes, 2022; Team Foods, 2020). The strategy began in the main restaurants, hotels, and supermarkets in the country. The growth in 76 municipalities in the territory is complemented by the strategy of reaching homes. Collection devices are being installed in residential complexes (Marce, 2020).

When engineering students were exposed to the existence of these organizations and their programs, they noticed a lack of knowledge or low recollection of their purposes. In this sense, it is that fields such as Communication for social change and Education for Sustainable Development (ESD) are included in the matrix of these projects to base the achievement of the objectives, at a personal and collective level.

In the formulation of this project, two aspects mentioned by Grosseck et al (2019, p. 2), about the Education for Sustainable Development (practice of teaching for sustainability) were considered. First, “can be seen as a holistic approach, involving the integration of major sustainable development issues into all teaching and learning strategies”. Second, “is a means of promoting key competencies for sustainability, such as critical thinking, systematic thinking, self-awareness, problem-solving, etc.”.

Within the learning outcomes of the course, there is no explicit mention of anything related to caring for the environment. However, the fact that they are not explicit does not mean that they should not be mentioned or considered. It should be clarified that although these environmental care activities have an academic recognition in the quizzes mark, it is more symbolic than practical, since 12 tests are usually carried out per semester and the average mark is higher than 4.0, for what the additional marks in 5.0 do not produce a significant change in this final mark (less than 0.02/5.00). What it does do is initially motivate students to start at least one program and, although there is no significant variation in the grade, they continue to do so in the following classes in which the same activity is offered.

From the first class, they are informed about this optional activity, and they are given the delivery dates. They must send a photo with the empty bottles before the sixth week of class, and they must send another photo with the progress of their work (it is not necessary that this 100% fills the bottle) before week 14. Having a bottle or more filled with single-use plastic or cooking oil, it only gives you a single additional quiz mark at 5.0. Figure 1 shows some of the submitted photos of the “bottle of love”. Initially, the photo was only of the bottles, but to make the activity more personalized, they should appear in the photo with the bottles.

Figure 1. Students showing their "bottles of love".

In Colombia, each person consumes more than 24 kg of plastic per person per year and only 56% of it is single-use, that is, straws, cutlery, plates, containers, and bags. (Semana, 2022)

Figure 2 shows some of the submitted photos of the “green hands” bottle.

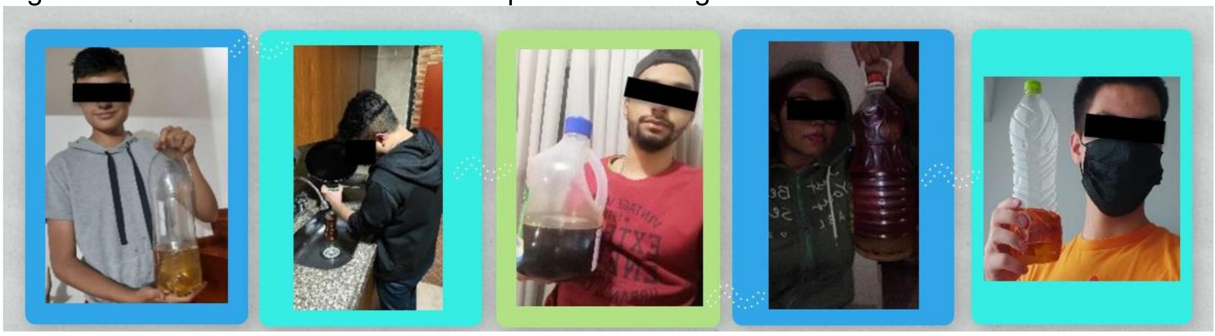

Figure 2. Students showing their bottles of oil, “Green Hands”.

It is estimated that just 1 liter of oil can contaminate 1 million liters of water (Oil Care, 2015).

Figure 3 shows some of the submitted photos of the “caps to heal”.

Figure 3. Students showing their “Caps to Heal”.

Plastic bottles and plastic caps can be deposited at different collection points throughout the city. On the campus of the university, there are these collection points, shown in Figure 4.

Figure 4. Collection point at the University campus.

The bottles with oil must be taken to a supermarket chain, which has a branch two blocks from the university campus. It should be clarified that there is no type of payment or economic compensation for the delivery of the bottles or caps.

The program began before the COVID-19 pandemic, in face-to-face classes, and continued during the time of the pandemic, in which it had a greater effect.

SURVEY AND RESULTS

A survey was carried out among the students who have taken the course in order to find out their perception of the proposed recycling activities. This survey was answered by 33 students, of which 18 were men and 15 women, the age of the participants is from 17 to 22 years. 88% of the students stated that they participated in the recycling activities. The students who did not participate stated that it was due to a lack of time or because they did not generate enough plastic at home to carry out the activity.

Students were asked what their motivation was for participating in this activity. The main motivations for participating in the program were to collaborate with the care of the environment and to obtain an additional mark in quizzes, with 72% of the students choosing these options. Carrying out a different activity was chosen by 69% and 66% of the students did it to feel good about themselves and 28% indicated that it was to learn something new.

It is curious that although the effect on the note is very small, it was one of the main motivations to participate in the program. This may be due to students trying to take every opportunity to improve their grades.

Regarding the importance that they give to their contribution to the solution of environmental problems in their environment, 78% that it is very important or important, while 38% indicate that it is moderately important.

Students were also asked how important they consider sustainable development to be in engineering. 79% state that it is very important and 21% that it is important.
Regarding the relevance of including optional activities related to the reduction of solid waste and recycling in Electronic Engineering subjects, the survey shows that 96% of those surveyed agree to include these activities.

The survey also asked about the recycling programs that they were aware of before starting the course. The "Bottles of Love" program was known by 44% of those surveyed, 36% were aware of the "Cap to Heal" program and only 12% were aware of the Manos Verdes program (oil recycling). Finally, 8% of the students stated that they did not know any of the programs.

An interesting result of the survey is related to the degree of influence you have caused in the family and/or in the people with whom the students live in their participation in these waste reduction and recycling programs. The results show that 62% of the students have a very high or high influence, a much higher percentage than their prior knowledge of recycling programs. While 28% indicate that it had a medium influence. 10% say they had little or no influence. Additionally, 83% of the students indicate that after finishing the course the importance they give to environmental issues increased.

Another question that was asked to the students was about what aspects related to the recycling activities were interesting for them when studying the subjects. Some students indicated that what was most interesting was that these activities involved several members of their families. For example, one student said: "*It was interesting to get my whole family to help me in this activity and to make a change in four families regarding recycling*"

Other students expressed the continuity of these learning activities after finishing the subject. For example, a student said: "*It was interesting to see that from then on, we continued recycling even though the subject had already finished, it was interesting to fill the bottles because we did it as a family*"

The students also highlighted the importance of giving plastic a second use, being aware of the amount of plastic they generate and the importance of recycling and environmental care. For example, a student stated that "*the process of transforming plastics into furniture for the home was interesting. The amount of waste that I produce per day that can be recycled*."

Finally, some students proposed some actions to strengthen the training of engineers in environmental issues. Here are some of the ideas proposed by the students:

- Conducting talks with people who work in these recycling programs
- Development of more awareness activities about caring for the environment and the importance of recycling.
- Development of engineering projects focused on sustainability, recycling, and awareness.
- Reducing the delivery of class work using sheets of paper.
- Development of citizen competencies that promote good habits towards the environment.

CONCLUSIONS AND FUTURE WORK

The crisis produced by the COVID-19 pandemic forced the educational system to assume the virtual space, which could provide a favorable aspect that requires further study, to the extent that it confronted students with the world of the personal, but also with local and global changes, the need for solutions and the importance of global citizenship. As the economist Mariana Mazzucato (2021, p. 8) states, “the COVID-19 crisis has revealed the fragility of capitalism”.

Due to the findings of the results and the feedback from the students, it is necessary to explore other links of knowledge and practices from Education for Sustainable Development and the Communication for social change. The project also favored the practices of interpersonal and communication skills.

The intention of the program to raise awareness about caring for our planet through individual actions and to influence our families and friends through these actions (standard 7, 11) was fulfilled, so much so that in some houses the spaces and number of garbage containers were reorganized. In addition, their interest and commitment to environmental protection increased (Optional Standard 1 V 3.0).

As future work, we want to extend this experience to other degrees and carry out more awareness activities, such as informative talks on small individual and collective actions that help reduce the impact on our environment.

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TEACHING PRACTICAL COMPUTER NETWORKING WITH LIMITED RESOURCES

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ABSTRACT

Computer Networks is an important, and often compulsory, course in most Computer Science curricula. Teaching it is often challenging due to the abstract nature of the subject, and the wide range of material that has to be covered. At the same time, an understanding of core concepts in computer networking is increasingly important to students, due to the increasing proliferation of networked devices, and the associated challenges in designing and developing networked and distributed applications. In this paper we discuss our experiences in bringing a stronger practical content to this course over several years,following the Conceive Design - Implement - Operate (CDIO) philosophy. This introduced a series of carefully designed practical assignments throughout the course, building on traditional simple client-server program exercises, through a puzzle based assignment using hand crafted packets, to the final project which involves the construction of a collaborative peer-to-peer network running on student laptops involving the entire class. We will discuss how the practical content is purposefully designed to support the more theoretical aspects of the course, as well as some of the technical challenges encountered.

KEYWORDS

Computer Networks, Project-Based Learning, Standards: 6, 7, 8

INTRODUCTION

Computer networks is a core subject in the modern computer science curriculum, and represents a significant body of theoretical and practical knowledge which provides an important basis for other advanced subjects like Distributed Systems and Internet of Things. Computer networking's principles are core to a wide range of critical economic and technical systems, ranging from distributed computing, through any form of programming that operates on more than one core or central processing unit (CPU), high performance computing, and the daily operations of core business IT systems. Unfortunately it has long been regarded as a highly technical, complex, dry, and difficult course by its students (Sarkar, 2006). Although it is widely recognised that it is a course that can benefit greatly from providing a practical design and implement experience, the dedicated networking equipment and laboratories to provide this experience are expensive and not always available.

Reykjavik University places an emphasis in its scientific instruction on hands-on learning with an emphasis on practical preparation for the challenges students will face after graduation.

The CDIO standard 6 suggests a physical learning environment that supports a hands-on learning process on a networked system. Computer networking equipment is typically expensive and practical training facilities are often confined to industry or only sufficient for a small number of students. We want to follow the CDIO emphasis on active learning in Standard 8.[1] When teaching the compulsory third year computer networks course, Tölvusamskipti (TSAM), however, adopting this approach had been problematic, as the university did not have the laboratory resources in support this approach, particularly for the large class size (200+ students) taking our compulsory third year computer networking course. Prior to the introduction of the changes described in this paper, practical exercises in the course had been restricted to analysing protocol traces using Wireshark, and re-implementing existing protocols such as the trivial file transfer protocol(TFTP) (Malkin & Harkin, 1998). The course was generally unpopular with its students, routinely described as "ridiculously hard" in student comments, and overall student performance was poor with an unacceptably high failure rate, particularly for a compulsory course.

The steps taken to address these issues that we discuss in this paper were relatively small. The lecture content remained substantially the same, although it was switched from following the Kurose and Ross (2016) approach which introduces the network stack from the application level and proceeds to the physical level at the end of the course, to the bottom up approach used by Tanenbaum and Wetherall (2011) and Dordal (2020) which does the reverse. A slightly larger emphasis on network programming was introduced in order to support the new projects. The project content was completely revised, and a series of projects were introduced that provided a hands on laboratory experience following the CDIO standard for Engineering work spaces in Standard 6, and a final project which emphasised CDIO Guided Design and Implement standard 5, using the student's own laptops as a development platform. The projects culminated in a class wide exercise which required students to create a class wide live peer-to-peer network providing an interactive messaging service for all participants. By dint of using the student's personal laptops as the nodes in this network, with some minimal support from instructor servers running on university facilities, it was possible to create these exercises without requiring any additional resources. Reykjavik University does have the advantage of having a state of the art backbone Cisco network which is a consideration, but the projects described here require little more than basic Internet connectivity, and could be attempted either on campus, or from home networks.

Following these changes, the course has now been taught successfully for four years, two of which were online due to the Covid Pandemic. Student reaction to the changes has been extremely positive, performance on the course has significantly improved, and the failure rate has normalised to typical third year levels. Although the course is still regarded as challenging by students, the project experience, and in particular the collaborative last project in peer-to-peer networking have changed student perception to the course to one where they "learn a lot", and even have fun.

[1] CDIO Standard 3.0 CDIO Standard 3.0

TEACHING COMPUTER NETWORKS

In their comprehensive review of 261 Journal and Conference papers on teaching computer networks, Prvan and OžEGOVIć (2020) distinguish four broad strategies in computer networks teaching: using network simulators, either physical laboratories or virtual simulators such as Network Simulation (NS2/NS3)[2] (Gupta, Ghonge, Thakare, & Jawandhiya, 2013), packet tracing where the detailed structure of networks packets is examined using tools such as Wireshark, visualisation techniques with videos, or interactive environments (Getchell, Miller, & Allison, 2005)[3], and virtualisation where laboratories are provided either by software environments, or remote facilities - an approach often favoured in industry for specialised manufacturer based training. To some extent the approach may depend on whether the focus of the course is the design and configuration of network equipment, or a broader focus on networking as a programming problem. Virtual simulators are supported by all the major manufacturers and can provide an excellent way of learning how to setup and configure networks (Gusev, Ristov, & Donevski, 2014), and this approach is also strongly favoured in industry for training to use network equipment. However although the skills required to setup and administer network equipment are congruent with those required to develop distributed and networked applications, they are not identical. At Reykjavik we provide a programming focus for our general networks course, and offer an optional more specialised network design and configuration course for those who wish to take it.

The typical undergraduate introductory computer networks course has a heavy lecture component, following the bedrock laid down by Tannenbaum's Computer Networks(Tanenbaum & Wetherall, 2011) first published in 1981, and still used widely today. This book was originally organised on the OSI 7 layer model for computer networks, and has been adapted over time to include newer technologies, remove obsolete ones, but retains its original format of introducing the network layers one at a time, beginning with physical connections, and ascending the application stack. Naturally, other textbooks, notably Kurose and Ross (2016) have developed the subject in the other direction, beginning with the application layer, today represented by web servers and the accompanying HTML protocol, and then descending the network stack to end at the physical level. Both approaches have entrenched proponents. The top down approach has the advantage of introducing networking with concepts that students have already encountered, and are familiar with, whilst the approach of beginning with the physical level has the advantage that concepts build on each other more or less naturally, and to some extent follow the historical development of the technology itself from small local area networks to the global network of networks, the Internet.

From the perspective of teaching computer networks using programming exercises, there is an advantage to Tanenbaum's order, in that the detail of network communication using packets, with packet headers and protocol exchanges is arrived at earlier, allowing early student exercises to be constructed around packet tracing and building packets by hand using low level programming. This also allows packet tracing to be introduced as support for debugging the student's own programs, following the Design-Implement paradigm of CDIO. Much of this detail is abstracted away by modern high level programming languages, and this can be problematic as it prevents students from developing the necessary knowledge to successfully troubleshoot

[2] `http://nsnam.org`

[3] In this context the 1999 Ericsson video, "Warriors of the Net" deserves special mention Warriors of the Net, Ericsson Media Lab 1999

network issues when they encounter them. This can be quite problematic, as the behaviour of a naively programmed application on a local, high speed network, can be quite different to the same application running over a wide area network due to issues of packet delay and fragmentation that may not be encountered under more ideal "laboratory" conditions. It is also the reality of many of today's internet based distributed programs that they incorporate their own software based networking in order to function, which has to solve many of the same problems as the underlying network equipment. By asking students to construct a peer-to-peer network in software, they are necessarily exposed to the reasons for many of the design choices underlying the creation of the Internet and today's distributed systems.

PROJECT BASED LEARNING

Whilst server resources were extremely limited, an important development here and elsewhere in the last decade is that all students can now be relied on to have laptops. Whilst dealing with vagaries in the different operating systems networking does present challenges, the ability to do so has always been an important, although not necessarily explicitly taught part of computer networking. To achieve our goals, we replaced the existing exercises with three consecutive, project based programming exercises which developed in complexity over the term:

1. A simple client-server program running between the student's laptop and a campus server.
2. A port knocking exercise using hand crafted packets to solve a series of server based puzzles.
3. Construction of a class wide peer-to-peer messaging network.

The first project was individual, but students were allowed to work in pairs for the second and third projects.

1: Client-Server programming

This assignment provided students with simple client/server messaging software and asked them to make small extensions to it. Developing network programs can be extremely frustrating for beginners simply due to the number of places things can go wrong, which are not limited to the student's code. Students need to learn to deal with the the vagaries of their local networking environment, and since unlike dedicated facilities laptops are prone to occasionally losing WiFi connectivity, the necessity of testing end to end connectivity is an extremely useful learning outcome. The main learning outcome of this exercise was to familiarise students with network troubleshooting, and the Berkeley sockets programming interface.

Network troubleshooting is perhaps the most valuable skill that we can attempt to impart in the general undergraduate networking course. Troubleshooting network issues can be a complex and demanding task. Even with simple undergraduate exercises, there are multiple points of potential failure besides the student's program. End to end connectivity in modern networks is challenged by features such as Network Address Translation(NAT), and security measures such as Layer 2 isolation which may invisibly block direct connections between student machines on the same WiFi segment. Whilst these can be frustrating to experience, they also useful provide reinforcement for key objectives in the course, and help to actualise what students are learning through lectures.

2: Port Knocking

Port knocking is a technique for restricting network access to applications by requiring a special sequence of packets to be sent to the application port, in order to establish full connectivity. In this exercise, which was developed by one of the courses TA's, Benedikt Þórðarson, students were asked to sent hand crafted UDP packets to a server, in order to unlock a series of puzzles, including the use of relatively obscure features of TCP/IP such as the "evil bit" (Bellovin, 2003).

The learning outcome of this exercise was to make lectures describing packet structures and protocols more relevant, and also to highlight key differences between TCP/IP and UDP, in particular with respect to packet loss. The puzzle element however, introduced a more interesting aspect to the exercise, whilst Instructor control over the target server made assisting with student debugging when necessary much easier, as server logs could be consulted to provide additional information.

Some technical challenges were encountered during this project, in particular it had to be designed around the behaviour of the campus VPN which blocked some packet settings. In later years we have been able to acquire a machine outside the campus firewall which avoids some of these issues, however non-standard firewall and VPN behaviour is increasingly becoming the norm, due to security considerations, so careful design and testing is recommended for these kinds of exercises.

3: Peer-to-Peer Networking

This was a class project, where students were asked to create nodes in a peer-to-peer TCP/IP based network, implementing a simple protocol to perform store and forward messaging between the nodes, allowing them to send short chat messages to other nodes on the network. In order to do this successfully, students needed to create a messaging layer using TCP/IP, which helped expose them to some of the underlying behavioural quirks of that protocol with respects to the arrival of bytes in the TCP/IP stream. TCP/IP guarantees ordered and reliable delivery of a stream of bytes, but makes no guarantees about the latency of their arrival. This can often create issues where networked programs work perfectly "in the lab" under ideal, uncongested conditions, but fail badly when deployed on more congested networks. This behaviour tended to occur naturally occur at the instructor nodes towards the end of the project, but modifications were also made to the instructor software to guarantee it in the last iteration of the project.

Students were provided with a simple protocol description, instructed that they could make extensions to it if they wished, and were encouraged to work together as a class to create as many network connections as possible between nodes, using the class piazza forum for discussions. Minor changes have been made to the protocol description every year to deter undue copy and pasting between the years.

Designing and implementing network protocols is not just a technical challenge, but on industry standards committees, can also be a non-trivial exercise in diplomacy and negotiation. Networking technology often offers choices between multiple solutions to a particular problem, and the realities that lie behind some design choices are not always apparent. In particular the challenge of getting changes accepted to existing protocols which have been widely deployed, are not always apparent to students. Part of the intention of the last project is to provide exposure to some of these issues surrounding protocol design. In the first, second and fourth years the project was set with a protocol that was deliberately incomplete, requiring students to reach a consensus on how to extend the protocol to resolve this. Since there were at least two different ways this could be done, this effectively created a class wide Fischer consensus problem (Fischer, Lynch, & Paterson, 1985) around agreeing which solution to pick.[4]

Classes have dealt with this issue in different ways. In the first year two competing standards were developed more or less simultaneously by two different groups within the class, who then actively and independently recruited other students to their standard. Attempts were also made to resolve the differences between the two approaches, but unfortunately this took the form of an extended debate about which was better. Although discussions on the class piazza forum were remarkably civilised, it is understood that the student's own facebook groups were slightly more heated. A number of student servers were developed that dealt with both protocols, and were awarded high marks for doing so. In the fourth year however, one student group spotted the issue with the description very quickly at the beginning of the assignment, wrote and circulated a detailed protocol extension with instructions on how to implement it, and also assisted other students with doing so. As a consequence the entire class adopted their standard.

Students are graded primarily on their implementation of the protocol, and overall code quality, but an ascending number of bonus marks are also provided for connectivity between groups, which provides an incentive both to provide continuously running servers, and to develop them as early as possible. This also helps to expose students to the critical importance in computer networking of extremely robust code that can run continuously for long periods. It also motivated students to write servers that were robust to minor variations in other student's implentations of the protocol, and to work with other student groups to resolve protocol issues - helping considerably in reducing instructor load for the project. Several instructor nodes were also provided running on a campus server, to act as backbone nodes for the network for connectivity purposes, and also to provide messaging load in the form of periodically broadcast MD5 hashes of messages that needed to be decoded. These nodes served as a known point that could be connected to by student nodes behind home network NAT protection, allowing these nodes to join the network, and then connect to other student nodes. The instructor nodes also provided useful output for debugging purposes, and some automated assessment.

DISCUSSION

It is easy when teaching computer networks to get lost in a dry discussion of the many data communication protocols used in the network stack, without managing to impart some of the broader aspects of protocol design and the technical challenges in actually implementing network communication mechanisms. Since many of these broader technical aspects are common to protocols at all levels of networking, asking students to create a software network provides practical experience that helps them implement some of the theories they are being exposed to. Developing techniques for routing messages between student nodes to maximise connec-

[4]This was not included in 2020, the first year of the Covid emergency, due to uncertainties around the success of this project in a purely online teaching environment.

tivity, determining methods to deal with nodes randomly entering and leaving the network, or sending malformed messages, helps reinforce and actualise the material they are receiving simultaneously in lectures. The traditional lecture material used for computer networks courses originated during a time when access to computer networks, even at university level, was very restricted. In Iceland at least, it is only in the last ten years that general availability of home network and laptop resources could be assumed in the student body. Now that these resources are available, it is possible to bring CDIO principles of active learning and design-implementation to the subject. Our experience is that this has dramatically improved educational outcomes and student satisfaction in the third year computer networks course. This was achieved without extra facilities simply by leveraging the student's own computers. Support software for the course was developed by the instructors.

Computer networking, one of the major contributors to the technological revolution of the last 50 years, should be an interesting and enjoyable course for students, even if its material can be complex. We believe the projects succeeded in part simply because they promoted student engagement with other students: building simple chat and messaging services in many ways parallels developments in the early days of the Internet, and students have described how they enjoyed chatting randomly with other students using the peer-to-peer network as they tested their software. This also helped to include students studying remotely, and effectively transformed the last weeks of a lecture based course into a virtual class collaborative effort.

We believe the general proliferation of cheap networked devices offers significant opportunity for further improving instruction in computer networking, and going beyond the examples in this paper, especially when combined with CDIO principles. We are adopting a similar approach for our computer security instruction, as are others(Buriachok, Sokolov, & Sokolov, 2020). Virtualisation also offers considerable opportunities to provide inexpensive but realistic networking workbenches (Yalcin, Altun, & Kose, 2015). Although peer-to-peer networking is generally considered an advanced topic in computer networking, constructing a simple class network with restricted capabilities has been consistently achieved by our students, and has provided a useful experience in practical networking for them.

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USING GITHUB CLASSROOM IN TEACHING PROGRAMMING

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ABSTRACT

Teaching students programming can be done in many different ways. One is to use Test-Driven Development (TDD) where the students can receive immediate feedback on their implementations, to correct them before submitting their assignments. The article describes a study performed on first-semester bachelor students in computer engineering in an introductory course on programming. Various tools were used to support the students learning, namely, GitHub Classroom, Visual Studio Code, and repl.it. The article discusses the pros and cons of using TDD together with the mentioned tools for an introductory course in programming. The results are based on a questionnaire filled in by the students to understand the outcome from the students' perspective, and also based on the experience from the teachers' point of view. The results were mainly positive from both the teachers' and students' points of view, with a few aspects where there were trade-offs and things that can be done differently.

KEYWORDS

Programming, GitHub, Professional Skills, Test-Driven Development, Software Development
CDIO Standards 2, 8, 11

INTRODUCTION

Becoming a professional software engineer (or other professional careers) requires that you ensure that the software you create is correct. We have – for many years – observed that our students in the first couple of years find it difficult to focus on both the creative and constructive process of "programming" and ensuring that their product ("the program") is correct.

Many modern software development methods prescribe that one should create the test of elements of the program before implementing the functions (Beck, 2003). This is known as Test-Driven Development (TDD), something that applies to software and is relevant to many other engineering disciplines.

We have started to use GitHub Classroom to support the students in their "programming journey" (GitHub, 2022). We are not the first ones to do so (see, e.g. Hsing and Gennarelli (2019)), but we are, as far as we know, the first to structure our use of it following the "Use – modify – create" (Lee et al., 2011) principle for structuring course activities.

The article discusses and evaluates one way of implementing Test-Driven Development (or one could call it Test-Driven Programming since the focus is not the entire development of a product from conceiving to implementation) using GitHub Classroom. It is based on quantitative data from a questionnaire sent to all students at the end of their course.

The article is organized as follows: firstly, it frames the work within the general knowledge area of introductory programming. Then it describes the research design, leading to an analysis of the data. Lastly, future work and the future development of a programming course based on (among other things) GitHub Classroom and TDD is described.

RELATED WORK

This section starts by summarizing general trends in learning to program and then focuses on others' work using GitHub in their introductory programming courses.

Trends in Learning to Program

Software development competencies have become more in need by the industry over the last many years (Istiyowati, Syahrial, & Muslim, 2020; US News, 2021). One of the core software development competencies is programming. However, many students experience challenges when learning to program (see e.g. Corney, Teague, and Thomas (2010); Guzdial (2010)). In her PhD thesis, Kaila (2018) states *programming is a very difficult skill to learn, and even more difficult skill to master. After introductory courses, various students typically still have difficulties in reading the program code and writing simple programs. Moreover, the dropout rates in introductory programming courses are typically quite high (p. 1)*. In various CDIO conferences, scholars reported on their challenges and experiences with teaching programming (see e.g. Martínez and Muñoz (2014); Matthíasdóttir and Loftsson (2019, 2020)).

Various approaches have been proposed for supporting students' learning to program. Some approaches focus on a structuring principle for the course (e.g. objects first (Cooper, Dann, & Pausch, 2003) or creative computing (Xu, Wolz, Kumar, & Greenburg, 2018)). Other focus on different tools for helping the students learn to program; for an overview see Naps et al. (2002); Sorva, Karavirta, and Malmi (2013). As an example, Sorva et al. analyses 46 different visualization systems built until the article was published in 2013; many more have been added after that (see e.g.(Staugaard, 2020) for a list of additional systems). The guiding principles for the course used in this research is described in section "The Course".

Giving feedback to students learning to program is a difficult and time-consuming task. Different approaches have been suggested to ease the task for the teachers (e.g. the use of automated feedback systems (Muuli et al., 2017; Thangaraj, 2021), the use of automatic calculation of different metrics of quality of code (Zaw, Hnin, Kyaw, & Funabiki, 2020))). The main objective of all these approaches is, that the teacher should spend time on giving feedback that "matters" and not on trivial things like syntax issues, indentation etc.

Test-Driven Development

As described in the Introduction, many modern software development methods have tests as a central part of specifying the functional requirements for a given piece of code. In general *Test-*

Driven Development is associated with extreme programming (Beck, 2000) and was initially described by Beck (2003). It is an iterative development process with the following steps:

- **Add a test**: When a new feature is needed in the program, it is specified by test case(s) such that if the test passes, the specifications are met.
- **Run all tests**: The systems should fulfil all but the newly added tests (which should fail for expected reasons).
- **Write code that fulfil the tests**: If some tests are not met, the code must be revisited.
- **Refactor if needed**: Modify the code so that it fulfils the quality standards. When doing so, ensure that the tests are still being met.

The course in question did not focus on the refactoring part and, in most cases, the code that the students should write was standalone, not a part of a big system (and thus, there were not a large pool of tests before the new feature (bullet one) was introduced).

Use of GitHub in Teaching Programming

Glassey (2019) surveyed eight publicly available version control tools including GitHub Classroom to help teachers select a solution for their courses. Technical features and pedagogical aspects of the tools were illustrated including 1) Repository creation and distribution to the students, 2) Team creation for a project or peer assessment, 3) Batch cloning of repositories of students repositories for assessment and evaluation.

Angulo and Aktunc (2019) studied the benefits and challenges of using GitHub for courses in a software engineering program for multiple years. Specifically, GitHub was used for teaching an Object-Oriented Programming and Design course and Java and Applications course. Initially, students were familiar with Learning Management Systems e.g. Blackboard but had no prior experience with GitHub. The authors report minimal challenges when introducing GitHub. Nonetheless, after a demonstration of the main functionality students became comfortable users of GitHub within 2 weeks. Further, students were able to collaborate (branching and merging) on group projects throughout the semester while maintaining the transparency of individual contributions for the teacher. The authors explain that creating and managing various GitHub repositories becomes challenging with an increasing number of students and assignments. They plan to adopt the GitHub Classroom application due to the simplicity of publishing and collecting assignments.

Glazunova, Parhomenko, Korolchuk, and Voloshyna (2021) focus on teaching collaborative software development through GitHub Classroom on the example of 29 Computer Science and Engineering students. The teacher combined the Learning Management System and GitHub to share theory, instructions and results, and allow the students to implement project tasks. The interviews showed that students favoured three features of GitHub; collaborative development of software, ease of bug tracking and accessibility of the code editor.

Diehl and Brandt (2020) present the use of GitHub Classroom to provide an interactive C++ development environment and introduce students to the concept of Git. They surveyed a group of 10 students. Students reported that they particularly enjoyed the interactive notebook feature for creating and testing their C++ code.

RESEARCH DESIGN

This section describes the research design. It starts with our research hypothesis, then gives the context of the research (i.e. the course, the participants etc.).

Research Hypothesis

One of the core ideas of CDIO is an integration of the student's technical skills and their professional skills. In many cases, there is a tension between the professional tools and processes students use when they work in industry and the tools used.

As described in Related work, many find learning to program difficult. Furthermore, much time is spent on feedback on low-level problems (the program cannot compile, the program fails the simplest tests etc). Our research hypothesis is, therefore:

> *Beginners find it easier to learn to program using TDD with GitHub and such tools makes it possible for the teachers to focus on giving higher-level feedback*

Research Context

This section describes the course, the tools used and the participants.

The Course

The research is done in an introductory programming course in the first semester of a bachelor of engineering program at Aarhus University, the second-largest public university in Denmark. The course is 10 ECTS (that is $1/3$ of the time in the semester should be spent on this course).

At the end of the course, the participants will be able to (Aarhus University, 2022):

- Describe and discuss commands and control structures of imperative programming;
- Describe the relationship between iteration and recursion;
- Describe and discuss structuring mechanisms in different programming styles;
- Implement their own programs using different programming styles;
- Explain the concept of imperative and functional programming;
- Describe assertional techniques for reasoning about programs;
- Reason informally about programs and relate this to tests.

Our guiding principles in the course used for this research could be described as:

- **Simplicity first**: Starting with the simple programming constructs and gradually enhancing the complexity.
- **Use-modify-create**: The students firstly see a programming construct, then they modify existing code and lastly they create new code.
- **Specification-Driven Development**: Before creating code, the students read, modify or create a specification. The specification includes pre- and postconditions as well as test cases.
- **Program is a verb**: We focus on the programming process (program as a verb) not just the program itself (program as a noun).

During the course, the students had to hand in 12 assignments. The assignments were graded (pass/fail) by two teaching assistants (the second and third author), and the student had to pass all 12 assignments to take the final exam. The course is divided into two face-to-face activities: Lectures and Programming café. In the café students can get help with their assignments.

The Tools Used

The main tools used during the course are: Replit (2022), GitHub (2022), and Visual Studio Code (2022). A test framework was only included for the assignments distributed through Github Classroom.

GitHub Classroom is a tool that allows teachers to create a template repository containing code, which can be distributed to students via a link. Repositories for each student is created when they log into GitHub and activate the link. The students submit their assignments by sharing the link to their GitHub repository with the assignment code.

The first tool learnt by the students was repl.it. Repl.it is an online IDE and compiler. It was mainly used for the students to get acquainted with the basics of programming. The students created their programs in repl.it and shared the link to their assignments with the teachers.

After four weeks of using repl.it, the students were introduced to VS Code and Github, where they had to download and install these programs, a C-compiler and other related programs on their own device. We selected VS Code for this course based on the fact that it is an open-source IDE, with the possibility to install extensions and to easily tailor it to one's needs. It was also the most used IDE in 2021, according to a developer survey performed by Stack Overflow (2022).

The assignments were created and distributed using GitHub/Github Classroom with skeleton projects. A project included test cases for each of the functions the students should implement as well as header and C files. An example repository can be found at `https://tinyurl.com/assgnment`. The students could run the test cases and get immediate feedback on their implementation. Errors in the implementation would show in the test results, allowing the

```
[ctest]     Start 1: usage_test
[ctest] 1/1 Test #1: usage_test .......................   Passed   40.48 sec
[ctest]
[ctest] 100% tests passed, 0 tests failed out of 1
[ctest]
[ctest] Total Test time (real) =  40.50 sec
[ctest] CTest finished with return code 0
```

Figure 1. Example output from a test run. Here the test PASSED.

students to narrow down the problem and correct the code. In later stages of the course, the students were allowed to modify and create their own test cases.

The usage of the *Use - Modify - Create* concept in this study is illustrated in figure 2. The students learnt to *use* and understand the predefined test cases that were made to determine if the students had implemented their assignments correctly. The idea was that the students should both get automatic feedback and learn that defining test-cases is a nice way of specifying the functional requirements. After the students were more experienced, minor errors were put into the tests cases, and the students were told to find and fix these as well as extend them. This is where the *modify* part comes into play, as the students need to learn how to modify the test cases, to ensure they are correct. The final step was for the students to create their own test cases from scratch. The difficulty increased gradually from the *use* step, to the *modify* step, and to the *create* step.

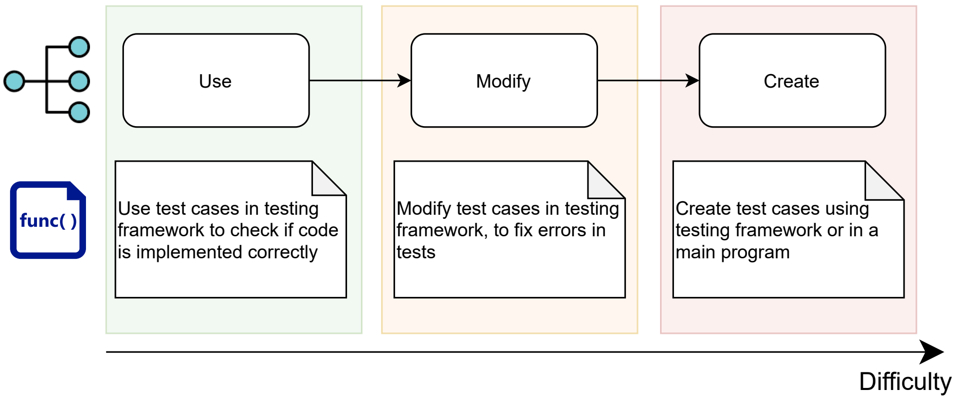

Figure 2. The main elements used in this study following the Use-Modify-Create structure, where the difficulty increases with each step.

The Participants

35 students participated in the course. Most of the students came from high school; a few of them have started another study program before this. Of the 35 students, only three were female. Approximately half of the students had programmed before (in many different programming languages/systems).

Data Collection

The data for this research was collected using a questionnaire at the end of the semester containing both closed questions (on a five point likkert scale) and open-ended questions. The questionnaire is sent out automatically to all students who participated in the course. The main purpose of the questionnaire is the quality assurance process of the university, but teachers can add both scale and free text questions to the questionnaire. To get a higher response rate, time during a lecture was allocated to allow the students to reply to the questionnaire.

The authors are the lecturer and the two teaching assistants for the course. Evaluation of their experiences is done through discussions among them.

ANALYSIS

This section analyses the data from the students (responses to the questionnaire) and describes the teachers' experiences. The closed questions was used for quantitative analysis. A generalizable study with statistical testing of the hypothesis requires a larger sample size.

The students' perspective

As described in Data Collection the questionnaire was distributed to 35 students. 20 students responded; the response rate was 60%. One student answered part of the questionnaire.

In general, the students found the outcome of the course significant (18 out of 21 answered either "very great outcome" or "significant outcome"). They found the course well organized (18 out of 21 either "agreed" or "mostly agreed" with that statement), and relevant for their studies on the whole (all either "agreed" or "mostly agreed" with that statement).

The students found it somewhat difficult to get the course infrastructure installed (compiler, git etc.) as can be seen in figure 3. Especially students who use a mac found it difficult. Some of the students were not present when the setup was introduced, and some found that the supporting material was not detailed enough (we made a video and a text document explaining the setup).

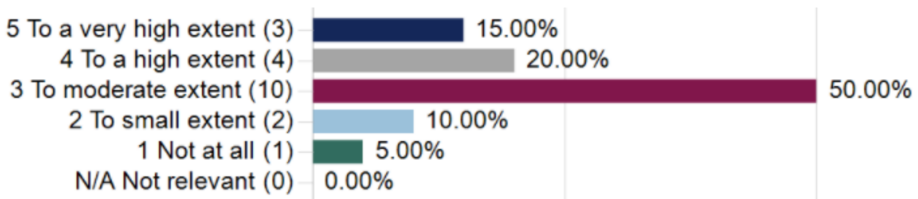

Figure 3. How challenging has it been to get the course infrastructure (compiler, git etc.) installed?

Some of the students found the transition from repl.it to GitHub challenging. It required a few weeks to get used to the new way of handing in. A few students had difficulties for quite some time and we (the teachers) could not help, since the problems were related to mac and none of the teachers had experience with a mac. As one of the students wrote *The main part of the* *time spent on the hand-ins was not spent on programming but on solving problems with the compiler and GitHub* (translated from Danish). Difficulties with the transition may be resolved by introducing a clear schedule for the exercises and transition during the first lecture and by describing the motivation for the transition.

One of our rationales for introducing GitHub was that the students should learn a professional tool. When asked “Do you think the tools you have learned in the course (especially GitHub, VS Code) will be relevant to your academic/professional career? How?” only a few of the students could make a connection to their future career.

All in all, it is difficult to answer “accept” or “reject” on the students’ part of our hypothesis. There have been some practical issues with the tools but it seems like the students have found them useful in their learning.

The students wish for better distribution of the difficulty of the exercises; this was a reappearing comment throughout the questionnaire. One student asked for larger freedom in creating the program structure. However, our aim was to guide the students during the initial exercises by providing a problem definition through the LMS and header files, data types and function skeletons through GitHub Classroom. Only during the last exercise the students were given an empty repository and were asked to create C files, header files and test cases.

The majority of the students reported that good opportunities for feedback and counselling regarding their academic performance were given (80% agree or mostly agree).

Noticeable disagreement was given when asked if the academic qualifications for participating in the course were good (45% agree or mostly agree). However, after participation in the course, the majority reported that their programming skills are sufficient to complete the course (75% agree, mostly agree or answer neutral when asked if their skills are above what is expected).

Thirteen students answered whether they felt the test cases helped them to see if their code was implemented correctly. Six students answered positively, 2 students answered negatively, and 5 students answered neutrally. There had been a few issues with some of the test cases making it difficult for some of the students to work with. The students that answered neutrally mainly viewed the test cases as a help, but did not like the fact that there were some issues with the test cases and had difficulties understanding them.

The students were asked to comment on what programming environment(s) and programming languages they used before enrolling in the course. Only one of the students had programming experience and worked in various languages. Two students used VS Code before enrollment. The majority of the class did report little experience (6 students) to no prior knowledge (14 students).

The teachers’ perspective

There is a trade-off between using test cases for scoring assignments, and manually understanding and checking if the assignments are implemented correctly. It is more time consuming to correct the assignments manually, but the feedback given to the students is more precise and helpful, which is exactly what is needed in the beginning of such a programming course. Correcting the assignments using the test cases minimizes the amount of time spent on checking the code, but also reduces the precision of the feedback given.

Many of the students found interpreting the output of running the tests a little difficult (see an example output in figure 1). It is not a nice and user-friendly output like many know from apps or other programs, so in retrospect, we should have spent more time introducing this part. In general, we should have spent more time introducing the "programming process" using the tools: when you have made a small part of the implementation, run the tests, interpret the results (and be aware that tests for non-implemented parts will fail) and modify your code based on the analysis of possible causes of failing tests.

One of the advantages of using GitHub and also repl.it, seen from a teacher's perspective, is that when the students have errors that may be difficult for them to understand how to solve, it is possible for the teachers to upload changes to the repository, to guide them in the right direction. This was especially useful if students had made errors related to the setup of the project, making it difficult to compile.

One of the disadvantages of using the test cases is that sometimes the students would have errors in one file, which resulted in the project not being able to compile. Some parts of the students' assignments could be implemented correctly, but due to errors in other parts of the assignments, the project could not be compiled altogether. This meant, that the teacher would have to either fail the students or fix the compiler issues themselves which in some cases was time-consuming.

The integration of GitHub Classroom and the LMS is missing, and therefore added an extra step for the students and teachers when handing in and correcting assignments.

DISCUSSION, FUTURE WORK AND IMPROVEMENTS

Learning to program is a process. In the beginning, many students struggle with syntactic issues (like a missing ";" at the end of a line), and test-cases do not help here. It is therefore important that the feedback (or feed-forward) in the beginning recognises this and is very detailed. Later in the course, feedback can focus on structure and less on details. In the next run of this course, we will make this even more happen.

Compiling and running code on different computers and operating systems can give different results, depending on the compiler used, the compiler settings and the computer architecture. When compiling the students' assignments, the teachers used the same compiler that the students had installed, to ensure the output of the compilation was as similar as possible. Even though this was done, there were still issues with running the code on different operating systems or computers with different architectures. One of the issues was a segmentation fault occurring on the teacher's computer but not on the student's. To avoid issues related to this, it would make sense to increase the compiler error and warning levels to the highest, to achieve as similar results as possible.

To run the test cases when correcting the assignments, the program must be able to compile.

If it could not compile, the teacher could choose to either fail the student or try fixing the issue. The reason it would make sense to fix the issue is that the students could have implemented most of the assignment correct but due to a minor issue, the program could not compile. In such a case, the student might have enough of the assignment correct to pass, but due to the compile errors, it is difficult to determine this since the test cases could not be run.

More focus will be put on the transition from repl.it to GitHub Classroom, to ensure the students understand every step and to avoid confusion. A potential assignment for the transition could be, that the students must copy their code from an assignment created in repl.it, and hand it through GitHub. In this assignment, the only new aspects the students will need to learn is how to use GitHub and how to hand in their assignment using GitHub.

CONCLUSION AND RECOMMENDATIONS

There is no silver bullet (Brooks & Kugler, 1987) in learning to program. It is a difficult and challenging task. The use of Test-Driven Development and tools supporting this process can be beneficial, but it is only one component as described and analysed in the paper.

Introducing technology such as GitHub requires that the students are comfortable with the tools and can understand their use. One recommendation from our research is, therefore, to remember to introduce the tools and especially the benefits for the students when using the tools. In our case, that could have been done better. On the other hand, the tools are easy to use and helps free up time to focus on.

The tools that we used in this study are not all necessary for working in such a manner, but they make it easier for the teachers and the students to work in this way. GitHub Classroom makes it easy to distribute the assignment by reducing the number of steps required, i.e. the students don't need to create their own GitHub repository and copy the assignment files into it, instead, they can just open a link that automatically creates a repository and clones the assignment for them.

Although we believe using the tools as we did in this study is a great way for the students to learn, it is important to understand that there is a significant amount of time the students spend on learning to use the different tools. This can be seen as a small overhead in the method used in this study.

Many institutions have a "bring your own device" policy – including Aarhus University. Using infrastructure that must be installed and with many different options require support. In our case, it would have been better if one of us had experience with macOS and could help students using Mac computers.

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EDUBOX:
A SELF-CONTAINED ENGINEERING LEARNING ENVIRONMENT FOR UNDERSERVED COMMUNITIES

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ABSTRACT

Education represents one of the essential building blocks of society. As soon as basic needs such as security, water, food and energy are secured for underserved communities and displaced people, education must be arranged to facilitate continuous growth of the community at multiple levels: from primary education to Vocational and Educational Trainings (VETs) to Higher Engineering Education.

Since the primary efforts of humanitarian aid are always invested in addressing the aforementioned basic needs, investment in education infrastructure is challenging owing to the expenses involved. This affects access to education, and consequently the quality of life of persons, especially the underserved. To address this challenge, a flexible classroom is proposed for fostering access to engineering and technical education by the underserved. The idea aligns with the UN Sustainable Development Goals 4 – Quality Education.

The design of a "learning environment", hereafter called EduBOX in this paper is discussed. The learning environment is essentially a retrofitted shipping container, designed to suit varying learning environments and deployed to regions affected by crisis and other adverse events including war. The classroom facilitates learning activities in the field of engineering education. The first concept for a learning environment for refugees in camps in Lebanon and Jordan is discussed in this paper as a starting point. Furthermore, the design phases of the innovative learning environment are explored, starting with a review of related solutions, and innovative design spaces. Secondly, needs and requirements of the EduBOX are explored, looking at different aspects such as engineering educational needs, learning outcomes, cultural factors and technical constraints. This step is carried out in collaboration with relevant stakeholders, including the host community. Finally, design concepts are generated, and an innovative design is explored for further detailing and prototyping. The selected concept is further evaluated, and showed a positive outlook considering usability, and from a didactic perspective.

KEYWORDS

Engineering Education, Underserved Communities, Learning Experience, Sustainable Development Goals 4 – Quality Education, EduBOX, Standard 6.

INTRODUCTION

The research project mission contributes to increasing the quality of education and vocational training for refugees and internally displaced persons in host communities. Jordan and Lebanon case were considered as a testing environment (University of Twente, 2020). The goal is to help students from underserved communities and refugees living in camps to access quality engineering education, resulting in better integration with the labour market. As defined by the UNHCR, "a host community refers to the country of asylum and the local, regional and national governmental, social and economic structures within which refugees live" (UNHCR Resettlement Service, 2011).

Problem Statement

Although the right to receive an education is included in the human rights of the United Nations (United Nations, 2021), higher education is perceived as a luxury for refugees. In humanitarian crises, most attention concerning education is often directed towards the primary and secondary school levels. Refugees above the age group of secondary school level (age 12 to 18) are considered less vulnerable than school-age children. However, higher education for refugees is argued to be of high importance, since it enables individuals and societies to rebuild their lives and fosters peaceful post-conflict reconstruction (Sheehy, 2014). Jordan and Lebanon host a disproportionate number of Syrian refugees lacking adequate infrastructure and resources. This has been compounded by the arrival of more than a million Syrian refugees, thereby placing great pressure on public services including the education system. Limiting access especially to technical and vocational education.

NEEDS OF EDUCATION FOR UNDERSERVED COMMUNITIES

Needs of the target group related to education in underserved communities

Jordan has been hosting many refugees throughout its history, of which most people are from Syria. Syrians are the newest group of refugees to come to Jordan or Lebanon as a host country. The total number of registered refugees is approximately 655,000 Syrians, 67,000 Iraqis, 15,000 Yemenis, 6,000 Sudanese, and 2,500 refugees from a total of 52 other nationalities (UNHCR, 2019).

To foster access, the EduBOX was conceived as part of an international cooperation project, between the Netherlands, and higher education institutions in Jordan, and an agency working with refugees in Lebanon. The prototype of the project targets beneficiaries in three refugee camps; Zaatari, Marjeeb AL Fhood, and Azraq, which are all located in the north of Jordan. Currently, refugees live and study in tent camps, with limited access to permanent education infrastructure, including classrooms. This motivated the need for a dynamic learning environment inside these camps should be mobile as well. Moreover, the mobile learning environment should be deployable outside refugee camps, where the majority of refugees live.

Together, this led to the following criteria for the learning environment shipping container:

- A learning environment that should fit the needs of Syrian refugees in Jordan and Lebanon.
- The learning environment should be designed to be easily transported and deployable to different locations where refugees require access to engineering education.
- The design should be easily deployed and fit in refugee camps, as well as in urban areas to educate the underserved.

What type of education do Syrian refugees currently follow in Jordan?

To understand the educational needs, we explored together with the host community challenges accessing education. Since the beginning of the Syrian conflict, Syrian refugees have received free access to public primary schools regardless of their official status as asylum seekers. The only consideration is having a service card issued by the Ministry of Interior (Beste, 2015). As may be expected, this has placed great pressure on the education infrastructure of the Jordanian public education system (Beste, 2015). This has had an undesired effect of forcing some primary schools to operate on double shifts, a morning shift for Jordanian children, and an afternoon shift for Syrian refugee children (Human Rights Watch, 2016).

Access to vocational training and higher education is a very relevant need for Syrian refugees, especially because of interests to access the labour market in Jordan. This includes training to gain skills in aspects such as coding, cookery, and artisanship that are very relevant from an entrepreneurship perspective. However, accessing vocational training and higher education is still a challenge, especially because of limited infrastructure capacity, limited of laboratories for engineering education and competition for limited slots with the local communities (Human Rights Watch, 2016).

Moreover, certification of vocational training and higher education programs is challenging, because of the often stringent requirements needed for non-Jordanians to enroll, creating a barrier of access to STEM skills training for the underserved in the community, including refugees. This is one of the overriding motivations for the EduBOX that attempts to fill this gap to provide certified vocational training, to enhance access to the job market by graduates.

What problems does this target group experience concerning education?

From initial need assessment prior to developing the EduBOX concept, challenges facing refugees were mapped and included:

- ***Infrastructure and quality of education***

Because of the pressure on the education system, lack of classrooms presents an important problem, with the Jordanian Government already adopted a double shift learning principle. Already this dates back to the 1960's owing to regional instability and conflicts and worsened by the influx of Syrian refugees. With the growing number of students (UNICEF, 2020), students study fewer hours, influencing negatively the quality of education, for instance, compared to schools operating a regular schedule (Human Rights Watch, 2016).

- ***Poverty, child labour and child marriage***

80% of the Syrian refugees are living in poverty, which results in most refugees being financially dependent on support from humanitarian agencies for survival. Many Syrian refugees families in Jordan have resorted to child labor to increase their income and child marriage to decrease the number of dependents needing support (Human Rights Watch, 2020). Moreover, a disproportionate number of children from 12 years too early adults continue to lack access to education, influencing negatively their future quality of life (Human Rights Watch, 2020).

- ***Jordanian labour market***

Syrian refugees are not allowed to apply for work permits with wages exploitatively low for the informal job market where often many refugees search for opportunities. Refugees must also show that they have specialized skills to access the skilled job market. Accessing low-skilled jobs is significantly more difficult compounded by inability to obtain work permits (International Labour Organization, 2015). Many such jobs are in sectors such as agriculture, construction where they often contend with low and often poor working conditions (Human Rights Watch, 2016). Skills from vocation training presents an opportunity for refugees to improve access and leverage on their skills to earn an income, e.g. cookery, coding, or internet-based outsourcing jobs. These courses were mapped as much needed skills from a need analysis perspective.

- ***Limited vocational training programs in host communities***

Several international humanitarian agencies and non-governmental organizations (NGOs) run vocational training programs in host communities. However, approval of their programs is skewed because of political sensitivities around the integration of Syrians in the Jordanian labour market (Human Rights Watch, 2016). This influenced several needs and access-related criteria for the EduBOX including:

- Enhancing access to educational infrastructure, while providing high-quality vocation training facilitated by online, blended learning activities and supported remotely by highly educated teachers.
- Should include basic infrastructures, such as windows, electricity, lighting, heating and cooling.
- Provide vocational training programs approved by the Jordanian authorities, with the programs fulfilling employment prospects of refugees.

Although approval of up-skilling courses is an important barrier for access to vocational training, this relates largely to formal skills training. For instance here, training requiring certification. For tertiary training, e.g. artisanship skills, the thresholds are much lower, with explicit need for certification not mandatory and training often requires proof of participation. The EduBOX therefore complements well up-skilling for lower-level vocational training, an important benefit for the community.

REQUIREMENTS OF LEARNING ENVIRONMENTS FOR UNDERSERVED COMMUNITIES

1. What are the basic requirements for a classroom in underserved communities?

There are no legal minimum space requirements concerning classroom dimensions. However, the Building Bulletin 103 (Department for Education, 2014) does set out that a general classroom should be around 55 m² per 30 students, but depending on the activities that take place in them, more space might be required. Therefore, an average classroom for 30 students should be around 70 m².

Together, these results led to the following criteria for the learning environment shipping container:

- The container should hold at least 30 students to maximize availability and minimize costs.
- The learning environment should be around at least 70 m² per 30 students.

Based on a field guideline report from the UNHCR about education for refugees, there are a few guidelines for education for refugees concerning the infrastructure and equipment, which should be met by the learning environment shipping container (UNHCR, 2003).

2. How can a modern and mobile classroom be redesigned to facilitate the most effective environment for learning?

The EduBOX should be a transportable and flexible space, which can be used for different educational programs. Throughout the existence of classrooms, they appear mainly in the same shape with forward-facing furniture (Cornell, 2003). Even though this set up of a classroom is still widely used, is it highly immobile and encourages 'passive learning', which is defined by Basye et al. (2015) as "transmission of knowledge" where teachers "passed on information that students learned, often by recitation and repetition, sufficient to prepare them for the lives they would lead" (Basye, 2015).

Over the last decades, the instructional practices have shifted towards a new style of 'active learning, which is defined by Brooker (2011) as "the antithesis to passive learning, wherein students construct their knowledge by engaging in educational tasks themselves" (Fehlandt, 2017). Students are stimulated to work more independent, think critically, collaborate and move. 'Active learning' is stimulated when flexible furniture can be adapted to change the learning environment to a new arrangement (Fehlandt, 2017). This includes adaptable furniture to enhance student collaboration and active learning (Basye, 2015). Table 1 offers an overview of the requirements needed to provide reliable and effective solutions and to guide the design process through the different needs of the final users.

Table 1. Self-Contained Engineering Learning Environment for Underserved Communities

Type of requirement	**Specific Requirement**
Functional requirements	• The architecture of the container should be modular, adaptable to adjust based on the local needs. • The container should be efficient to transport, install and operate. • The design of the container should ensure natural lighting and ventilation and usable in all weather conditions. • All components within the container must be accessible for quick maintenance or replacement.
Technical requirements	• Should have a correct size according to the ISO measurement and only contain a door on one side. • Should offer a similar ratio of 70 m² per 30 students.
Educational requirements	• The inside layout of the container should be flexible to adapt to different education programs. • Should include all necessary facilities to follow online classes plus a learning lab. • Should include basic furniture (chairs, tables, desks etc…) and either laptops or tablets.

Moreover, collaboration between students is further enhanced by the shape, size, orientation and clustering of tables and desks (Cornell, 2003). Fehlandt (2017) discusses three themes, including space, flexibility and mobility, that attribute to the achievement of an effective learning environment.

- **Space:** Duncanson (2014) associates a physical space to a classroom and argues that increasing the area by a little less than 1 m² per student, promotes 'active learning' leading to fewer distractions and a cleaner classroom organization (Duncanson, 2014).
- **Flexibility*:*** Focuses on space utilisation hence allowing a variety of learning opportunities adapting to the individual needs of a student (Basye, 2015). This allows students to adjust to an endless amount of educational activities and collaboration in the form of group work (Fehlandt, 2017).
- **Mobility:** Cornell (2003) states that to facilitate this multipurpose classroom with a variety of educational opportunities, classrooms will need to be reorganized regularly (Cornell, 2003). To allow this, the content within the classroom should be mobile, including the ability for movement in the furniture itself which supports more engagement and higher achievement (Fehlandt, 2017).

These insights leads to the following criteria for the learning environment shipping container:

- A learning environment that should be flexible enough to adapt to different teaching approaches and educational programs.
- Furniture that should be adaptable which allows for different setups, as well as creating more physical space.

3. *Alignment with the CDIO (Conceive-Design-Implement-Operate) framework?*

The EduBOX project is working with educators, to develop innovative learning content to suit the needs of the underserved communities. This is a particular challenge and needs of underserved communities are diverse, influencing CDIO (Conceive-Design-Implement-Operate) standards, including:

- Standards 1, 2 & 3: Defining concretely the education needs of the underserved and designing education curricula with clear learning outcomes to suite defined needs.
- Standards 5: Design-implement experiences, including innovative delivery of education, through blended learning, interactive micro-lectures, and tailored teaching.
- Standard 6: Optimising learning spaces, to improve the learning experience.

DESIGN OF THE SELF-CONTAINED ENGINEERING LEARNING ENVIRONMENT

The final design of the self-contained learning environment exists of two main parts; the first part includes opening sidewalls to expand the classroom's area while the second part includes a small lab in the back of the container behind a separating wall (Figure 1). Figure 2 illustrates the outside dimensions of the EduBOX.

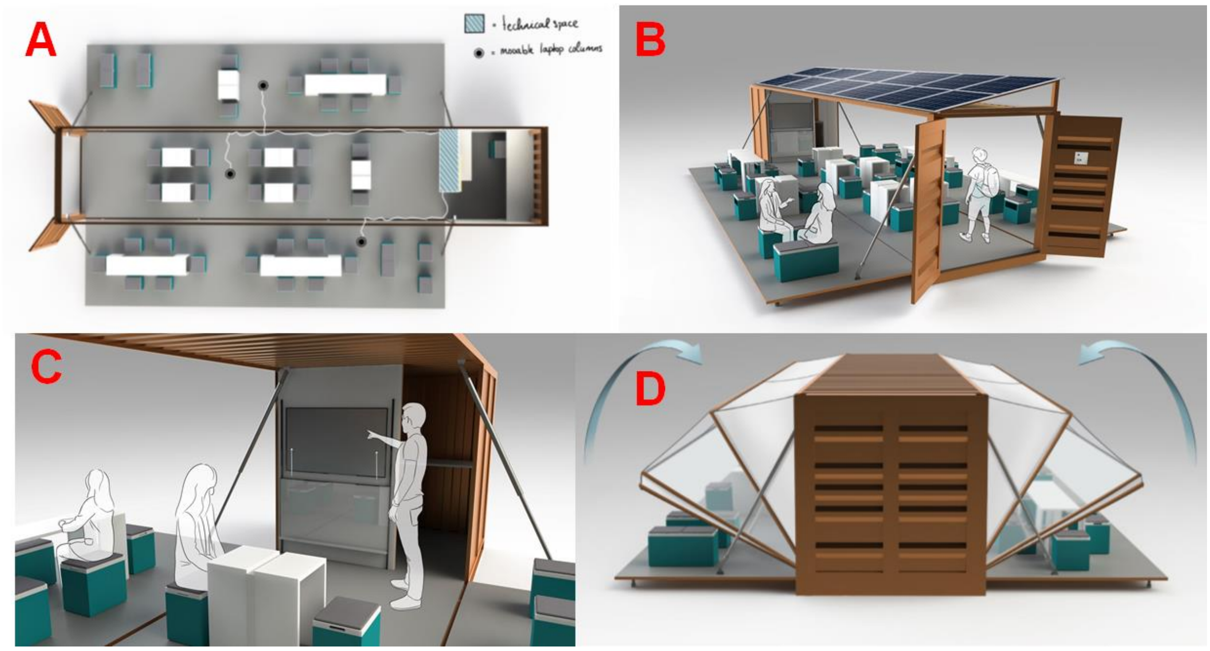

Figure 1. A: top view of the EduBOX; B, C: 3D view of the EduBOX; D: view of the canopy structure.

When closed, all furniture inside the container can be stacked together compactly, leaving enough space for the solar panels and its mounting system. To use the learning environment, the container must be unfolded actuated by four linear actuators. When closed, the learning environment could still be used since there is provision of artificial lighting, though this is not optimal from a functional perspective due to space limitations when closed. Solar panels are mounted to ensure energy independency for off-grip applications (Figure 1B). The side part of the space created unfolding the side walls (Figure 1D) will be protected using a canopy system mounted on the frame of the container. This system will be able to let the sunlight illuminate the learning environment, offering a better experience to the users.

The Lab

As said, in the back of the container there is a small lab (Fig. 1A and Fig. 2) that can be used also for Technical Vocational Education and Training (TVET). The lab is closed off by a separating wall and a sliding door, to avoid interruptions with the classes given at the same moment in the classroom. Inside the lab, two workbenches face each other to make the best use of the available space. The tables are at a standard standing table height of 110 cm, which enables the students working at the lab to stand while working, or stack two chairs on top of each other to create a barstool. The lab can be used by two people at the same time for different purposes, and also different variations of this lab can be designed and implemented in the EduBOX. As an example, the lab could include one or two additive manufacturing printers, that can be placed on the smaller table against the separating wall.

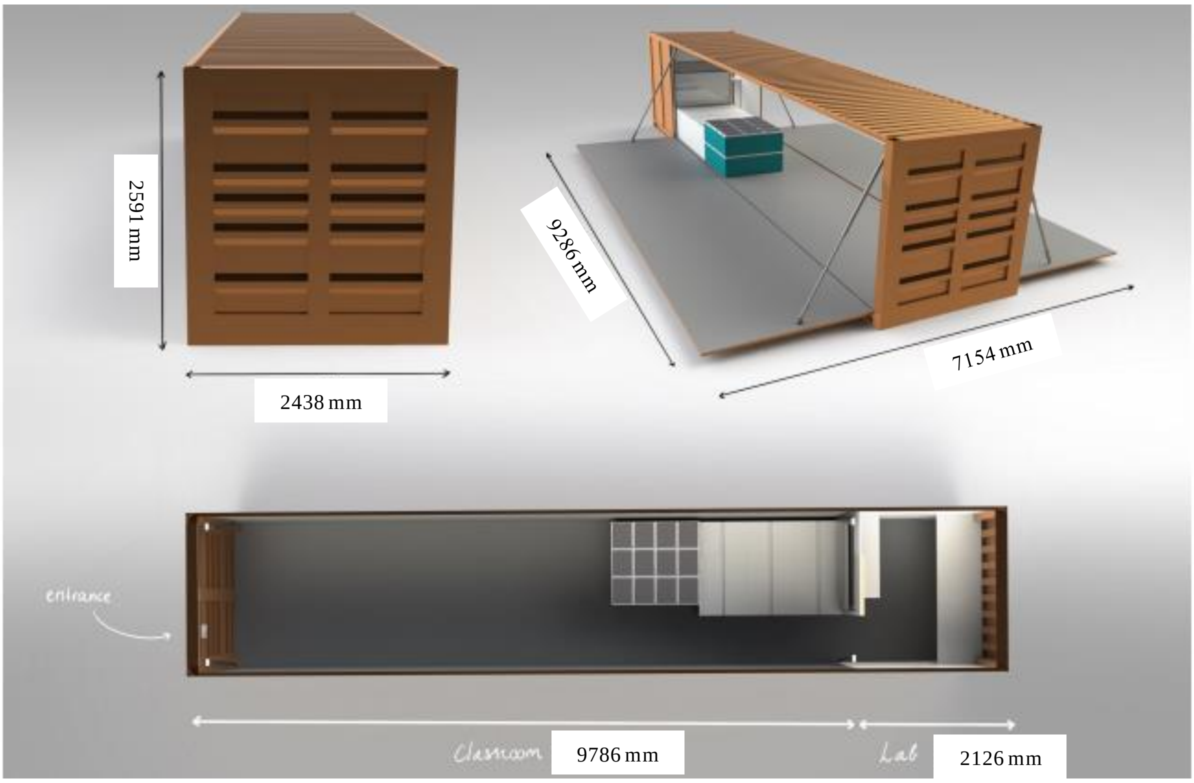

Figure 2. External dimensions of the EduBOX.

Teaching materials

On the other side of the separating wall, a monitor is attached that can be used for online classes or digital teaching material. Below the monitor, there is a whiteboard, which can be pulled upwards in front of the monitor by a sliding rail. This way, the two main components used for teaching can be attached using as little space as possible. Apart from the teaching boards, there will be tablets available for the students in the EduBOX, which allows them to work also independently. Most likely there will be a few spare tablets in case one break or runs

out of battery. The tablets contribute to the flexibility of the learning environment, as books and other teaching material can be uploaded and used on the tablets. This way, most education programs can make use of the EduBOX without necessarily having to bring their material.
To provide an internet connection for all tablets and laptops, the container will include a Wi-Fi router.

Work-in-process

Figure 3 shows images of the prototype currently being constructed at the University of Twente. It includes a lab that can be customized to match varying engineering education skills.

DISCUSSIONS AND CONCLUSION

The overall goal of the research project was to offer refugees and people in underserved communities a chance at a better life. Refugees in Jordan, as well as other countries, are currently not enrolled in higher education. The EduBOX project offers these refugees and other people in underserved communities a chance at a better life by providing a learning environment. The EduBOX is a shipping container that has been redesigned into a self-contained, flexible and modular learning space that can easily be transported to places in need. The container is completely self-sufficient, which makes it a great fit for remote, developing and disaster-affected areas. It offers places in need, such as refugee camps or underserved communities, a place that can be used as a learning environment by different TVET or higher education programs. Although the focus throughout this project has been on the implementation of the EduBOX in Jordan, the design is universal and therefore can be used in a different context.
The final design of the EduBOX consists of two unfolding sidewalls, which will increase the usable space within the EduBOX. A canopy structure will unfold with the sidewalls, which completely closes off the container, or can be used as a sunshade when partly opened. This flexibility allows the container to perform in different weather conditions. The lab space is customizable to suit alternative applications for engineering education. It's external dimensions are within those of the international standard which allows it to be transported on top of a flat rack container (ISO,1995). This aspect results in flexibility and ease of transportation and set-up.
The EduBOX is moreover flexible enough in use, so different educational programs will be able to use the EduBOX as a learning environment. Research shows that the rate at which teaching methods change due to societal transformations is different from the rate at which school design can change (Fehlandt, 2017). The design of the EduBOX meets this requirement through flexible furniture that can completely be arranged based on the preferred teaching methods.
This way, it will fit most education programs and can evolve with the societal transformations, which will make the design more durable.

Fig. 3: Prototyping of the EduBOX

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UNIVERSITY AND CONTINOUS ENGINEERING EDUCATION – PERSPECTIVES ON INTEGRATING STUDENTS

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ABSTRACT

Practical and relevant competence ready to apply in an industrial setting is of crucial importance for University Engineering Education (UEE). However, what is considered as industrial relevant knowledge and skills are changing in an increasing pace and the gap between the research front and application in industry is decreasing. Within manufacturing industry, engineers must be able to jointly optimize the design and operation of manufacturing systems and products, transferring newest research, knowledge, and technology into the business at fast pace. Continuous Engineering Education (CEE) commonly involves development of theoretical skills together with the practical work in a company setting. In this paper, learning activities comprising both CEE and UEE students are studied. By mixing students from the two groups potential benefits could be achieved within each group. The purpose with the paper is to describe how learning activities integrating CEE and UEE can be achieved to strengthen the CDIO goals as well as exploring the benefits and challenges related to the mixed student group. Learning activities combining the student groups were studied in 4 CEE courses. Several types of learning activities gathering the student groups were identified including project work in industrial settings, lecture discussions, and project presentation seminars. Challenges identified related to e.g., the differences in background knowledge and skills in the areas affecting the design of project works as well as practical factors such as scheduling.

KEYWORDS

Continuous engineering education, Lifelong learning, Mixed student groups, Standards: 7 (Integrated Learning Experiences), 8 (Active learning), 9 (Enhancement of Faculty Competence)

INTRODUCTION

To prepare engineering students for future working life through hands-on learning characterized by active learning methods encouraging problem solving and practical engagement is a corner stone in CDIO-based education. The importance of practical and relevant competence ready to apply in an industrial setting is crucial for University Engineering Education (UEE). However, what is considered as industrial relevant knowledge and skills are changing in an increasing pace and the gap between the research front and application in industry is decreasing in many areas such as in production development and Industry 4.0. (Medini, 2018). The latest theory and research must faster be transferred into industrial applications in order to secure industrial competitiveness (Fink, 2002). The UEE students play a crucial role in this transformation as carrier of knowledge and skills based on recent research and theory. However, it is a challenge to keep the industrial relevance of UEE up to date due to the rapid industrial development.

Employment of UEE students in industry is one mean to disseminate knowledge and skills to industry. However, due to the fast industry development there is also an increasing need for continuous lifelong education for industrial professionals to constantly update the knowledge and skills. Within the field of industry 4.0, engineers in manufacturing industry must be able to jointly optimize the design and operation of manufacturing systems and products, transferring newest research, knowledge, and technology into the business at fast pace. The pressure to constantly increase and develop knowledge and skills is increasing in an accelerating pace. Life-long-learning, also labeled as Continuous Engineering Education (CEE) within the engineering field, usually involves development of theoretical skills together with the practical work in a company setting (Fink, 2001). Compared to UEE, the need for work-setting relevancy and application of learning to companies and daily work is strong and must characterize the CEE education.

Both student groups are crucially important for the manufacturing industry. However, the student groups normally differ in terms of e.g., theoretical, and industrial knowledge and skills, working experience, and age. Due to this difference, combined with the mutual goal to achieve industry relevant knowledge and skills, there is a potential future avenue to mix the student groups in learning activities. Therefore, in this paper, learning activities comprising both CEE and UEE students are studied. By mixing students from the two groups potential benefits could be achieved within each group. The purpose with the paper is to describe how learning activities integrating CEE and UEE can be achieved to strengthen the CDIO goals as well as exploring the benefits and challenges related to the mixed student group.

THEORETICAL BACKGROUND

Industry relevant university engineering education

The CDIO initiative aims to develop engineering education that prepare students with knowledge and skills for their future working life as engineers. Engineering graduates from a CDIO based education should be able to conceive, design, implement, and operate complex value-added engineering systems in a modern team-based engineering environment (Brodeur & Crawley, 2005). Courses should, thus, both be of relevance for manufacturing industry and be structured in a way that the students get prepared for the way of working as engineers. The CDIO standards (Crawley et.al., 2014; Bennedsen et.al., 2016) is a guidance for course developers in this task where several standards are explicitly referring to the industrial relevance, such as:

- Introducing students in tasks and responsibilities of an engineer, and the use of disciplinary knowledge in executing those tasks (Standard 4)
- To create design and implement experiences by letting the students develop product, process, and system building skills. Also, to develop the ability to apply engineering science, in design-implement experiences (Standard 5).

- To get used and learn in engineering workspaces that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning (Standard 6)
- To incorporate professional engineering issues in contexts where they coexist with disciplinary issues (Standard 7)
- To arrange for learning based on active experiential learning methods (standard 8)
- Enhance the faculty competence including for example professional leave to work in industry, partnerships with industry colleagues in research and education projects, inclusion of engineering practice as a criterion for hiring and promotion, and appropriate professional development experiences at the university (Standard 9).

All these aspects call for courses with high industry relevance and to prepare students for the current engineering tasks directly after graduation. The benefits of decreasing the gap between industry and UEE have often been researched and discussed in the CDIO community. To use project work and internship as central learning activities increases the industry relevance of UEE. In a survey Munoz et.al (2019) show that internships for engineering students strengthen their technical knowledge as well as interpersonal skills. They stress that the courses need to be adapted for industry collaboration and the value for both industry and academia need to be secured. Moreover, the positive effects to include project work together with industrial companies to solve actual problems through problem-based learning is described by e.g. Martins et al. (2019) and Grishmanovskiy et.al. (2020). A roadmap for improving knowledge dissemination and value creation for both university and industry and the students was proposed by Bridgwood & Sørensen (2020). The value of bridging the gap between academia and industry in different learning activities has got large attention. Still, there is limited research related to CEE and bridging the gap related to this type of education.

Continuous Engineering Education

Lifelong learning education including professional development and continuing education has traditionally been an activity run by private providers of courses and not by universities. CEE or continuing professional development (CPD) commonly includes the development of theoretical skills alongside the practical work in a company setting. The need for work-setting relevancy and application of learning to companies and daily work is stronger compared to UEE (Fink, 2001; Fink, 2002). Due to the increasing need for CEE and the need to fast reach out with the latest knowledge based on research, universities have become an important provider in this field (Fink, 2002). In Swedish universities a large number of courses for professionals on advanced level, i.e., on master level, has been developed closely related to the developed research. Both advantages and challenges have been identified related to CEE courses on advanced level. There are large differences between CEE education and UEE both in terms of the students' previous skills and concerning requirement of the content of the course. The CEE student normally requires immediate application of the theories into their daily practice (Fink, 2002). In a study by Andersen and Rösiö (2021) the challenge to translate novel research results to knowledge ready to apply in industry was highlighted. Often, the course literature is a challenge and the literature available are journal articles, not easy to comprehend for the CEE student.

In a five-stage framework for lifelong learning in engineering education and practice Uhomoiibhi and Ross (2019) describe the phases of Pre-employment, Early Employment, Mid-Career Employment, Later Employment, and Post Employment. This framework intends to show the large spectra of potential students where only the first phase would represent UEE while all the other represents CEE. It is crucial to establish a link between education, lifelong learning and employment and the framework show the complexity in the variance of students (Uhomoibhil & Ross, 2019).

METHODOLOGY

In this paper, courses developed within a project called PREMIUM were studied. In the project 9 CEE courses within the field of knowledge intensive production development were developed for professionals by School of Engineering, Jönköping University. The courses were advanced level courses of 5 ECTS credits, running on 25% pace. The courses were designed to enable combining studies with a full working position. The courses were initially planned to include a mix of online events and face-to-face meetings. Due to the Covid 19 pandemic the main part of the course occasions were accomplished online. The courses were supposed to follow a pedagogical model including co-reading with UEE courses within the master programs, figure 1.

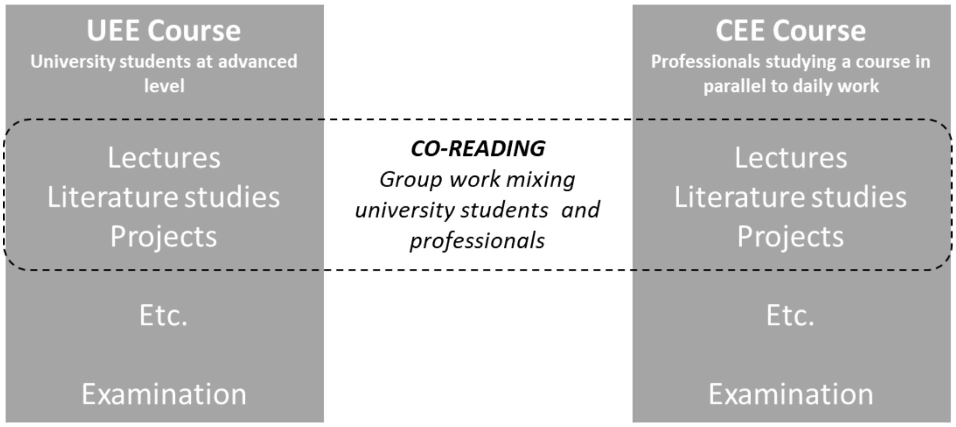

Figure 1. The principle of co-reading in certain activities in UEE and CEE courses

Relations and synergies towards similar courses within 4 CDIO based UEE programs at master level were considered during the development. The 9 CEE course syllabuses were compared with the course syllabuses of the master programs to identify similarities. Based on this, a matrix was established matching CEE courses to UEE courses, figure 2. Thereafter, the matrix was followed up with the program manager, main responsible for the different master programs. Finally, the matrix was presented for the CEE and UEE course responsible. Consequently, all CEE courses in the PREMIUM program were connected to at least one master program course to give prerequisites for all CEE courses to apply the principle of co-reading. Thereafter, it was the responsibility of the course leaders to decide if and how joint reading would be implemented in the CEE course. In this study both CEE courses and the master programs were under development. Thus, in some cases the co-reading was not yet possible due to that the courses had not been conducted when this study was made.

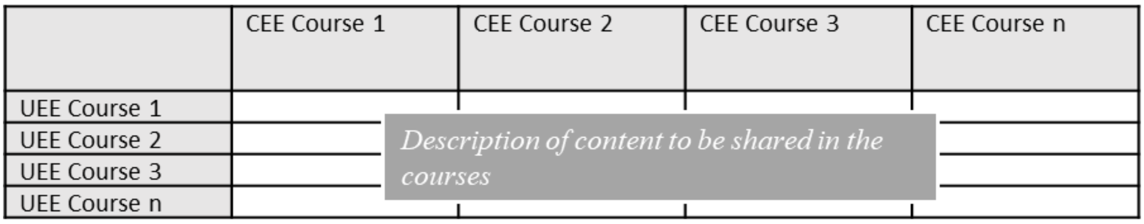

Figure *2*. Principle of matching content between UEE and CEE courses

In this paper, learning activities combining the student groups were studied in the CEE courses within the PREMIUM project. Data collection was initially done through interviews with course responsible. 9 course responsible persons where interviewed. 4 of the courses had applied co-reading, therefore, these courses were focused in the study. The interview questions included 11 questions:

1. What is the name of your Premium course?
2. Have you gathered program students and master's students in the course on any occasion?
3. On how many occasions in the course did you gather program students and master's students?
4. What master program did the students study?
5. What was the name of the course the master students were studying?
6. In what type of activity did you gather the student groups?
7. Describe with a few sentences the activity/activities.
8. What was the main purpose with gathering the students?
9. Describe the main values of mixing the student groups.
10. Describe the main challenges of mixing the student groups.
11. Do you want to share some other reflections related to the topic?

The interviews were followed up with document study including course information documents and course syllabus.

RESULTS

Four courses had applied co-reading between CEE and UEE students. Among the ones that had not applied the principles of co-reading the reasons were, among others, that the CEE course or the UEE course was given for the first time, and it was a too complex task to involve two target groups at this initial stage. In some cases, they could not establish co-reading due to practical reasons such as scheduling or different course pace.

All courses involved design and development of new production systems or work procedures but related to different areas. In all courses a CDIO approach was applied since problems were investigated in relation to the CEE students own practice covering the stages of conceive design, implement, and operate. The operate phase, however, consisted of discussions and analysis of developed solutions related to the use of the implemented production system or work procedure to reach the intended value.

The four courses that applied the principles of co-reading and, thus, were studied in this paper had the titles: (1) Agile production development, (2) Changeable and reconfigurable manufacturing, and (3) Human Factors Engineering, and (4) Maintenance for production performance.

In the course Agile production development, the student learned about agile principles for effective implementation of projects in production development. The course was alternating theory and practice, adapted to the needs of the participants daily work or industrial experience. The course covered all phases of a project, from initiation and planning to implementation and project completion. Co-reading was applied with master students from a course covering similar topics. The co-reading included participation in the same lectures. The main values for co-reading were, according to the course responsible, for CEE students to get recent knowledge in the field and for the UEE students to build a network of contacts for future employment. The course did not apply co-reading related to the project work since it required practical experience and a work position to which the projects where connected. The UEE did not have enough practical experience neither a working position.

The course Changeable and reconfigurable manufacturing intended to build competence in design and development about changeable production systems to provide efficient production to better deal with variations in e.g., product types and volumes. The course was centered around a project work where the CEE participants continuously applied theories to practice in order to develop a conceptual reconfigurable production system. In this course UEE students were invited to attend lectures and project presentations in the CEE course. The UEE students were master students from the final course of their program, Final project work in production systems. The students invited to the CEE course were, thus, students doing master thesis projects within the topic. The reason to involve these UEE students were to broaden the student knowledge in the field and to get the opportunity to learn from other companies, except the ones that they collaborated with in their thesis project. The CEE students were invited to participate in thesis project presentations by the UEE students. Also, this was an opportunity to discuss and learn from each other on the topic.

The course Human factors engineering provided knowledge and insights on how products and industrial systems could be designed considering people's natural strengths and limitations and result in usability, efficiency, sustainability, and well-being. In this course the industrial problems by the CEE students were investigated by the UEE students. The CEE students formulated a problem from their organization that was interesting to get investigated related to the topic of the course. Project works for the UEE students were defined based on the problems. The CEE students had the roles of supervisors related to their own problems. This approach of co-reading aimed to support the CEE students in their learning related to their own industrial problem. By acting as supervisor, they had to explain and discuss the problems related to new theories with UEE students. The UEE students got the chance to investigate a real industrial problem with supervision from a professional. This concept involved several challenges. It required a lot of time from the course responsible since he had to guide the CEE students in supervision as well as guide the UEE students related to the theoretical field. Another challenge was to be one step ahead and creating the vision for the benefits from the next step, without constraining too much the relationship between the CEE and UEE students. It was important to allow them freedom to create their own bonds and positive mutual enhancements but pointing a path at the same time for collaboration. This type of co-reading was seen as a win-win way of working, for all the parties involved. The UEE students appreciated to be in contact directly with company employees sharing the same interests and learn from them. From a teacher perspective, besides an increased learning, the teacher was strengthening his leadership skills managing the interaction between the two groups in a growth approach for everyone. The CEE student got their problem investigated by students.

In the course Maintenance for production performance the CEE student gets knowledge and skills to motivate a maintenance strategy to develop the company's production performance. In this course, the participants were invited to participate in two guest lectures about how production flow simulation was applied and used in practice. The guest lectures were given together with students in a third cycle course (PhD level). The reason for this co-reading was to get maximal advantage of the opportunity to learn from this experienced guest lecturer since it was a relevant topic for both student groups.

In each of the courses co-reading had taken place between 2 and 5 times. The courses were on advanced level and the UEE students were master students, and in one case PhD students. In none of the co-reading activities mutual examination were conducted. Only in the course in Human factors engineering the co-reading activity was a compulsory activity in the course.

DISCUSSION

In order to strengthening the competence within manufacturing industry education for professionals (CEE) and traditional education (UEE) play an important role. The types of co-reading activities identified in the courses in this study were:

- participation in the invited guest lectures – UEE and CEE students were gathered in the same classroom (virtual or face-to-face) to listening to the invited guest lecturer and get the possibility to discuss the topic of the lecture
- participation in lectures by university teaching staff – same as above, but the teacher was the regular teacher of the UEE and/or the CEE course
- seminars and project presentations – UEE and CEE students met to discuss e.g., project results or course literature
- project work –UEE students worked with problems identified by the CEE students supervised by the CEE student and the teacher of the course

The activities differed in terms of character, extension, and purpose. By combining the student groups in different types of activities benefits for both UEE and CEE student as well as the teacher/course responsible could be identified. In the same way challenges could be identified related to the three roles. In table 1, the benefits and challenges with the co-reading activities are summarized related to the three different roles.

Co-reading activities should ideally lead to a win-win situation between the two student groups. If it only benefits one of the groups or the challenges are large in relation to the benefits the value of the co-reading activity might be pointless. The value for the teacher is also a perspective to highlight. This type of activities was in the courses contributing to enhancing the faculty professional competence (Standard 9), according to the course responsible teachers. The project has strengthened the ability to support students to achieve a deeper working understanding of the relevant disciplinary fundamentals, which is something that is addressed in this standard.

Many different aspects might affect the extent of the benefits in the co-reading activities. The professional experience can highly differ between CEE students, according to the framework by Uhomoibhil & Ross (2019). In the CEE courses participants with a large variety in competence and working experience were included, from persons that were recently graduated and newly employed to students with a very long and qualified working experience. Also, the size of the student groups affected the benefits of the co-reading. The size of the student groups differed between approximately 5-20 students. In small student groups the co-reading was more motivated than in larger groups in order to increase the number of perspectives by the students.

Table 1. Overview of co-reading activities and related challenges and benefits

	UEE student	**CEE student**	**Teacher/ Course responsible**
Participation in the invited guest lectures	+Industry perspective in any discussions/ questions		+Increased possibility to invite guest lecture due to a larger student group
Participation in lectures by university teaching staff	+Industry perspective in any discussions/ questions -Less focus on the UEE students' needs	-Less focus on the CEE students' needs	+ Save time
Seminars and project presentations	+Get the industry perspective into the discussion	+Get the perspective from UEE students with "fresh eyes"	+ Increased learning through the two perspectives
Project work	+Possibility to work with industry relevant problem and be supervised by a professional	+Get "fresh eyes" on their industrial problem as well as support in solving the problem -Spend time on supervising the UEE students	+ Support in identifying relevant industrial problems +Support in supervising the UEE students -Spend time on training the CEE students in supervision -Spend time in supervising the UEE students on the theoretical part of the problem -Require more planning/organizing

In this study both the CEE (the PREMIUM courses) and the UEE (the master programs) were recently developed and only held one or a few times. Some of the master courses that were matched to the CEE courses in accordance with the matrix (described in figure 2) were under development and still not carried out. Consequently, the concept of co-reading was still not fully established. To fully develop and draw advantage of the concept a higher level of maturity is required in both the UEE and the CEE courses.

This study perhaps most clearly contributes to strengthening standard 7, Integrated Learning Experiences, where it is pointed out that incorporating professional engineering issues in contexts where they coexist with disciplinary issues is important. UEE students have gained an industry perspective on their issues and problems. They have also been given the opportunity to work with industry-related tasks and have been supervised by professional CEE students.

Standard 8, Active Learning, has also been strengthened through the PREMIUM project. The project has given UEE students the opportunity to get involved in and to solve real industrial problems. They have discussed in small groups together with professional CEE students and had the possibility to debate various concepts and solutions.

CONCLUSION

The purpose with the paper was to describe how learning activities integrating CEE and UEE can be achieved to strengthen the CDIO goals as well as exploring the benefits and challenges related to the mixed student group. Several types of learning activities gathering the student groups were identified in this study including project work related to problems formulated by CEE students, lecture participations and discussions, and seminars. Benefits and challenges related to the UEE student, CEE student, and teacher were identified. In the study the co-reading benefited the three roles in different ways. The UEE student got increased insights in the industry perspective while the CEE student widened their perspective through the co-reading with UEE students. The co-reading activities also contributed to enhancing the faculty professional competence. Challenges identified related to e.g., the differences in background knowledge and skills in the areas affecting the co-reading activities in lectures and in project work as well as practical factors such as planning and scheduling. The results indicated clear relations to CDIO standards related to (7) Integrated Learning Experiences, (8) Active learning, and (9) Enhancement of Faculty Competence.

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BIOGRAPHICAL INFORMATION

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Part III

Engineering Education Research

SELF-EFFICACY AND STUDY BURNOUT AMONG IT STUDENTS: CHALLENGES AND POTENTIALS

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ABSTRACT

There is a risk of student dropout in the field of engineering, particularly in the domain of information technology. To find novel pedagogical and technological solutions to prevent student attrition, we must better understand student experiences regarding their learning and studying processes. This study was conducted within the introduction of a new engineering degree program at the University of Jyväskylä and focused on first-year students. The research questions are: How do IT students experience study burnout at the beginning of their studies? What kind of self-efficacy beliefs do IT students have at the beginning of their studies? How are the self-efficacy beliefs of IT students associated with their levels of study burnout at the beginning of their studies? Student experiences were gathered through a validated survey that measured student self-efficacy beliefs and their experiences regarding study burnout. The results indicate that most students have high self-efficacy beliefs but, at the same time, a few of them experience quite a high study workload stress at the beginning of their studies. Studying the development of the student experiences over time provides an understanding of the relations between the experiences of study burnout and self-efficacy. This knowledge may support the development of novel pedagogical and technological solutions so that students may be provided timely guidance, leading to improved student well-being and ultimately to decreased dropouts in the field of engineering.

KEYWORDS

Engineering education, Learning experiences, Burnout, Self-efficacy, Student attrition,
CDIO Standards: 10, 12

INTRODUCTION

There is a risk of student dropout in the field of engineering, particularly in the domain of information technology (IT). Typically, only half of the engineering students ever graduate (Schuman et al., 1999). Research indicates that a significant portion of students discontinue their studies during the first academic year (Watson & Li, 2014). Such is the case in Finland. Between 2005 and 2020, approximately 255,000 students started their bachelor's studies in Finnish universities, and 188,000 received a bachelor-level degree. In the field of information and communication technologies (ISCED 06; see e.g. UNESCO, 2015) the respective figures for new students and graduates between 2005 and 2020 were 20,000 and 12,000. That is, the total graduation rate was approximately 74%, whereas in the field of IT, the total graduation rate was only 57% (Vipunen, 2021). Although the student intake among different fields and programs has varied over the years, the difference is clear.

The factors associated with engineering student attrition include issues regarding classroom and academic climate, experiences of low academic achievement and conceptual misunderstanding as well as topics in self-efficacy, self-confidence, social integration and career goals (Araque et al., 2009; French et al., 2005; Geisinger & Raman, 2013; Tinto, 1975). Many engineering education researchers and developers have sought ways to improve student retention. For example, introduction of active learning strategies, elements balancing the ratio between theoretical and practical contents in the beginning of the studies, and different student care activities have been introduced (Bennedsen, 2011; Lauritsen, 2012; Tanner et al., 2019). To find novel pedagogical and technological solutions to prevent student attrition, we need a better understanding of student experiences of learning and studying processes. Understanding these phenomena both in general as well as in the local context also facilitates the development of degree programs and provides information to enhance faculty teaching competence (CDIO Initiative, 2021; Malmqvist et. al, 2019).

The challenge with student retention is present also at the University of Jyväskylä (JyU), where this study was conducted. The ratio between the new bachelor-level students and graduates from 2005 to 2020 was 72%, whereas in the field of IT, the ratio was 47%. According to the JyU student register data, approximately 63% of discontinued IT students over the past five years completed less than 30 ECTS (European Credit Transfer and Accumulation System) credits (corresponding to a half year's study progress goal), and 75% completed less than 60 ECTS credits. A research project connected to the educational development of the faculty was initiated upon the introduction of engineering as a new discipline at the university. The aim of the project is to provide research-based knowledge to support the enhancement of teaching, learning practices and learning environments among the IT department faculty. The project focuses especially on activities conducted during the first academic year in the engineering and computer science programs.

This study focuses on student experiences of learning and studying processes, especially as they relate to student self-efficacy and levels of study burnout, in the beginning of their studies. The study was conducted jointly within a new engineering B.Sc. and M.Sc. (technology) degree program in information and software engineering, and the first-year students of the B.Sc. and M.Sc. (computer science) degree programs in mathematical information technology and education technology at JyU. By developing new understandings of the emergence of self-experienced learning, its associations with IT student self-efficacy and the challenges of study burnout, this study will promote the sustainable and ethical development of higher education. This will assist in developing study programs in the IT domain.

LITERATURE REVIEW

Student experiences of stress and heavy workload may have a negative impact on engagement in studies, academic achievement and study progression (Asikainen et al., 2022; Madigan & Curran 2021, Salmela-Aro et al., 2009). Thus, novel solutions are needed to prevent interrupted studies, lengthened graduation times and dropouts. The concept of school burnout can be divided into three components: exhaustion, cynicism and inadequacy. Exhaustion can be described as fatigue resulting from schoolwork and its demands. Loss of feelings of meaningfulness and interest may manifest as a cynical attitude toward schoolwork, and low beliefs of one's own competence and achievements can cause feelings of inadequacy (Salmela-Aro et al., 2009). Burnout is often linked to exhaustion and high workload, but it is only one aspect for understanding burnout. Also, aspects of cynicism and inadequacy measure more broadly the motivational and psychological aspects of burnout (Leiter & Maslach, 2016).

Potential risk factors for burnout may include experienced high demands on studies, decreased interest, insufficient support, lack of learning and studying skills, low self-efficacy, surface approach to studies, mental health problems and uncertainty about future and career (see e.g. Asikainen et al., 2022; Neumann et al., 1990; Yan 2021). Asikainen et al. (2022) investigated the approaches of first-year university students to learning and study burnout by measuring these items with a HowULearn questionnaire and discovered that the burnout was positively correlated with the surface approach to studying. Understanding burnout as a phenomenon and its potential risk factors may enable better understanding of student engagement and attrition (Neumann et al., 1990).

Feelings of inadequacy are shown to be related to school burnout (see e.g. Salmela-Aro & Read, 2017). On the other hand, experiences of self-efficacy, used here to refer to student beliefs about their capabilities to perform in studies, are related to motivation, learning and academic performance (Richardson et al., 2012; Zimmerman, 2000*)*. Self-efficacy beliefs "influence how people think, feel, motivate themselves, and act" (Bandura, 1995, p. 2). Parpala et al. (2021) used the HowULearn questionnaire to investigate student learning profiles and self-efficacy beliefs in different disciplines and found out that deeply organized students had the highest self-efficacy levels in all disciplines. Self-efficacy beliefs are forward-looking and may predict studying behaviours and interests. Therefore, long-term tracking of student self-efficacy scores may be one tool for recognizing and anticipating challenges or gaps in learning (see e.g. Brennan & Hugo, 2017; Dinther et al., 2011; Luo et al., 2021; Zimmerman, 2000). Brennan and Hugo (2017) investigated experienced self-efficacy among engineering students and found out that self-efficacy was lower in technical areas than professional areas.

RESEARCH QUESTIONS

This study focuses on student experiences of their learning and studying processes in the beginning of their studies. It aims to generate information about student experiences at a very early stage of their university studies to guide the development of a novel degree program. The research questions (RQs) are:

- RQ1: How do IT students experience study burnout at the beginning of their studies?
- RQ2: What kind of self-efficacy beliefs do IT students have at the beginning of their studies?
- RQ3: How are the self-efficacy beliefs of IT students associated with their levels of study burnout at the beginning of their studies?

MATERIALS AND METHODS

Context and participants

The study was conducted at the University of Jyväskylä. The university has hosted IT programs since 1967. In 2020, JyU introduced an engineering program into its portfolio. The new curriculum is novel in the sense that it combines the studies in IT with mathematical and logical reasoning and a student chosen field in the humanities. The aim is for students to learn not only computer science and programming but also achieve a broader view on the reasons and needs for which IT is exploited. This is a rather ambitious goal, and consequently, it is important that students achieve experiences of insights to build motivation.

The first students in the combined B.Sc. and M.Sc. in information and software engineering commenced their studies in autumn 2021. The participants in this study were the first-year students from 1) the new engineering B.Sc. and M.Sc. (technology) degree program in information and software engineering and 2) the B.Sc. and M.Sc. (computer science) degree programs in mathematical information technology and education technology.

Data

Student experiences were gathered through a HowULearn questionnaire (see details, Parpala & Linblom-Ylänne, 2012). The questionnaire was selected due to its wide use and validation in Finnish and in international contexts (see Parpala et al., 2021). The questionnaire will be repeated a total of four times throughout the bachelor-level studies of the students participants. The questionnaire was sent to the participants via email. To address our research questions, we used the student responses from the first part of the survey conducted after one month of studying. In total, 38 students answered the survey (response rate 36%), and the respondents were quite evenly distributed between the degree program in information and software engineering (N = 20) and the degree programs in mathematical information technology and educational technology (N = 18). The information and software engineering program has partly the same studies as the mathematical information technology and educational technology programs (e.g. a basic programming course), but its overall curricular structure differs. Because the program of information and software engineering is new to the University of Jyväskylä, and the programs of mathematical information technology and education technology have longer histories, both were included in the study to allow for possible comparison between these programs.

The survey has items that measure student study burnout and self-efficacy beliefs. Study burnout (RQ1) was measured with a part of HowULearn questionnaire that consists of a Study Burnout Inventory (SBI-9), originally based on the school burnout questionnaire by Salmela-Aro et al., 2009 (e.g. “I often have feelings of inadequacy in my studies”). Study Burnout Inventory measures three different dimensions of burnout with nine questions regarding the following: exhaustion (four items), inadequacy (two items) and cynicism (three items). The students responded to each item on a 5-point Likert scale (1 = totally disagree, 5 = totally agree). Originally, the part of the HowULearn questionnaire measuring student self-efficacy beliefs (RQ2) has been modified from A manual for the use of the Motivated Strategies for Learning Questionnaire (MSLQ; Parpala & Lindblom-Ylänne, 2012; Pintrich, P. R., 1991). Student self-efficacy was measured with a section of the HowULearn questionnaire including five questions about student beliefs regarding their future performance in studies (e.g. “I believe I will succeed in my studies”).

Analysis

Differences between the information and software engineering program and the mathematical information technology and education technology programs were tested with a non-parametric Mann-Whitney U Test. Since we did not find significant differences between these programs, we performed the following analyses for the whole sample. To address RQ1, a sum variable was formed based on all nine questions measuring study burnout. One sum variable was relied upon since the correlations within and between the subsets of the items (exhaustion, inadequacy, cynicism) were similar. To address RQ2, a sum variable was formed based on all five questions measuring self-efficacy beliefs. In addition to the descriptive statistics of the sum variables in RQs 1 and 2, the distributions, means, and standard deviations of the different items were considered separately. To address RQ3, we plotted the associations between the study burnout (RQ1) and self-efficacy beliefs (RQ2). The sum variables were used as measures of study burnout and self-efficacy beliefs and included a linear regression line to the plot, modelling the association between the two sum variables.

RESULTS

Study burnout

Regarding RQ1, some students seemed to experience study workload stress at a very early stage of their studies. The average of the sum variable measuring student study burnout was 2.5 (SD = 0.9). Every second respondent (50%) agreed they were often worried about studying in their free time. One-third of the respondents (34%) agreed with the claim "I often have feelings of inadequacy in my studies". Also, more than one-third (34%) felt overwhelmed with schoolwork. Over one-third (37%) of students agreed with the claim "I used to have higher expectations of my schoolwork than I do now". Almost one-fifth (18%) agreed that they were not sleeping well because of study issues. Student experiences of study burnout varied already at the beginning of their studies. Figure 1 illustrates the typical distribution of the responses concerning study burnout (Item 1 in Table A-1). All nine items measuring study burnout with their means and standard deviations are shown in Table A-1 in the Appendix.

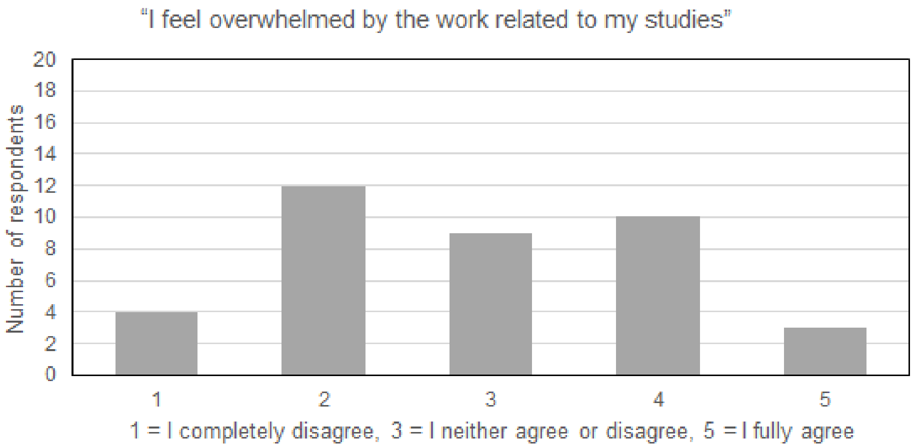

Figure 1. Student experiences regarding their levels of study burnout based on the item "I feel overwhelmed by the work related to my studies" (N = 38).

Self-efficacy

In a seeming contradiction at the same time, when it comes to RQ2, the respondents had high self-efficacy beliefs. The average of the sum variable measuring student level of self-efficacy indicated high self-efficacy beliefs (mean = 3.9, SD = 0.8). For example, more than three-fourths (76%) agreed with the claim "I believe I will do well in my studies", and 71% agreed that they will understand the most difficult materials in their studies. Furthermore, 71 %

expected to do well in their studies. Almost four-fifths (79%) of students agreed with the claim "I am confident I can understand the basic concepts of my own study field". Student experiences of their self-efficacy varied less than the reported study burnout experiences. Figure 2 illustrates a typical distribution of the responses concerning self-efficacy beliefs (e.g. Item 1 in Table A-2). All five items measuring self-efficacy with their means and standard deviations are shown in Table A-2 in the Appendix.

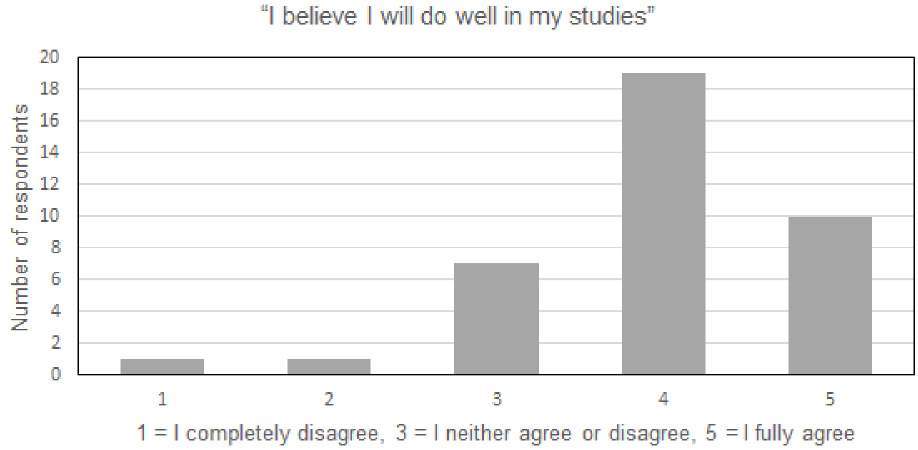

Figure 2. Student experiences regarding their self-efficacy based on the item "I believe I will do well in my studies" (*N* = 38).

Figure 3 presents the averaged self-efficacy beliefs and levels of study burnout. The results reveal that most of the students experienced high self-efficacy beliefs (the averaged value 3.9 or more) with low experiences of study burnout (the averaged value 2.5 or less). Many students with higher levels of study burnout (the averaged value more than 2.5; see the dashed line in Figure 3) had lower self-efficacy beliefs (the averaged value less than 3.9; see the dashed line in Figure 3).

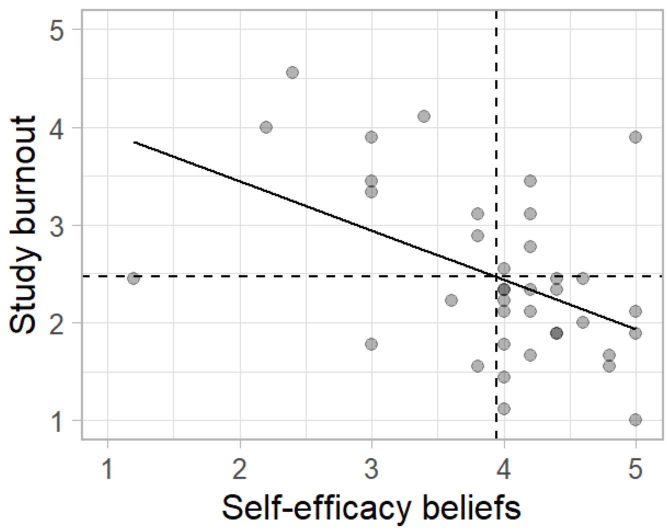

Figure 3. Student study burnout and self-efficacy beliefs so that each dot represents a student. The solid line has been fitted based on the linear regression model. The horizontal and vertical dashed lines present the mean of the study burnout and self-efficacy beliefs, respectively.

DISCUSSION AND CONCLUSIONS

In the light of the results, a clear potential is that most of the students are experiencing high self-efficacy beliefs in the beginning of their studies (RQ2). High self-efficacy among IT students can empower individuals to become active agents in their studies, future working life and society (e.g. Zimmerman, 2000). When it comes to challenges, this study highlighted that some students experience quite high study burnout at the early stages of their bachelor-level programs (RQ1). Students with higher self-efficacy beliefs were, in several cases, experiencing lower levels of burnout (RQ3). This is aligned with previous research that shows that self-efficacy correlates negatively with burnout (e.g. Yan 2021). Feelings of inadequacy have been defined as one aspect of burnout (Salmela-Aro et al., 2009). However, burnout is a much broader phenomenon and also includes aspects of exhaustion and cynicism, and the reasons behind burnout may be even more multidimensional.

Feelings of burnout at such an early stage of studies could also indicate changes in learning practices upon transition from high school to university and the changing demands and challenges faced in studies. The current COVID-19 pandemic may also have had an impact on experienced levels of exhaustion and burnout at the beginning of the semester (e.g. Gonzalez-Ramirez et al., 2021). Since the number of respondents remained relatively small and the data was collected only from one cohort, conclusions on the results should be drawn with caution. Longitudinal data collection is needed to study the development of study burnout and self-efficacy beliefs during studies. The research team aims to repeat the questionnaire for the new cohort starting their studies autumn 2022 to better understand student experiences at the beginning and during their studies. More data would also enable us to further examine the associations between study burnout and self-efficacy beliefs.

Studying the development of student experiences of self-efficacy and burnout throughout the bachelor stage of this new degree program provides an understanding of the associations between their experiences over time. This knowledge, along with better recognition of possible risk factors for burnout, may support the development of novel pedagogical and technological solutions to provide timely guidance to students. Primetime learning is an example of a research-based instructional strategy that aims for enhanced student activity and social integration (Koskinen et al., 2018). Such new solutions and teaching methods that take student activity and social aspects of learning into account can pursue improved student well-being and, ultimately, decrease dropouts in the field of engineering.

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BIOGRAPHICAL INFORMATION

Raija Hämäläinen, a Full Professor (PhD), works in the field of technology-enhanced learning at the Center for Research for Learning and Teaching at the University of Jyväskylä, Finland. Belonging to the elite global top 3%, the JYU research centre is among the leading European research groups in learning and teaching. Recently, Raija and her research group were awarded the European Commission's VET Excellence Award. The driving force for their research is a rapidly changing world in which structural change is reshaping learning and professional development. The preconditions for designing future learning and professional development are the analysis and understanding of learning and interaction processes and their contextual adaptations. Specifically, Raija and her group seek to understand learning and professional development by investigating how learning and interaction processes occur and unfold over time with novel methods, such as eye-tracking, heartrate variability and prosodic analysis of voice.

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APPENDIX

Table A-1. The nine items that measured student study burnout with their means and standard deviations (SD).

Study burnout	*Mean*	*SD*
1. I feel overwhelmed by the work related to my studies.	2,9	1,2
2. I feel a lack of study motivation and often think of giving up.	2,0	1,2
3. I often have feelings of inadequacy in my studies.	2,8	1,3
4. I often sleep badly because of matters related to my studies.	2,1	1,1
5. I feel that I am losing interest in my studies.	2,1	1,1
6. I'm continually wondering whether my studies have any meaning.	2,2	1,3
7. I brood over matters related to my studies during my free time.	3,2	1,3
8. I used to have higher expectations of my studies than I do now.	2,9	1,4
9. The pressure of my studies causes me problems in my close relationships with others.	1,9	1,1

Table A-2. The five items that measured student' self-efficacy beliefs with their means and standard deviations (SD).

Self-efficacy	*Mean*	*SD*
1. I believe I will do well in my studies.	3,9	0,9
2. I'm certain I can understand the most difficult material in my studies.	3,7	0,8
3. I'm confident I can understand the basic concepts of my own study field.	4,3	0,9
4. I expect to do well in my studies.	3,8	0,9
5. I'm certain I can learn well the skills required in my study field.	3,9	0,9

COVID-19 FORCED REMOTE TEACHING AND UNIVERSITY EDUCATION AFTER IT

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ABSTRACT

The COVID-19 outbreak at the beginning of 2020 disrupted students' and teachers' learning and teaching activities worldwide as it led to a quick transition from education, including face-to-face interaction to emergency remote teaching (ERT). During this ERT period monitoring research on the experiences and innovation needs was done at Wageningen University & Research. This was supplemented with small teacher and student group consultations. The results show that a focus on student well-being is needed in the years ahead. The ERT was appreciated as it kept education going on. Still, students indicated lack of sense of connectedness and a strong desire to have face-to-face education as part of the Teaching and Learning Activities (TLA). For the following years, online versions of most courses should be available to stay prepared for online education when needed. That includes online alternatives for vulnerable TLA's like labs and excursions. The ERT courses hastily developed in 2020 can be redesigned in combination with a blended learning curriculum for less restricted times. This requires a well-designed mix of TLA's to activate students, rather than simply flipping one kind of TLA for another. In combination with the (re)design of courses geared to sense of connectedness, this might add up to the resilient curricula we need for the following years.

KEYWORDS

Emergency remote teaching, well-being, online & face-to-face learning, education design, resilient curricula, CDIO standards: 6, 7, 8, 10.

INTRODUCTION

The COVID-19 outbreak at the beginning of 2020 disrupted students' and teachers' learning and teaching activities worldwide. It led to a quick transition from regular higher education, including face-to-face interaction, to emergency remote teaching (ERT) (Hodges et al., 2020). Crawford et al. (2020) describe the initial responses to COVID-19 in higher education across 20 countries. The actions up to March 2020 ranged from having no response through to social isolation strategies on campus and rapid curriculum redevelopment for fully online offerings. In March 2020, most European higher education institutions were implementing a response plan to the COVID-19 outbreak or developing one (Rumbley, 2020). Gaebel et al. (2021) surveyed 368 education institutions from 48 European Higher Education Area countries. They found that in April 2020, practically all of those institutions managed to pivot to blended and online learning. They also found that the rapid shift to ERT was possible due to a much higher acceptance of digitally enhanced learning and teaching in 2020 compared to 2014. This shift also happened at Wageningen University & Research (WUR). During that ERT, research was designed to monitor the transition process in education by examining the perceptions of relevant stakeholders such as teachers and students. That research consisted of (1) large scale student and teachers surveys (Stevens et al., 2020a, 2020b), (2) a small in-depth teacher survey on requested innovation (van Puffelen & Tauecchio, 2021) and (3) online student and teachers consultations. This paper combines all these results to draw conclusions on the design needed for university education in the years ahead.

METHODS

The pandemic came as a surprise, and the research was planned after the ERT had already started. There was no comparable situation in the past, and a mix of quantitative (surveys) and qualitative research (interviews) was chosen to explore the new situation.

Teacher survey

All teachers involved in teaching or coordinating a course from March till July 2020 (the ERT period) were invited by email to partake in an online survey. They were informed about the study and the option to fill in the survey anonymously by leaving some items blank. Participants were first asked if they spent at least 6 hours teaching in the given period to validate a minimum active role in the teaching period. In total, 289 teachers (21%) participated in the survey. Teachers were asked to indicate their age, gender and role: 'course coordinator' (responsible for the course and involved in many teaching activities) or 'lecturer' (teaching a part of a course). An analysis of the characteristics of the respondents indicated a representative sample of the teacher population at WUR in terms of age (N = 112, M = 45, SD = 11.26), gender (N = 157, 54% male, 46% female) and teaching role (N = 272, 60% lecturers, 40% coordinators). The survey included questions about teachers' attitudes towards online teaching, beliefs about students' learning, stress level, digital and didactic self-efficacy, their professional development and the perceived level of support. For each construct variable, we used multiple items with a 5-points answering scale (mostly Likert scales ranging from *'strongly* *disagree'* to *'strongly agree'*). The percentage of teachers that agreed or strongly agreed with a given statement was calculated to indicate the general support for a statement. In addition, teachers were asked about the use of and satisfaction with education support services (11 items), teacher training (11 items), and online teaching tools (39 items). The use of a service (support, training, or tool) was measured as '*yes'* or '*no'*, and overall use was established into a variable based on the total 'frequency of use' for each type of service. Finally, the evaluation of a support service, teacher training and online teaching tool was measured on a 5-point satisfaction scale. The variables, items, their mean and standard deviations are shown in tables 1 and 2. The reliability measures were satisfactory.

Table 1. Statistics of construct variables

	N cases	*N* Items	*M*	*SD*	*Cronbach's Alpha*
Attitude towards online teaching	287	3	3.53	0.83	.65
Beliefs about students' learning	269	5	2.43	0.58	.76
Experienced level of stress	287	3	3.73	0.93	.70
Self-efficacy	286	2	3.82	0.77	.64
Beliefs about professional development	286	3	3.65	0.81	.67
Perceived level of support	287	4	4.01	0.72	.74

Table 2. Statistics of variables

Variable	*N* cases	*N* items	Item options	*M*	*SD*
Use of (participation in) teacher trainings	288	11	binary yes/no	1.42	1.61
Satisfaction about teacher trainings	189	11	5 point satisfaction scale	3.66	0.90
Use of support services	288	11	binary yes/no	4.05	2.54
Satisfaction about support services	259	11	5 point satisfaction scale	3.47	0.87
Use of on-line tools	288	39	binary yes/no	6.96	4.02
Satisfaction about online tool	275	39	5 point satisfaction scale	3.58	0.76

Student survey

From March till July 2020 (the ERT period), questions about student perceptions of online education were included in the student course evaluations (3850 responses out of 14.150 students in 207 courses) and collected through an additional student survey that focussed solely on online education (1251 responses). An analysis of the respondents of the student course evaluations indicated a representative sample of the student population at WUR in terms of age, gender, nationality and study program. However, in the survey about online education, female students, Dutch students, and first-year students were overrepresented. The survey included questions that covered the themes: student services; experiences and evaluation of online education; well-being; self-perceived learning performance; the use and experience of new tools for online teaching; the experience of new learning activities and forms of assessment (e.g., virtual lectures, group work, proctored exams).

Teacher survey about future education innovation

These surveys were supplemented with a small-scale in-depth survey on requested topics for future education innovation at WUR. A small group (21) of education staff subscribed to innovation news was asked to respond to an anonymous online survey, and this option was also offered on a WUR intranet website. The questions were about their opinion on required education innovations and about the importance of five education innovation topics that were considered important in internal discussions of the four Dutch technical universities:

1. Entrepreneurial learning/academic entrepreneurship
2. Educating for responsible engineering/the ethical or responsible engineer
3. Information technology and the information technology-driven engineer
4. Challenge-based learning
5. Teaching excellence in education

They could score each topic's importance on a 5-point Likert scale: 1: Not at all important, 2: Slightly important, 3: Moderately important, 4: Very important, 5: Extremely important. Also, there was an option to give free-text feedback on each topic.

Consultation of small groups of students and teachers

A team dedicated to working with small groups of students and teachers to gather different education experiences at WUR, organised online sessions on ERT-related topics between July 2020 and June 2021. These topics were requested by WUR's management and education support staff and included 'Following a Course Online' (July 2020, 8 students), 'Blended and Hybrid Education' (November 2020, 18 students), 'Teaching During Corona' (February 2021, 6 teachers) and 'Alternatives for Practical Education' (June 2021, 7 students). The sessions aimed to find potentially successful areas to improve education during and after the ERT. Outcomes were used to inform workgroups and policy-makers at WUR. A design thinking approach was used, including making a shared inventory and prioritisation, identifying underlying needs and tackling the main issues in small groups by creating new designs. The online setup of the process is shown in figure 1.

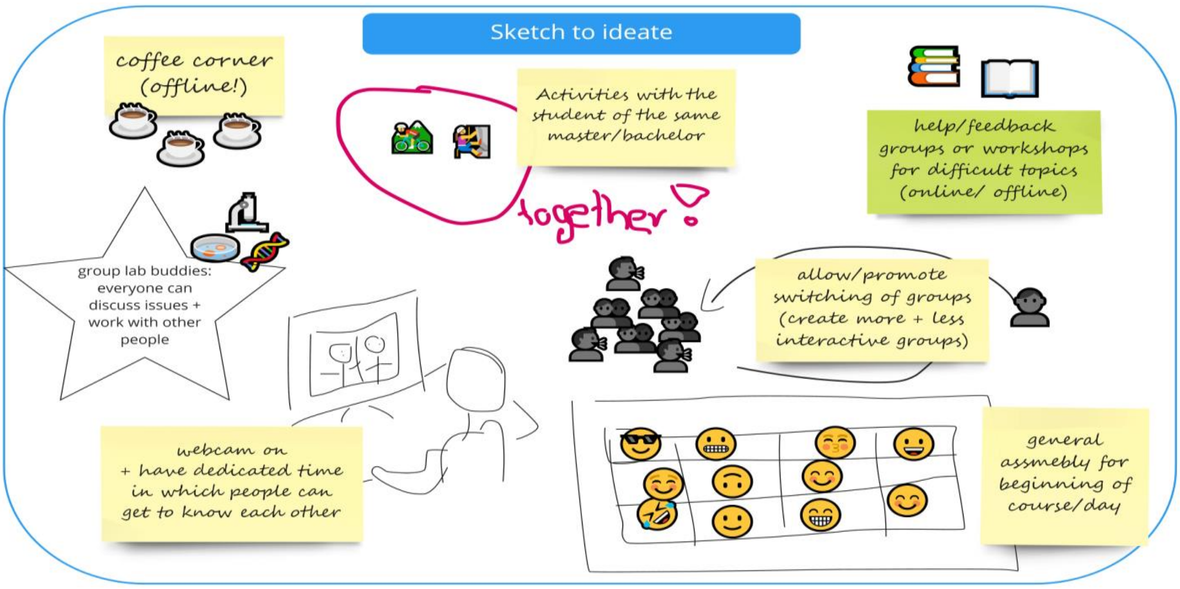

Figure 1. Student group's ideation process during online consultation.

The student sessions were about their experience of the transition to online education: aspects that worked well or didn't work well; the main difficulties and (unexpected) opportunities; effects on learning goals, motivation, focus, feeling of connection and commitment; expectations of teachers' and students' roles. The teacher session was on their lessons learned during ERT, focusing on positive aspects; what they would like to maintain or improve for future teaching; and how they would optimise their course(s) if they could redesign it completely. As these sessions were meant exploratory, thematic content analysis with basic inductive coding was used to process the input given during the sessions (Green & Thorogood, 2018). Both Dutch (58%) and international students (42%) participated in the three student sessions. This means a slight overrepresentation of international students, who comprise around 22% of the total student population at WUR between 2019 and 2022. Most of the participants were master students (74% versus bachelor students, 26%). Among the international participants, male and female students were represented alike (46% male vs 54% female), while most Dutch participants were female (17% male vs 83% female). The session with teachers included mostly Dutch (83%) and female participants (83%).

RESULTS

Teacher experiences

The results of the teacher survey showed that teachers experienced stress (66%), difficulties working from home (51%) and an increased workload (80%)[1]. Teachers spent 43.8% more time on teaching during ERT than during pre-covid times. The increased workload was frequently mentioned as a key concern in the open comment section of the survey. Few teachers liked online teaching (29%), but most were motivated to teach online (74%). Teachers felt they had the digital skills (83%) and didactic skills (59%) to teach online. Overall, they felt they managed to teach their course online successfully (85%). Taken together, teachers experienced an increase in workload but were still motivated to teach online and felt they were able to teach their courses online successfully.

Student experiences

Students felt supported by teachers and the university, and they were satisfied with the services (student support, IT, communication). However, most students indicated they were not motivated to study online (69%). Students found it difficult to combine personal life at home with online education, and they experienced various physical and mental problems such as feelings of loneliness and stress. In the open comment section of the survey, they indicated that they particularly missed personal contact. Personal contact was considered essential for their well-being and learning (discussing course content, freely exchanging thoughts, learning from others) and creating a sense of community (connecting). In contrast to teachers, students did not experience a significant increase in their workload. Few students 'liked' online education. These results show that the motivation of students to study was low and that they experienced physical and mental problems during ERT.

Learning performance

Both students and teachers indicated that students' learning performance in complete online education was worse compared with (partial) on-campus education. The feedback of teachers

[1] The percentage of research participants that agreed or strongly agreed with the statement

to students, the collaborative learning among students, the motivation of students, and the engagement of students were all considered lower in online education, both by students and teachers. However, grades were slightly higher, and course satisfaction was comparable with pre-covid times. Thus, there seems to be a discrepancy between teachers' and students' general beliefs about the effectiveness of online education, students' performance (grades), course satisfaction, and self-perceived learning.

Online Teaching Methods

The survey results showed that many online tools and teaching methods were used by teachers for the first time, such as Virtual Classroom, Microsoft Teams, and Zoom. Teaching methods were often being revised rather than just maintained or entirely replaced. Most teachers intended to maintain some changes in teaching methods (despite the overall negative attitude towards online education). Students differed in evaluating different learning activities and new online teaching methods. This could indicate that there is no single 'best method' for online teaching and that to cater for different types of students, it is essential to combine different online teaching methods.

Future education innovation survey

The response to the small future education innovation survey was limited to 17 persons. Therefore, statistical analyses were not carried out, but the free-text responses yielded valuable ideas consistent with the scores. The ideas on innovation projects, workshops and training needed for the years ahead emphasised finding new approaches in blended learning with vital roles for on-campus and face-to-face interaction. The five presented topics were recognised as important with some differences. "Teaching excellence in education" and "educating for responsible engineering/the ethical or responsible engineer" were seen as very to extremely important. "Information technology and the information technology-driven engineer" received the most positive comments on the "IT for learning" subtopic. The responses on the "IT skills" were mixed. "Challenge-based learning" was seen as a good idea, but there were concerns that it would result in not enough time for training academic skills and take too much time from teachers. "Entrepreneurial learning/ academic entrepreneurship" received support for education and students' future, but there were concerns like being less relevant for the first years of BSc and taking away too much time for training academic skills.

Consultations

The student consultations yielded the following observations:

- Students viewed the lack of social contact and difficulty of online interaction as a main issue: contact and interaction were intertwined with meeting their learning goals, maintaining motivation, and feeling supported. Interaction was also seen as essential to feel part of the WUR community and create a solid professional and social network.
- Students experienced the benefits of having more time and flexibility of online education. However, having more time and flexibility also affected their attitude and mindset. While this provided an opportunity for balance and growth (self-reliance, self-starting) in some cases, it also led to a lack of motivation and limited progress in other cases.
- Students missed being able to use all senses during online alternatives to practical education and felt this affected their ability to learn. Also, enrichment of content, e.g., through knowledge clips in preparation for a practical, might help to learn more effectively.
- Working in smaller groups, facilitating peer support, and variation in educational tools and methods might help address the need for improved, more direct interaction. Mentioned

examples were small Q&A sessions as part of the course, small group discussions, informal (real-life) breaks, online interactive tools for group work, and dedicated time to get to know their fellow students.
- Students experienced improved motivation and mental health during blended education versus complete online education.

The online consultation of the teacher group indicated that they:
- Saw positive aspects of working with online tools during ERT but needed more time and support to learn to work with these tools properly.
- Stressed the importance of student interaction but felt that it was difficult to realise it online; it might help to let students ask questions less publicly; the barrier to asking questions will even be lower than offline, which might result in improved student engagement.
- Felt that it is essential to work together as a group and learn from each other, being able to divide tasks can help with that.
- Learned what worked well by asking low-barrier feedback from students.

DISCUSSION AND CONCLUSIONS

The large-scale teacher and student surveys

Teachers and students struggled with the sudden move to online education. Teachers did so mainly because of the increased workload during ERT, and students suffered from a lack of motivation and a decline in well-being due to the lack of face-to-face interactions. Although both teachers and students showed a negative attitude towards online education in general, they were positive about specific pedagogical adaptations (online teaching and learning methods) and their performance. Their negative attitude towards online education should thus be interpreted in light of the sudden involuntary move to the online world and the broader societal context. The discrepancy between teachers' and students' general beliefs about the effectiveness of online education and students' performance (grades) may also be explained by this. An overall negative affective attitude can influence beliefs about effectiveness. ERT is an externally forced change that diminishes feelings of voluntariness and autonomy and impacts motivation and attitudes. Providing the conditions to experience autonomy (giving choices), competence (positive performance feedback, optimal teacher support services), and relatedness (collaborative learning and innovation, solidarity) can help to increase intrinsic motivation and mitigate stress.

Future education innovation survey

In general, teaching staff saw options for more online education than pre-pandemic. But they stress the importance of face to face and campus education. That is not much different from pre-pandemic opinions, as van Puffelen, van Berkum, and Diederen (2018) described. The ideas on more online education are generally not about merely flipping the classroom by exchanging two forms of Teaching and Learning Activities (TLA's). Most ideas in the survey responses require optimising the complete combination of TLA's geared towards higher learning goals and more active and personalised learning. This can be achieved by selecting TLA's on their characteristics towards a type of learning and creating a smart design using (many) kinds of TLA's as described by van Puffelen (2017). In the years before the pandemic, the reported education innovation at WUR was more on the course than on the program level (van Puffelen & Vonk, 2020). In 2020, the pandemic shift towards online education could only be done by quick changes on the course level (course: a unit of teaching typically lasting no longer than one academic term). That might still be on the responders' minds as most remarks were at the course level. But there were remarks at program level as well (program: all courses required for a degree), mainly on learning goals at the program level for the skills needed in the future. The ideas for those learning goals differ amongst the respondents. Some feel that the recent introduction of more general skills education has already caused less focus on academic skills and the connection between research and education. Others see a need to focus more on other skills, including IT and a value-creating mindset seen with challenged based and entrepreneurial education. In general, there seems to be a need for a new balance and integrated plan for all types of skills mentioned above. That could also be seen as a follow-up on the vision of education (Wageningen University, 2017).

Consultations of small groups of students and teachers

The consultations showed that students and teachers preferred some face-to-face interaction. But if that becomes limited due to new Forced Remote Teaching, the advice offered under results "consultations" provides education design guidelines that improve the situation.

Combining the results

In general, the three surveys and the consultations did not lead to contradicting results, but they show differences in aspects of common topics:

- the well-being of teachers and students
- appreciation of the ERT
- education design for the years after the ERT

These topics are discussed below.

The well-being of teachers and students

Teachers experienced an increase in workload but were still motivated to teach online and felt they could teach their courses online successfully. The well-being of students was low during the ERT. This is also reflected in mental health survey amongst 28.000 higher education students in the Netherlands in spring 2021 (Dopmeijer et al., 2021). At that time, there was closure of the hospitality sector, a nationwide curfew and ERT. Around half of all students (51%) had psychological complaints, such as feelings of anxiety and sadness. Of this group, 12% had serious complaints. Their mental well-being was out of balance. They also found that students experienced significant levels of stress, performance pressure and sleeping problems. The survey questions did not separate the general effects of the pandemic from the impact of online education. The strong general restrictions on life (like curfews), worries about health and relatives, and extreme online life during the ERT period caused severe stress for many. Student rooms are often small, which is ok as long as students spend much of their time outsides of them. But during curfew and lockdown, small rooms might feel like prison cells. This is even more a problem for students being outside their home country as they have no option to temporarily move to parents or relatives. Questions on well-being and appreciation of education during the pandemic might measure that effect combined with the impact caused by the shift in education. In addition, there might be an interaction between these two effects: for instance, the forced general online life adding up to the online education work stress. Also, some students left their university towns to study online from other places. But even before the pandemic, there were quite some well-being issues amongst higher education students in the Netherlands (Dopmeijer et al., 2021), and new periods of forced remote teaching might be ahead of us. So, a clear focus on student well-being is needed in the years ahead.

Appreciation of the ERT

The ERT enabled education to go on, and that was appreciated. And it helped that there had been face-to-face education before the ERT. Nevertheless, the students indicated lack of sense of connectedness and a strong desire to have face-to-face education as part of the Teaching and Learning Activities.

Education design for the years after the ERT

In 2020, ERT saved higher education from being completely stopped. Now, face-to-face education is possible again in many countries, but sometimes with restrictions. The battle with new virus mutants will continue in the following years, and the potential for new outbreaks remains (Mostafavi et al., 2022). So, it is wise to stay prepared for 100% online education when needed. This requires focusing on the well-being, sense of connectedness of students and staff and having online versions of most courses available. The experience with ERT is valuable for that, and we can now try to integrate the ERT online courses into our blended learning curriculum for less restricted time. That will reduce maintenance costs compared to keeping separate ERT courses. This can be done using a few guidelines in mind. First, students differ in preferences towards online and other TLA's (van Puffelen, van Berkum & Diederen, 2018). A carefully designed mix of TLA's is needed to activate most students; it is not a matter of simply flipping one kind of TLA for another. Also, the combination of synchronous and asynchronous TLA's need more design time than our teachers had at the beginning of the ERT with CDIO standards (Malmqvist, Edström & Rosén, 2020) 6, 7, 8 and 10 in mind. In addition, we need to address the challenges for (partial) online alternatives regarding lab education, excursions and alternative assessment methods. In combination with the (re)design of courses geared to a sense of connectedness, this might all add up to the resilient curricula we need for the following years.

ONGOING WORK

WUR is doing follow-up research to explore students' and teachers' perceptions of and experiences with blended education in the present situation. The main research questions are: (1) What are the perceptions of students and teachers of blended education? (2) Are perceptions of students and teachers and their stress levels different compared to online education? (3) What are the experiences of students and teachers with blended education? (4) What key features of online education should be kept for blended education? Students' and teachers' surveys have been sent out, and data have been collected. The preliminary results indicate higher motivation, higher workload, and more stress for teachers in the present situation, and for students, lower stress, higher motivation, and higher workload experiences. In-depth results will be disseminated in scientific and practitioner communities. In addition, other related work will be shown as projects in the 4TU.CEE innovation map (4TU.CEE, 2022) and a project page (Researchgate, 2022) about Education design for new educational challenges of universities.

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BIOGRAPHICAL INFORMATION

Emiel van Puffelen is the leader of the 4TU.Centre for Engineering Education at Wageningen University & Research. At Wageningen University, he supervised the creation and full-scale operation of the University Teaching Qualification program. He also developed MOOC production teams, knowledge clip studios, education innovation consultancy, the educational portal, and a team for the innovation of the IT learning environment. He is a senior consultant for higher education innovation and has worked for national organisations. He has a particular interest in activating learning, blended learning, training teaching staff, and the novel design of curricula and courses.

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Perry den Brok is chair of the 4TU Centre for Engineering Education and chair of the Education and Learning Sciences chair group at Wageningen University and Research. He also chairs the division of Higher Education of the Netherlands Educational Research Association. He supervises the large-scale survey and interview study described in this paper. As a full professor and expert in educational innovation, he supervises several post-docs and PhD students on teaching and innovation in higher education, regularly gives keynotes and publishes many articles and other contributions. He is also one of the key persons at WUR with respect to educational innovation.

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FINDING SOLUTIONS TO DIGITAL INEQUALITY IN A BLENDED LEARNING ENVIRONMENT

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ABSTRACT

The move to off campus learning and teaching in Higher Education (HE) in the UK due to the Covid-19 pandemic resulted in innovative and exciting opportunities for students to study in a more flexible, bespoke way from home using a Personal Computer (PC) or equivalent device. However, for an Engineering student to benefit from these opportunities they would require regular and prolonged access to a working, up-to-date PC, which they can use to download and access software and applications, join group discussions, access learning materials etc. This access is perhaps less likely for students from lower income backgrounds or areas of higher deprivation, and there is a risk of digital inequality widening the attainment gap.

At Aston University (AU), a Virtual Desktop Interface (VDI) was implemented in order to provide students with a way to access high performance PCs remotely using their own device from home in order to use software and applications. To evaluate the VDI as a solution to digital inequality, a questionnaire (QNR) was developed and sent to AU students studying across a range of engineering programmes, and across a range of year groups.

Results from the QNR (n=53) showed that almost three quarters (73.6 %) of respondents accessed the VDI during their study, with students being able to rate the usefulness of this for different activities. Of those students that did not access the VDI, the most commonly chosen reason was that they did not need to use it (50.0 %).

The VDI system implemented at AU was well used by respondents, and comments were positive overall. Administering an online QNR presented some limitations to this study. Therefore, a paper-based QNR will be used for future research, which will be conducted at the end of this academic year. This will also allow a comparison of results between those in fully online learning environments, and the current blended delivery modes used at AU.

KEYWORDS

Digital inequality, blended delivery, online learning, digital infrastructure, Standard 7

INTRODUCTION

IMD, or Index of Multiple Deprivation, is a Government Index that measures relative deprivation for small areas in England (Gov, 2015) and is a way of understanding trends in a number of domains including income, employment, health and education. Within English Higher Education (HE) there are demonstrated patterns for students from higher levels of deprivation including higher dropout rates, lower achievement of higher-class degrees and less progression to higher levels of study or highly skilled employment (Lewis, Bolton, & Hubble, 2021). At Aston University (AU) the attainment of higher-class degrees for students from IMD quintiles 1 and 2 was 3.3 % lower than students from quintiles 3-5 in 2020 (AstonUniversity, 2021) for example. However, in 2020, AU was named University of the Year by the Guardian for its work in reducing the attainment gap between Black, Asian and minority Ethnic (BAME) students, and White students (AstonUniversity, 2020). And in 2021, AU was ranked 2nd overall in an English Social Mobility Index (SMI), in a paper commissioned by the Higher Education Policy Institute (hepi.ac.uk). This rank was attributed to AU enrolling over 55 % of students from the IMD quintiles 1 and 2, and having continuation rates for these students of 95 % (Phoenix, 2021). A report commissioned by the Institute for Fiscal Studies (Britton, Drayton, & Erve, 2021) indicates that AU is ranked second (outside of London) in terms of it's mobility rate. This mobility rate is based upon the proportion of students who received free school meals and who became one of the top 20% of earners at age 30.

The move to a mixture of on and off campus learning and teaching in Higher Education (HE) has resulted in innovative and exciting opportunities for students to study in a more flexible, bespoke way with videos, quizzes, online labs, group work etc. accessed from home using a PC or equivalent device. However, for a student to benefit from these opportunities they may require regular and prolonged access to a number of things in their home i.e. a quiet workspace, a desk, a working up-to-date PC with camera and microphone, downloadable/cloud-based software, and a good internet connection etc. This access is perhaps less likely for students from lower socio-economic backgrounds. Indeed, Ramirez (2021) reflected on this digital divide and the greater awareness of it created by the Covid-19 pandemic. And specifically, Cullinan *et al* (2021) noted that Irish students from socially disadvantaged areas were also more likely to live in areas with poor broadband coverage and suggested students deemed at risk should be provided with targeted support.

The attainment gap between students from different backgrounds in the HE sector could well widen due to digital inequality if appropriate steps are not taken to understand the key requirements and mitigate against this.

A number of studies have looked at the impact of socio-economic background on the effects of School-aged student's ability to study online during the Covid-19 pandemic. E.g. Tran et al (2020) examined the effects of learning behaviours in School pupils studying from home in Hannoi, Cuisia-Villanueva and Núñez (Cuisia-Villanueva & Núñez, 2020) looked at the effects of socio-economic background for school children learning online in the Philippines, and Flack et al (2020) reported that Australian students from disadvantaged backgrounds were worst affected by the move to home schooling. In the UK it is accepted that there is a digital divide in School children, but that studies are limited (Coleman, 2021).

However, in HE, there is often an assumption that all students will have access to a good quality computer or laptop, that they will have internet at home which is of sufficient quality, and that their home environment provides a suitable place for them to study. This is not always the case and it is important to understand student's digital resources in order to best support them. Staff at AU have noted multiple occasions of speaking with students who only have access to a shared computer at home, students who have a shared bedroom with no 'quiet space' to work, their PC is old, cannot load software, does not have a suitable camera or microphone etc., and their internet connection is low and often not sufficient to remain in meetings, watching videos, performing group work etc. In addition to the above, students at AU have also reported that their only form of connecting remotely is via their mobile phones. Utilising AU as an example of a richly diverse HE provider, the aim of this study is to evaluate any proposed solutions to digital inequality from a student perspective.

METHODOLOGY

Prior to the Covid-19 pandemic, AU had invested in an online platform for students known as the Virtual Desktop Interface (VDI). The VDI can be accessed from any on campus or personal device such as a computer, mobile phone or tablet. It allows the user to connect to a virtual University PC over the internet, with full access to the Apps and Software (specialist and standard), which a student would usually need to be logged onto a campus PC for. It consists of two independent server clusters located in secure data centres, is available for Windows, macOS, Linux, iOS Android and ChromeOS and is based on a HTML5 web based access (AstonUniversity, 2022). The VDI is managed by the Digital Services team at AU.

This VDI has the potential to meet the challenge of students who do not have access to an individual and/or high specification PC at home, providing opportunities for accessing and using software without having to visit the campus PC rooms.

In order to evaluate the effectiveness of this solution, a digital questionnaire (QNR) was developed and sent to students from three engineering disciplines; Mechanical Engineering, Biomedical Engineering and Design Engineering, from foundation year through to final year studying. The QNR was anonymous, and contained a mixture of multiple choice, multiple selection, and open comment questions.

Ethical approval was granted by the local Research Ethics Committee.

RESULTS AND DISCUSSION

The QNR participants were asked to identify themselves by their year and programme of study, their student status and disability status. The breakdown of these responses is shown in Table 1.

Table 1. Breakdown of QNR participants (Fd = Foundation, Yr = Year, F = Final) where n (%age) is displayed and where total n=53

Year of Study	Fd Yr 2 (3.8 %)	Yr 1 6 (11.3 %)	Yr 2 19 (35.8 %)	Yr F 24 (45.3 %)
Prog of Study	Mech Eng 32 (60.4 %)	Des Eng 6 (11.3 %)	Biomed Eng 10 (18.9 %)	
Student Status	Home 50 (94.3 %)	EU 2 (3.8 %)	International 1 (1.9 %)	
Disability Status	Yes 3 (5.7 %)	No 47 (88.7 %)	Prefer not to say 2 (3.8%)	

One of the key questions in the QNR asked participants if in the last academic year they had used the VDI. The results from this question (Figure 1) show how almost three quarters of participants had used the VDI.

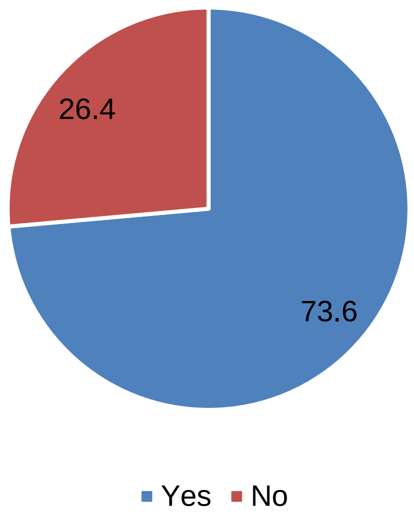

Figure 1. A pie chart displaying the percentage of participants who accessed the VDI for University work in the last academic year

An open comments question then asked those participants who had used the VDI (n=44) to share the reason why they had chosen to use it. The two key themes that emerged from these open comments were that 1) Access could be gained to software which could not be downloaded to own device, and 2) To be able to work from home without going into University. Comments included "*Because my pc is very slow compared to the VDI*", "*It was the only way to do my coursework while the university was closed*" and "*VDI allows you use a Aston university computer from home. Without the need to physically be on a university desktop. Specially engineering softwares which are easier to use on the VDI then install on your own computer due to the shear size these programs take up*."

Knowing that AU has around 55 % of students from IMD quintiles 1 and 2, it is the hope that this high usage of the VDI is enabling students to access digital resources which otherwise would be unavailable to them during a period of online learning.

The participants who had used the VDI (n=44) were also asked to evaluate the usefulness of the VDI for three key activities, and the results from this are shown in Figure 2. Over 70 % of participants found the VDI useful for learning activities, 53 % for tutorial exercises, and 65 % for assignments and project work, with 20.5 %, 11.6 %, and 18.6 % finding it not useful for these activities, respectively.

An additional open question asked participants if they had used the VDI for any other activities not listed. Participants mentioned activities such as accessing general University work and files, practicing software outside of the course requirements, and using software for a collaborative volunteering project. By understanding why students are using the VDI, and what they find it useful for, the solution can be further developed and customized for key activities.

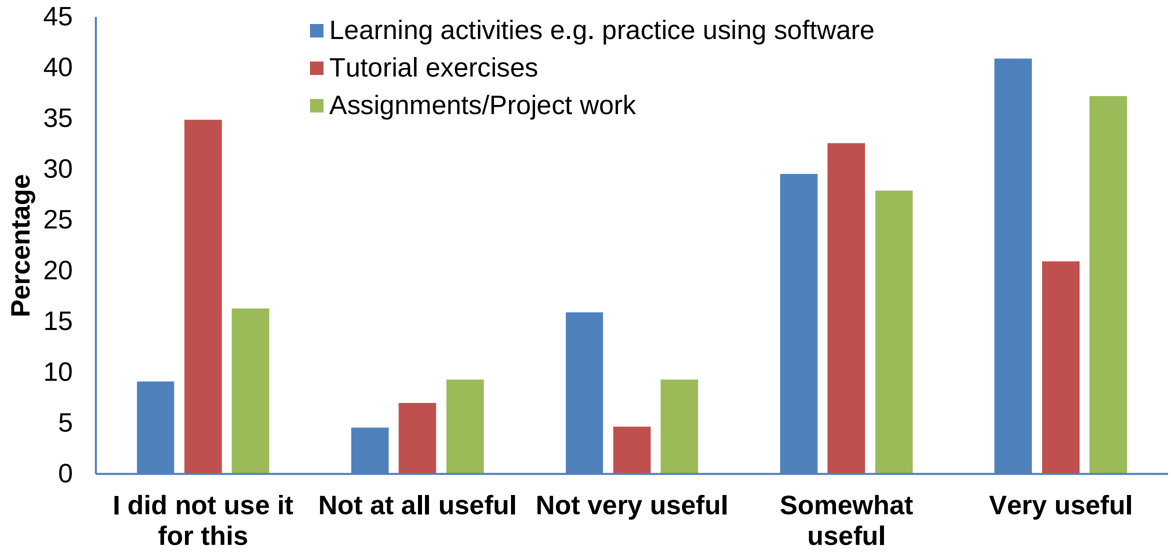

Figure 2. An evaluation of the usefulness of the VDI for assisting with various activities (n=44)

The participants who had used the VDI were asked to comment on the positive experiences of using the VDI, and also make any suggestions for improvement. A selection of comments were received and quotes from these which are representative of those comments are shown in Table 2. A key theme from the comments for the positive experiences included being able to access software and files from anywhere without any downloads. A key theme for improvement was that there was often a 'lag' when using the software across the VDI.

Table 2. Samples of quotes from both the 'Positive Experience' and the 'Suggestions for Improvements' open comment questions

Positive Experience Quotes	**Improvement Suggestion Quotes**
• *Can complete work started in uni, use the software without complications of storage or ram* • *It meant I didn't have to pay for the software* • *It didn't slow my pc at all and could keep it on the side, while doing other stuff on the actual pc* • *Can access it from multiple devices like a tablet or even on a phone if needed and all the software and things are already on there* • *It doesn't require storage space and lets you access any of the university softwares from home* • *Allowed me to be flexible with working around my home situation, for university work that included technical software programmes.*	• *More computing power assigned* • *It was lagging too much* • *Solidworks can sometimes be laggy, I think this may be down to internet connection and the VDI rather than the performance provided by the PCs on campus powering Solidworks* • *If it wasn't as glitchy and laggy*

In Figure 3, the results from a question asked solely to those participants who had not used the VDI (n=14) are shown. The question asked participants why they had not used the VDI. The most selected reason from participants was that they did not need to use the VDI (50.0 %). However, there were 42.9 % of participants who responded to say they did not know what the VDI was.

For those students who did not need to use the VDI, further study is planned to explore the reasons why. It could be because they have the digital resources at home, or it could be those students were not taking modules which required the use of specific softwares, or a combination of factors.

The results also suggest that more work should be done on introducing students to the VDI and engaging them with the uses of it.

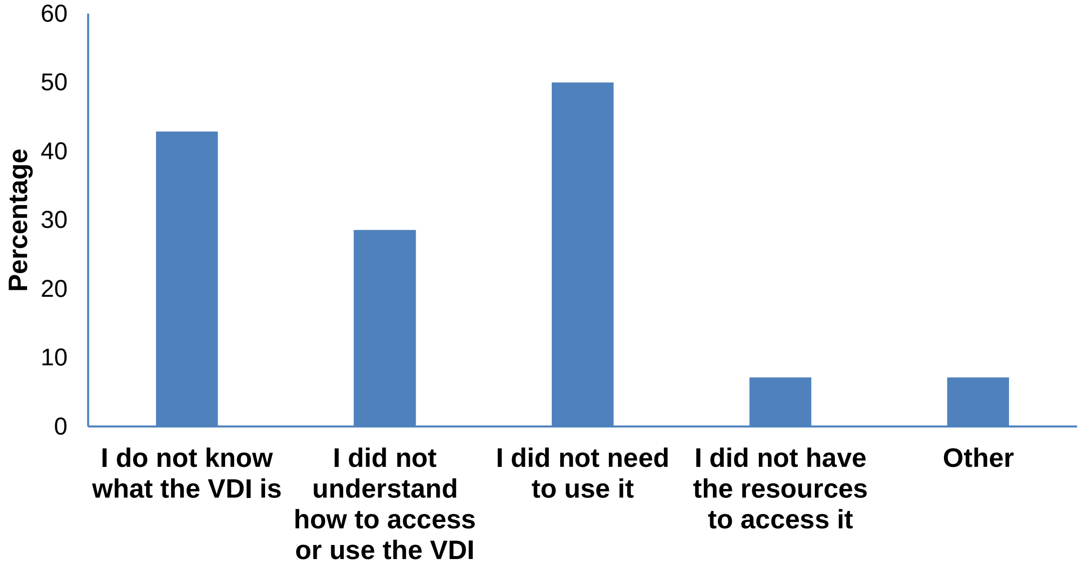

Figure 3. A question asked to those participants who did not access the VDI was to explore the reasons for this and the results of this question are shown here (n=14)

CONCLUSIONS AND FUTURE WORK

The aim of this study was to evaluate the VDI supplied by AU as a solution to digital inequality in an online learning environment. This evaluation was performed using a QNR, which was completed by 53 participants from across three engineering disciplines. Almost three quarters of participants had used the VDI, and the key reasons stated were that students could access software that they either could not or did not want to download to their own device, and that that they could access the software and files at University from their home environment.

Positive aspects of using the VDI again had themes around not needing to download software to own devices. Suggestions for improvement had the theme of removing ‘lag’ from software use.

From these preliminary results, the VDI appears to be well received by students, and useful for exactly the reasons it was implemented, to provide a digital resource to a diverse population of students, levelling the playing field and providing access to all. This can be useful for any taught programme where access to software which requires a high powered PC is required. At AU this included, for example, students studying computer-aided-design where access to Solidworks (Solid Solutions, Warwickshire, UK) is a necessity for all students. Though they have the option to download the software to their personal device, or use on campus PCs with access to the software, the VDI provides an option for those to work off campus without downloading the software.

However, a high specification PC is only one element of the resources required for students to learn in an online environment. Resources such as home internet quality, time and space will should also be explored. The VDI does not, for example, alleviate issues for students with poor Broadband connection in their place of residence, which is a limitation of this type of off-campus support and should be further explored.

The sample size, though small, was great enough to give a representation of students. However, one of the key limitations of this QNR was the electronic delivery mode. It is a natural assumption that students with a good digital infrastructure are more likely to respond than those without. To further this study, a paper QNR will be delivered at the end of this academic year (2021/22). This will not only capture a wider audience but will also enable an evaluation of the VDI in a year in which a mixture of online and on campus learning has taken place.

The next step in this research is to evaluate other solutions to digital inequality at AU and other HE Institutions and to enable the sharing of best practice between HE Institutions.

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MAKING GOOD CHALLENGES GREAT – ENGAGING EXTERNAL PARTIES IN CBL ACTIVITIES

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ABSTRACT

This paper aims to investigate the challenge-based learning (CBL) approach from the perspective of challenges and challenge providers (CPs), that is, how to successfully collaborate with external CPs and design challenges that work well in university courses and events.

We base this paper on three pillars: literature studies, our own experience teaching CBL in two courses, one at Linköping University and the other at Twente University and interviews with companies and organizations that have participated in the courses as challenge providers.

Regarding the literature studies, we can conclude that the literature on CBL, in general, is extensive. However, it is rather scarce when it comes to studies on how to work with challenges and especially with external CPs in practice; hence, there have not been many theoretical contributions from which to draw. However, those found are in line with our own experience. Through the analysis, we have created a list of learnings that hopefully can benefit organizers of CBL courses and events in their work of creating great challenges.

KEYWORDS

challenge-based learning, experiential learning, enhancement of teaching methods, challenge-based innovation, entrepreneurship education, challenge providers, open innovation, sustainability. Standards: 1, 2, 7, 8, 9, 10

INTRODUCTION

Challenge-based learning (CBL) is a pedagogical approach that has become popular in recent years – both in practice and in the number of research papers on the topic. Challenge-driven innovation is also high up on the agenda of initiatives such as HEInnovate and Horizon 2020 (European Commission, 2015). Also, entrepreneurship is on the agenda, and today more than a thousand higher education institutions within the EU educate tens of thousands of engineering students in the theory and skill of entrepreneurship (HEInnovate, 2021). The EU has distinguished entrepreneurship competences as one of the eight key competences for lifelong learning (Bacigalupo et al., 2016), defining entrepreneurial education to cover all activities "that seek to prepare people to be responsible, enterprising individuals who have the skills, knowledge and attitudes needed to prepare them to achieve the goals they set for themselves to live a fulfilled life" (Erkkilä, K. 2000, p 229).

In CBL, the learning starts with a challenge, often based upon a real-world “wicked problem”[1] and is supplied by an external party – here labelled “challenge provider,” and hereafter abbreviated CP. The students must define and decide how to tackle the challenge, what questions to ask to frame its essence and then design and launch some kind of solution. CBL, especially within the ECIU community, is also known to strive for cross-disciplinary teamwork and focus on challenges related to sustainability. The CBL approach could be used both in curricular courses and for shorter and more occasional events.

For CBL to work, three main ingredients are needed: (1) engaged students/participants, (2) teachers/organizers and (3) interesting challenges. To date, the research on CBL has largely been based on hands-on experiences from engaged teachers/organizers and uptakes of opinions from participants in CBL activities (cf. Leijon et al., 2021). A search through the literature on CBL and related learning approaches shows ample evidence of how CBL affects and benefits students in higher education (Kohn Rådberg et al., 2020). When it comes to the role of the teachers and organizers in CBL, we can find at least some advice in the literature – although this is not as well investigated as the student-related aspects of CBL. To remedy the knowledge gap from the teacher/organizer perspective on CBL, we have written a companion paper (Eldebo et al. 2022) that primarily focuses on the teacher/organizer roles in CBL. The third ingredient in CBL is about working with challenges from external challenge providers (from here on, CPs), creating great challenges and ensuring stakeholder engagement. Also, the CBL-related literature is rather scarce in this area – despite the challenges being a crucial part of the pedagogy. The aim of this paper, therefore, is to investigate the CBL approach from the perspective of challenges and CPs, that is, how to successfully collaborate with external CPs and design challenges that work well in university courses and events.

The paper is outlined as follows: Firstly, we review the literature on CBL and build a frame of reference to underpin our analysis. Next, we give a brief description of the methods used in the paper. This is followed by our data and analysis. Finally, we give our conclusions and advice to those who want to engage in CBL and create great challenges.

CHALLENGE-BASED LEARNING – SOME THEORETICAL STARTING POINTS

CBL in General

CBL is a pedagogical approach that has its roots in the evolution of experience-based learning practices that originated more than eighty years ago by John Dewey (1938; 1963) and later were further developed in pedagogical approaches such as problem-based learning (PBL), action learning, adventure education, simulation and gaming (Kolb & Kolb, 2017). At Linköping University, the tradition of PBL has deep roots, especially in the medical education programs,

[1] Wicked problems are those that are loosely formulated and thereby open to reformulation, cf. Coyne, R. (2005)

whereas project-based learning, which probably also could be seen as one in the above-mentioned family, has deep roots in engineering education. CBL has been described by authors such as Malmqvist et al. (2015) as an evolution of PBL, although with the difference that CBL is more open and has a value-driven and entrepreneurial approach to solving societal concerns.

CBL is both applied and defined in various ways, and there seems to be no single and accepted definition or exact way of how it should be run (Gallagher & Savage, 2020). According to Apple (2008), which was out rather early in CBL, it can be described as an engaging and multidisciplinary teaching and learning approach where students work collaboratively and solve authentic problems. Pérez-Sánches et al. (2020) describe CBL as a pedagogical approach that "actively involves students in real-life, meaningful and context-related situations" (p. 6). According to the literature review of Gallagher & Savage (2020), CBL is characterized by (1) global themes, (2) real-world challenges, (3) collaboration, (4) technology, (5) flexibility, (6) multi-disciplinarity and discipline specificity, (7) creativity and innovation and (8) challenge definition. The issue of multi-disciplinarity is also discussed by Heikkinen & Isomöttönen (2015), who put forward that the teams should be cross-disciplinary. Based on what has been written, we have chosen to define CBL as an experiential learning approach that starts with wicked, open and sustainability-related real-life challenges that students, in cross-disciplinary teams, take on in their own way and develop into innovative and creative solutions that are presented in open forums.

In recent years, CBL has found its way into our education system, not least due to the formation of the ECIU – the European Consortium of Innovative Universities – in 1997, where Linköping University is a member (Gunnarsson & Swartz, 2021). Over the last few years, challenge-based innovation and CBL have been advocated as the main approach within the ECIU, and on their website (www.eciu.org), the following citation can be found: "The core of the ECIU University is the challenge-based approach – a model where learners, teachers and researchers cooperate with business and society to solve real-life challenges." The ECIU website states that "CBL is a learner-driven method, where learners take ownership of their challenge, define the problems they want to work on, and acquire the necessary knowledge and skills to solve the challenge. Teachers guide and facilitate team culture, help students to manage the tasks and enable students to move towards innovative thinking." The phases in the ECIU learning cycle are (1) Engage, (2) Investigate and (3) Act. Within the ECIU, sustainability aspects, particularly the focus of Sustainable Development Goal (SDG) 11, titled "sustainable cities and communities," are put forward as the focus.

CBL has also been related to the CDIO framework used at Linköping University since 2006 (cf. Ouctherlony, 2006). There are several similarities between CBL and CDIO, as shown in the paper by Gunnarsson and Swartz (2021). In this work (ibid), the CDIO framework (Crawley et al., 2007) is used as a template when the authors develop and suggest a framework for education among the ECIU. Also, Kohn-Rådberg et al. (2020) relate the frameworks of CBL and CDIO and find them compatible.

Regarding the benefits of experiential learning approaches such as CBL, the literature is extensive – especially regarding what is in it for the students – and factors such as networking, real-life practice and skills related to technical, managerial and organizational aspects are listed (Gallagher & Savage, 2020). Apple (2008) advocates that CBL enables 21st-century skills and creates active learning and motivation in the classroom. Lackéus (2020) finds that value-creation pedagogy (which is close to CBL) showed the highest development of both entrepreneurial skills and curricular knowledge and skills. In addition, the students' motivation was high, probably because of the connection to the real-world problems they solved. Among the drawbacks could be mentioned that non-traditional teaching methods could entail insecurity among students, especially as they might lack knowledge of the specific industry or context (Norrman & Hjelm, 2017).

About Didactics in CBL

The didactic competence of the teacher regarding how education is planned and organized is important for the students' learning process, and according to Børte et al. (2020), there has been a change in the teaching practice in higher education toward a more student-centered approach. However, the same authors stress that the pedagogy in itself is still stable, although utilizing new technology. This is even though it is shown (cf. Leong, Singh & Sale, 2016) that the pedagogic competence of the teacher influences the learning among the students.

The palette of teaching methods facilitating student-centered learning within the education system is extensive. Some approaches are mentioned above, and most fall under the label of experiential learning and are hence claimed to be student-centered. According to O'Neill & McMahon (2005), the term "student-centered learning" can be interpreted in many ways. However, one incommon aspect is that the students are put in the center, and they state that "that knowledge is constructed by students and that the lecturer is a facilitator of learning rather than a presenter of information" (ibid, p. 28). Irrespective of how student-centered learning is applied, it entails requirements of change in the teacher role. For example, in CBL, the students are seen as active searchers for knowledge and skills and the teacher as a facilitator of this process.

This implies that staff working with CBL need skills that exceed the traditional teacher skills; we discuss this more deeply in the paper by Eldebo et al. (2022). As the teacher role is different, the term "teamcher" is suggested (Gunnarsson & Swartz, 2021) as a label. Eldebo et al. (2022) show that the teamcher role includes both the enabling of knowledge and skills and the ability to set the scene for this. They define a teamcher "as any individual that, either on its own or as a part of a team, arranges, leads and supports CBL activities." (ibid).

About Challenges

As CBL opens academia to real-world wicked problems, the design of the challenges becomes essential. Hauer and Daniels (2008) talk about open-ended group projects (OEGPs). The challenges in OEPGs are so-called open-ended problems or "ill-structured" problems that train students in dealing with similar types of problems they will meet in their upcoming work life. Working with external challenges is also something that is encouraged by the European Commission; see, for example, Hero & Lindfors (2019).

In CBL, the challenges are often labeled so-called "real-life challenges," which entails that they originate from external parties from trade and industry, the public sector or NGOs – that is, they are not about desktop products. Challenges can be of different types, for example, mini, nano, standard and strategic, and can be defined as situations or calls for action (Gudonienė et al., 2021). The same authors define a challenge "as a situation or activity that creates a sense of urgency and superior action and enables individuals to find sustainable and innovative solutions" (ibid, page 2). A bearing thought is that the challenge just shall challenge the students and make them act. Membrillo-Hernández et al. (2019) stress in their study that "[a] challenge is a real experience with a high level of uncertainty, designed to expose the student to a challenging situation in the real-world environment in order to achieve specific learning objectives" (p. 1110). This matter of ambiguity forces the students to investigate, contact experts and gain knowledge to come up with a solution. However, ambiguity may also cause frustration. Frustration may also grow from the fact that the students are forced out of their comfort zone and have to engage in areas that are complex or accommodate conditions they do not master. Hence, the students need support from facilitators. According to Membrillo-Hernández et al. (2019), the gains from such situations are that the students mature and grow. The ability to handle what Bennett & Lemoine (2014) name the "VUCA world" (volatility, ambiguity, complexity and uncertainty) also corresponds to what is inherent in the concept of 21-century skills (Kans, 2016).

According to Gudonienė et al. (2021), it is important that the CP creates and describes the challenge. They also stress the importance of tight relations between the CP and the course organizer. This is to "refine the expectations of the challenge provider in order to be able to advise the students in the context of solving the challenge" (ibid, page 15). This is also supported in other studies, such as Membrillo-Hernández et al. (2019), who point out the importance of the organizers making sure that the challenge fits the learning goals of the course or event. They expressed this as follows: "the learning modules were designed to achieve the goals of both the company and the school. The challenges brought forth issues such as ethical dilemmas, valorization, design planning, scientific methodology and recycling options of solid waste products" (ibid, page 1103).

Regarding the size of the CPs, different approaches have been tested. Membrillo-Hernández et al. (2019) used large world-leading companies that participated with several coworkers as so-called "training partners." Heikkinen & Isomöttönen (2015), on the other hand, focused their work on the collaboration between the university and SMEs with the aim to improve regional collaboration and knowledge transfer. They found that although the challenge was working well, the industry partners had limited resources when it came to engagement. Challenges might also stem from societal challenges like the SDGs from non-profit organizations.

There are several reasons why external actors engage in university courses as challenge providers. One reason is societal change, and ever since the Brundtland Report concretized "sustainability" in 1987 (World Commission on Environment and Development), companies have been increasingly aware of the paradigm shifts needed to avoid a natural catastrophe, and at the same time, enable continuous development of society (Steffen et al., 2015). The drivers for private companies to engage in sustainability for the larger world are debated. On the one hand, the management literature has long argued that companies need to look for long-term sustainable business in a volatile and uncertain world (Burke, 1985). But to take the step to actually heed the more political question of, for example, the Paris Agreement (2015), the corporation has to move outside the boundaries of its organization and take a more holistic view of its stakeholders and surrounding society (Lozano, 2011). That is, it must head for "open innovation" processes, a concept coined by Henry Chesbrough (2003), defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough, 2011, p. 1). The concept has been largely accepted by researchers as a method of dealing with the world of innovation pacing at an always accelerating speed. Private companies have to deal with new ways of innovation flows, and the role of the Innovation Manager is no longer only facing internal processes and people but also dealing with different partners for innovation supply and how the incumbent firms position themselves in an innovation ecosystem (Jones et al., 2016). Collaboration with universities and their students is a part of this.

Lozano (2011) points out several drivers for companies to engage in innovation for sustainability with universities and students. Brand recognition is one of them; finding new employees is another apparent reason. But other internal factors also play a role, like ethics and personal drivers in management, the need for business intelligence on new technology and the development of new, more sustainable products. Developing products or changing the supporting processes in product manufacturing could be key to finding great challenges for students. According to the BS 8001:2017 Framework for implementing the principles of the circular economy in organisations – guide, the largest environmental impact is found in the designing of products. Product development is thereby an important way for a company to become sustainable in economic terms. As companies start to design for sustainability, it has also been noted that they tend to expand the horizon from a purely technical focus to a more holistic socio-technical scope (Ceschin & Gaziulusoy, 2016). Companies simply need a strategy for innovation that is not internal anymore (Enkel & Sagmeister, 2020; Teece, 2007).

METHOD

Two projects underpin this study, an internal pedagogical development project (PUG) financed by Linköping University and the EU ERASMUS+ project S4S, Scale Up for Sustainability, where the partnership consists of two universities, one academic institute and seven companies (see also Acknowledgements). In our work with CBL in these projects, we recognized that the areas where most efforts were needed were the role of teachers and how to work with challenge providers. To deal with this, we decided to write two papers – one on each topic. An implication is that parts of the frame of reference and parts of the data are shared with Eldebo et al. (2022).

This paper is based on three main sources of information. Firstly, we have reviewed the literature on experiential learning in general and CBL in particular, focusing on challenges and CPs. We have also regarded different frameworks for learning, such as CDIO and the development within ECIU. Secondly, we have used our own experience in arranging and running CBL courses and activities over several years. This research approach is described by Lewin (1946) as action research and by Hayano (1979) as autoethnographics. If we go back to the roots, Dewey (1938; 1963), who advocated experience as the "means and goal of education," utilizing our own practice and reflecting on it to move forward is in practice what CBL is about. Thirdly, we have interviewed CPs that have participated in our courses.

As the empirical study objects for this, two courses have been investigated. The first is ECIU inGenious – Cross Disciplinary Project Course (799G52) – which comprises 8 ECTS credits and runs once or twice a year at Linköping university in cooperation with Almi East Sweden AB since 2014; in total, 15 rounds have been given thus far. In total, about 279 students have worked with 68 challenges from external CPs from the start and up to now. Second is the Fujifilm challenge, which comprises 4 ECTS credits and has been given annually since 2016 (in total, 5 rounds) and has since then engaged 222 students at the bachelor's and master's levels and one challenge provider – however, it is well represented regarding staff as, in total, 29 individuals have been involved and 47 new ideas have been generated so far. Taken together, this implies that our empirical base covers several years and contains more than 500 students and more than 115 ideas/challenges treated.

CHALLENGE-BASED LEARNING - OUR EXPERIENCE

The inGenious Course

The course has been given under different names since 2014 and primarily as a cross-disciplinary course for students at Linköping University. Since 2020, we have a multicultural element as the course has been open for ECIU and, thereby, more exchange students and ECIU students have joined it. The course has always been student-centered, but since 2018 we began to label this as challenge-based learning.

The inGenious course is a single-subject course that requires 90 approved credits to be admitted to the course. The course is both interdisciplinary and multidisciplinary. Following the definition of Heikkinen & Isomöttönen (2015), it can be labeled as cross-disciplinary. Each project group consists of four to six students from different faculties and programs. The challenges come from trade and Industry, the public sector and non-profit organizations, mainly from the region around Linköping University. Besides the idea- and development process, the course focuses greatly on teamwork and group processes. Other focus areas are communication and especially pitch technique. Also, ethics, by means of how to think responsibly during an innovation process, are part of the course.
Linköping University (LiU) and Almi East Sweden AB (a regional co-owned and co-financed subsidiary in the state-owned Almi Företagspartner Group) have joined together in a partnership regarding the inGenious course. Almi East Sweden AB takes the responsibility of establishing contacts with trade and industry and supplying the course with challenges, while the university is responsible for the academic part of the course. What is unique with the inGenious course at LiU is that the students have opportunity to capitalise on what they develop connected to the challenge with which they are provided. To become a CP in the course is free of charge. After the course is finished, the CP has a first right-of-refusal to the results for a symbolic payment (maximum about 5000 euros). If not, the students are free to exploit the results themselves with support from both Almi East Sweden AB and the innovation support facilities at LiU. When choosing CPs, much work is invested in getting the presumptive CPs to understand what is required from them and what they can expect from their engagement. They are informed that the students are not consultants that will work on a specific path pointed out by the CP but instead are to make their own thing.

Challenges that result in solutions that are regarded as innovative and with commercial potential or in another way can be utilized in society are in most cases challenges formulated to create a bigger value from a sustainability and/or societal perspective. In addition, we have experienced that these challenges to a large extent, come from CPs who have been involved in the students and are interested in their idea development processes. Less "successful" challenges are commonly those that are narrowly formulated and formulated in a relatively targeted manner. These challenges can be perceived more as "consulting." Our experience is that it is important to strive to get challenges from CPs with the right approach, that is, those who are curious about the students and appreciate that the project group works independently and without influence and understand that the solutions may be something else than what was initially thought or expected. We have learned the importance of carefully clarifying what is expected of a CP and what they can expect (and not expect) from the students who take on their challenge. We also explain that this is not about a consulting assignment and that we want the students to reformulate the challenge so it suits the project team and their competencies. They must develop a solution they believe in themselves.

Furthermore, it is important to maintain contact with the participating CPs, for example, keep them updated on activities they are expected to participate in, make sure that they take the time to answer students' questions and provide feedback, for example, at pitching occasions. We have seen that participating companies get essential input to their business through interaction with the students. The CPs get new ideas and (innovative) solutions and new knowledge, not least in the area of sustainability. The CPs can follow the students throughout an entire course and see their skills and abilities, which often leads to increased interest in the students – as master's thesis workers or future employees. Through Almi East Sweden AB, the CPs can contact students even after completing the course.

As an example of a challenge used in the course, the one from Ligna Energy Ltd. can be given. Ligna is a green tech start-up company that collaborates with the Laboratory of Organic Electronics (LiU) to develop disruptive technology and products for large-scale electrical energy storage. The Ligna Energy battery solution is relatively bulky since the energy density in Wh/kg is a factor of 10 less than competing technologies. Cheap materials enable cost efficiency, but customers must accept higher weight and volume in the storage system. The challenge given was formulated as follows: Find ways to manage bulkiness for the Ligna Energy battery customers – to minimize the impact of this product drawback. This may be done in many ways, and we are open to adaptations of the shape and arrangement of the battery packs.

The Fujifilm challenge

Fujifilm Ltd, known for its photographic and imaging activities, focuses increasingly on new markets with substantial, sustainable impact: bioengineering, energy and environment and healthcare and medicines. Fujifilm has a mission to improve the quality of life for people worldwide. To achieve this mission, it is eager to receive fresh new ideas from students. The Fujifilm Future Challenge (FFC) program started in 2016. Student teams co-create with Fujifilm's open innovation hub to develop new sustainable business models with Fujifilm's technologies. In a 10-week program, it has developed 47 new business ideas. In total, 222 bachelor's and master's students and 40 staff of 5 academic partners participated in the program, while Fujifilm involved 29 R&D staff. The international interdisciplinary teams produce two video pitches and two business model canvasses and then pitch their business solution to a professional jury. They develop and test business models based on real customer feedback. Apart from an educational program, the challenge serves research purposes concerning the impact of entrepreneurial and innovative traits (Innovator's DNA) on new venture performance.

Creative solving of complex wicked sustainability problems is a vital element of the FFC program. Therefore, teams identify, explore and define a real problem into an initial business model-in-four: value proposition (what is the "pain" and "gain"), customers (to whom and how to sell), how to implement (main activities and partners) and the monetary aspects (categories of income and expenses). In the second half of the FFC program, participants validate their initial business models.

The FFC focuses on creativity, innovation and acting like entrepreneurs. In the FFC, Fujifilm is an external CP and an enabler: R&D managers are available for discussions with the student teams and provide technological and market context. As real entrepreneurs, the student teams are expected to take the initiative in the discussions. The teams develop and test new business ideas based on the vast array of core technologies of Fujifilm. Specialists at Fujifilm are their technological sparring partners, while teachers coach the teams weekly and monitor their progress.

In the FFC, participants are highly committed (score 8.4 on a scale of 1-10). They highly value the creativity and team components (8.0 and 8.1, respectively). These ratings are higher than the perceived complexity. With the help of some creativity tools, weekly coaching sessions and technological support, students can find and test possible solutions to wicked sustainability problems. Afterward, due to their real experience with a high-tech company, students feel more confident in innovative entrepreneurship. As examples of learnings from the Fujifilm challenge could be mentioned that commitment and team processes are the strongest predictors of new venture performance. Furthermore, the format could be upscaled and digitalized; a larger scale adds to the program's impact.

Among the weaknesses in the Fujifilm collaboration is the risk of being too dependent on only one company, giving the students less freedom. Also, the fact that the setup is time-consuming needs to be mentioned (cf. Fichter et al. 2020).

In this course, Fujifilm is the CP. Fujifilm is the world's largest photographic and imaging company. However, it is less well known that it is a leading innovator in the fields of bioengineering, energy and environment, medicine and membranes. The company states it has a mission to improve the quality of life for people worldwide and that input from students hence are of importance.

The challenge was formulated as follows: “To develop and test new product ideas based on the technologies of Fujifilm. You will have access to specialists at Fujifilm and will be coached to develop ideas, spot opportunities and test how your ideas in the market in a great international company. Learn about creativity, innovation and acting like an entrepreneur!”

Some voices from challenge providers that have participated in our courses

inGenious CP1 is a rather large company within the paper and tissue industry. Its reason to engage as a CP was to get closer to the university. It was also interested in getting new ideas in connection to a new sustainable material that it had obtained. It appreciated that the students actively volunteered for its challenge, as this was seen as a guarantee that the students were curious and engaged and therefore could be expected to do their best. The CP chose to buy back what the students had developed and paid about 2500 euros for their solution. They report that they gained new and deepened knowledge in, for them, important sustainability-related issues.

inGenious CP2 is an SME that creates software for digital displays. The company sought a solution that could make it possible to use digital displays without connecting to the mains and indoors where daylight is missing. The CP had wished that the student group would have continued to develop the solution and then formed a joint venture with the company, but since the students did not want to continue, the solution became that the idea was repurchased for the sum of about 1000 euros.

inGenious CP3 is an SME within the workwear industry. It sought solutions to develop internet sales. The students were a good way toward developing such a solution when they learned that another group in another course was working on a similar idea. For that reason, they decided to abandon their initial solution and instead go for another one – far away from the initial challenge. Their new solution was instead focused on recycling worn-out workwear and was broadened to meet upcoming regulations on recycling, and hence focused on the needs of the entire workwear industry. The CP did not repurchase the solution, but there is still a much learn from this case. The CP said that it wanted to cooperate with the university and regarded it as a societal responsibility to participate in joint projects. It also said that the cooperation keeps up creativity and that the university contacts help with recruiting. Finally, it noted that challenges too close to the firm's core business are problematic for several reasons: “If the challenge is too closely linked to the company's existing core business, difficulties may arise for both the company and students. The company can, for example, find it difficult to share sensitive information with students, and students may find it difficult to create something new because the company has already thought through many possible scenarios and solutions.”

Regarding the Fujifilm challenge, Fichter et al. (2020) show that business partners joined in as CPs because they wanted to acquire new knowledge, new markets and new ideas. One of their biggest challenges reported was the ability to stay open to the questions they got from the students – that is, to not immediately jump towards the solution but to stay more open for their questions. In the past, Fujifilm was confronted with the quick erosion of its analog photo business. Therefore, it considers it vital to explore and develop completely new markets. To operationalize its new mission (improve the quality of life for people worldwide in bioengineering, energy and environment, medicine and membranes markets), it uses the Fujifilm Future Challenge as a "window to the world," that is, to get an impression about the needs and interests of new generations. Participating students and R&D officers of Fujifilm discuss and develop to co-create new business opportunities. Every edition of the Fujifilm Future challenge has different focus points, depending on the needs of the company. Regarding long-term effects, the impact on the business level was limited and more inspirational in character. Fujifilm also reported that its corporate image toward students, as future employees, was strengthened. It also benefited from the contributions regarding the sustainability goals (SDGs). Some citations are worth mentioning from the evaluation by Fichter et al (2020). These are:

“A module like this becomes very dependent on the actors involved, and adding a business partner to a module can be challenging. Therefore, it is important that participating actors are motivated and engaged” (p. 66).

“Regarding weaknesses or challenges: the strength of having a close collaboration with only one company can also be a weakness since the module becomes very dependent on that specific company. The strength mentioned by the teachers, that is, that competition between student teams brings motivation, is somewhat contradicted by the business partner, who noticed that sometimes a lack of competition faces the potential risk of student teams being too relaxed.” (p. 67)

DISCUSSION

Different perspectives

An optimal challenge is built from different perspectives. In this paper, we have identified four main perspectives: the didactical perspective, the student perspective, the external stakeholder/CP perspective and the university outreach perspective.

The didactical perspective

From a didactic perspective, a challenge must be formulated in a way that gives the students good chances to reach the learning goals of the course. It also needs to challenge the students and give them skills that make them attractive in the labor market. Hence, the planning of a course needs to start from the questions of what, why and how (Børte, Nesje & Lillejord, 2020) we should think, act and organize in order to strengthen the learning process. When working with external, real-life challenges, academia and the surrounding ecosystem of companies, organizations and public bodies meet and interact. This is to be seen as an opportunity for the students, and it adds relevance and context to the courses as they are being prepared for future employment (cf Norrman et al., 2014). Working with challenges in cross-disciplinary teams trains students in their ability to work in groups, communicate with other professionals and stakeholders, think critically and be responsible when working with innovation. These are the skills required to navigate a future landscape characterized by volatility, uncertainty, complexity and ambiguity (cf. Bennet and Lemoine, 2014).

The student perspective

From a student perspective, it is good if the challenge enables opportunities to get real-life experience (Gallagher & Savage, 2020; Apple, 2008) and build a network, both on the social and professional levels. As an example, this could be about learning to know individuals or companies that could provide opportunities for a master's thesis or even employment. It is also good if the course or event helps the students to develop and grow as individuals. Such skills are pointed out in previous studies (cf Pérez-Sánches et al., 2020) and ought to be one of the most important outcomes of cross-disciplinary teamwork with external stakeholders, as such work forces the students to cooperate, negotiate and communicate. This also seems to hold true in our study.

The stakeholder/challenge provider perspective

The size of the challenge provider does not seem to be a crucial factor. As shown by Membrillo-Hernández et al. (2019), it is possible to work with large firms – this was also the case in the FujiFilm challenge. On the other hand, the study by Heikkinen & Isomöttönen (2015) shows that SMEs are suitable CPs, which is also proven in the inGenious course. Instead of size, it seems to be about engagement and the CPs' ability to let the course team develop their idea from their own prerequisites.

From a CP perspective, it is the desire that the challenge leads to new input or even a new innovative solution that the stakeholder can benefit from (cf. Lozano 2011). Firms and organizations that hand in projects to the inGenious course are aware that their participation allows them to buy back what the students have developed. They are also made aware that participation as a CP requires engagement.

The reasons why a CP chooses to engage in CBL can vary depending on strategy, size of the company and internal needs, according to the literature (cf. Heikkinen & Isomöttönen, 2015; Jones et al., 2016; Lozano, 2011; Membrillo-Hernández et al., 2019). In our interviews, the external CPs' attitude toward the university and their reason to engage vary accordingly. Some, and especially those that lack formal contacts, participate due to curiosity and regard being a CP as a way to approach the university. Others are interested in meeting researchers. Some, who already have good contacts, engage for other reasons, for example, to market themselves and come into contact with students or to get new eyes on problems.

For CBL to work, it is our experience that the commitment of the external parties is crucial, as also stated by Membrillo-Hernández et al. (2019). The most desirable reason for participation is that CPs engage to acquire new eyes, insights, ideas and solutions, irrespective of whether it will lead to commercialisation.

The university outreach perspective

It is also beneficial for universities to engage in CBL and work with external actors, not least due because the universities are demanded to reach out to society (Heikkinen & Isomöttönen, 2015). Hence, engagement in CBL can be seen as a way to reach out to the surrounding ecosystem of industry and public organizations. In other words, it is about networking and the diffusion of knowledge.

To summarize our analysis, we have created a checklist of aspects to benefit organizers of CBL courses in their work to make great challenges.

A great challenge …

- ought to be wicked and structured as a “big idea” that is open and able to be broken down into a graspable take – however, still big enough to constitute a challenge in terms of requirements on the student team when it comes to engagement, problematization and investigations in order to form a solution.
- entails that the solution is not obvious to the CP nor to the students. The challenge should not be able to be solved immediately, but instead require engagement, thorough investigation and hopefully also lead to some kind of action.
- must be a real-life challenge but could be formulated by the teacher or the students themselves, but cooperation with external stakeholders such as industry partners, governmental bodies or organizations is desirable as this adds real-life relevance to the work.
- should be formulated in a way that it becomes possible for a cross-disciplinary team of students to take it on in an open innovation process, irrespective of their backgrounds, respectively. That means that all students in the group must be able to latch on to the challenge in their own way. Hence, if two groups take on the same challenge, they will most probably come up with different problem definitions and solutions.
- utilizes the team and its complementing skills, as dynamic teams work more efficiently (Wheelan, 1999) and seem to go further in finding (innovative) solutions.
- originates from a CP or stakeholder that is curious and interested in keeping in contact with the students and likes to interact and cooperate with them. It is desirable that the CP follows the students' process as a speaking partner and provides them with feedback – but without trying to steer them into a certain track. To ensure this, aligned expectations and clear communication between “teamchers” and CPs are crucial. If this relation fails, “teamchers” must always be on the students’ side and be prepared to encourage a Plan B.
- has a pedagogic purpose for the students to acquire both knowledge and skills that they can benefit from in future work life. It also entails opportunities to build a network – both with fellow students and external parties.
- enables the open innovation process and is directed toward sustainable and responsible innovation. Furthermore, it should strive to lead to practice – by means that it leads to utilization and implementation. Within the ECIU, this is incorporated into the ACT phase and following CDIO, it is about the ability to enter the “operation” phase and realize the idea.
- has as its goal to lead to a solution that is of interest not only to the CP but also to a wider group of stakeholders and interested parties, for example, on the regional,

national and even international levels. This opens up opportunities for cooperation and open innovation.

Challenges that are too narrow or too focused on a certain technology risk becoming hard for all students in a group to latch onto. To remedy this, we recommend that challenges are formulated in cooperation between the teamcer team behind the course and the CP. In working with challenges, we should strive to avoid:

- regarding the students as consultants that should follow a presupposed track and leverage a solution that is determined from the beginning, and hence are more interested in getting a solution to commercialize than being curious about the students' knowledge and what new input this could lead to. To remedy this, we recommend the “teamcher” team makes sure that the CPs are aware of the prerequisites so that their expectations become aligned with the purpose of the CBL activity.
- unrealistic expectations in terms of output and time spent. Therefore, discussing what the CP can and cannot expect from its engagement in a CBL course is vital for a lasting relationship. In addition, the communication patterns between participating students and company officials should be clear.
- abandoning the students and the CP making themselves unavailable for contact. To remedy this, we recommend the “teamcher” team makes sure that the CPs are aware of the prerequisites and what is required to act as a CP in the actual situation.
- leveraging challenges that are too close to the organization's core business, as this may entail problems with secrecy issues and thereby also the supply of adequate information. Furthermore, there is an immediate risk that the organization will focus on a presupposed solution rather than an open mind for any solution.

CONCLUSIONS

This paper aimed to to investigate the CBL approach from the perspective of challenges and CPs, that is, how to successfully collaborate with external CPs and design challenges that work well in university courses and events.

We define CBL as an experiential learning approach that starts with wicked, open and sustainability-related real-life challenges that students, in multidisciplinary teams, take on in their own way and develop into innovative and creative solutions that are presented in open forums. Furthermore, we have developed a checklist of what to consider when working with external CPs in CBL courses. We have reached the following conclusions:

Firstly, we have realized that the literature is rather scarce when it comes to the practice of working with challenges, especially regarding the collaboration with external challenge providers, and hence there have not been many theoretical contributions to draw upon in our analysis. However, those found are in line with our own experience.

Secondly, we have observed that the difficulties lie in the creation and design of challenges that are wide enough to create a certain amount of VUCA and allow for an open innovation process, but at the same time aim at pushing the students to engage in the challenge and investigate and act upon the challenge. Challenges that foster open innovation are, even if tough to handle, often seen as more inclusive as they enable students with different backgrounds to latch onto them. Furthermore, such challenges open the students to find *a* solution rather than *the* solution.

Thirdly, we have found that the collaboration inherent in CBL is a win-win situation for all parties concerned. Challenge providers get new perspectives and contacts with both students and university staff. Students gain real-life experience and important skills that future employers will demand, plus contacts and a network. For universities, it is a way to reach out to and interact with the surrounding ecosystem; it implies significant work and can sometimes force them outside of their comfort zones, but it also allows them to expand their business network and help their students develop and grow.

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HEALTHY CHALLENGING DESIGN EDUCATION FOR ENGINEERS

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ABSTRACT

Teaching design skills to engineering students has long been one of the main building blocks of the bachelor curriculums at the TU Delft faculties of Industrial Design Engineering and Architecture & the Built Environment. We observe that our students achieve high-level (design) competencies during their study time at TU Delft. But we also observe that design education goes together too often with over-aroused students and ambitious teachers, leading too often to higher levels of student stress. With the support of the Dutch 4TU Centre for Engineering Education, we asked first-year bachelor IDE and ABE design students about their perceived levels of arousal and the factors within the design education learning environment, which contribute to a positive or negative study experience. This paper will show our understanding of our design education pedagogies, our model of spheres of influence, and potential coping strategies for students and tutors. We indicate five spheres of influence for our design students: the student self, design tutors, classmates, the learning environment, and society at large. Each sphere consists of various potentially stressful factors. The coping strategies we propose focus on helping students to find ways to become aware of their feelings and thoughts, the meaning they give to them, and the kinds of behaviors and (short-term and long-term) consequences which follow from there. We also emphasize the role of the community of teachers and students to help individual students assess those (potentially) stressful situations constructively.

KEYWORDS

design education, self-leadership, workload, health, coping strategies, Standards: 8, 9

INTRODUCTION

Teaching (physical) design skills in small studio groups of 10-25 engineering students has long been one of the main building blocks of the engineering curriculums at the TU Delft, in particular in the fields (and faculties) of Industrial Design Engineering (IDE) and Architecture & the Built Environment (ABE). The small group teaching approach in design education brings many advantages, such as community building between students (and mentors), student commitment, student engagement, and student visibility. The design studio is a stimulating and activating learning environment (Lawson & Dorst, 2009; Ghassan & Bohemia, 2015; Van Dooren, 2020) (Figure 1). It is the physical place where students get together many hours during the week to work on their individual and/or group assignments and projects. It is also the physical place where the students meet their tutors[1] for discussion, feedback, review, and assessment.

Figure 1. Typical TU Delft IDE/ABE design studio situation for undergraduate students

We observe that our IDE and ABE students achieve high-level (design) competencies during their study time at TU Delft. But we also observe that design education goes together too often with over-aroused students and (over-)ambitious teachers, leading to higher levels of student anxiety and stress. This results in the threat of underperforming students, increased levels of student dropouts, and increased levels of student burnouts.

So, despite the positive nature of the studio learning environment, we see that our design education also brings many challenges with student well-being. At TU Delft we fully share the positive and negative experiences expressed above. We know from all kinds of research and faculty education evaluations from within and outside the faculties - such as the Dutch national student survey, our faculties' Quality Assurance Agencies, our study associations, our study counsellors - that the workload for IDE and ABE students is (perceived as) very high and that study stress is almost a given fact. In 2019, the VSSD – a TU Delft-wide student organization – did research on the perceived levels of stress among Delft engineering students (VSSD, 2019). It was shown that engineering students from all eight TU Delft faculties experience relatively high stress levels, but students from the IDE and ABE faculties together make the top 2. Both faculties feel the need to improve significantly here and to work towards a more healthy, but still challenging learning environment for their students.

[1] In this paper we will use 'tutor' to indicate the person who helps, teaches, and coaches the design student(s). Other words which we could have used are: teacher, coach, mentor, supervisor.

This paper aims to present on the one hand the conditions that (could) make design education stressful, and on the other hand how students and teachers can cope with these conditions in a constructive, positive way. With the support of the Dutch 4TU Centre for Engineering Education, we asked hundreds of first-year bachelor IDE and ABE design students (in the period of 2020-2021) about their perceived levels of arousal and the factors within the design education learning environment, which contribute to a positive or negative study experience. Questions and evaluation criteria were based on and derived from literature reviews focused on perceived stress scales, self-determination theory, and study success and student health. These questions were integrated into the regular course evaluations run by the Quality Assurance departments of the IDE and ABE faculties. Some questionnaires were followed up by a panel talk with a limited number of students to get a better understanding on the given answers.

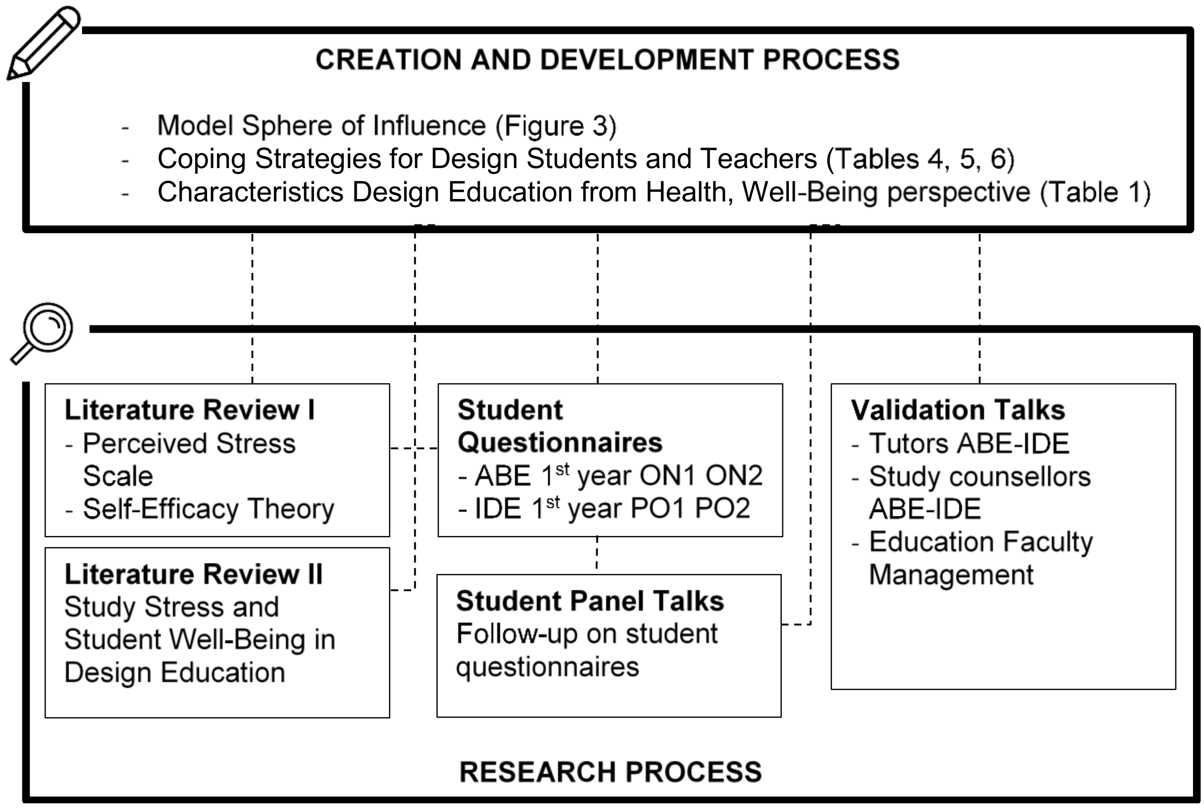

Figure 2. 4TU.CEE Healthy Challenging Design Education Project Approach

Supported by the quantitative and qualitative data we developed a model named ‘Spheres of influence’ and an approach towards potential coping strategies for students and design tutors. This process of ‘creation’ (see Figure 2) we did together not only with three first-year design project coordinators from both faculties but also with an external consultant who specializes in secure-based leadership approaches and three Quality Assurance staff members from both faculties. As a validation step, the synthesis of these results was discussed with faculty student counsellors, three mixed panels of design tutors from both faculties, and faculty education management.

Since early 2020 the COVID-19 pandemic has put additional pedagogical, health, and well-being challenges to higher education; for students, staff, and management. It also impacted our Healthy Challenging Design Education project that was initiated long before winter 2020. For design education, the 100% online and hybrid learning environments have also been unknown territory for the large majority of students and staff to learn and teach design. How this journey of online design education will go in campus universities, is still to be seen. First research results have become available on the impact of the pandemic on engineering education in general (e.g. Lomans et al., 2021).

STUDY SUCCESS AND STUDENT HEALTH IN TODAY'S HIGHER EDUCATION

Study success, health, and well-being of students are not only discussed intensively in universities worldwide but also in society at large. There are many, yet quite 'normal' and 'logic' stressors for students, such as financial insecurity, dealing with a new situation in life (new study program, new institute, new home, new city, new friends, etc), binding study advice policies from universities, dealing with (exam) deadlines, and the high expectations which many students have themselves, or from their parents or family. Most of these are elements which automatically go with higher education. And we cannot avoid, and perhaps even do not want to avoid these, as they are part of the academic journey and maturing.

Let's be clear: some level of stress is good and healthy for people, and makes people perform better. And of course, different people respond differently to stressful environments or stressful moments. But in general, it is destructive for people to have too high stress levels, or high stress levels for a too long period, or to have too little recovery time. For the (partly) 'unavoidable' stressors, it might be most smart to help young adults to develop personal leadership skills to better manage uncertainty, dynamics, and complexity in one's (new) life as a student in an effective way. For the 'avoidable' stressors, such as poor organization of education, or too many conflicting deadlines, there is a large responsibility for teachers and education management.

Although study stress in higher education has been researched in several disciplinary contexts, or for specific universities, or in more general terms to better understand the notions of health and wellbeing in (higher) education (e.g. Centre for Education Statistics and Evaluation, 2015; VSNU, 2020), study stress and student wellbeing have not been researched in-depth in design education specifically. Two pieces of research in the field of architecture and the built environment pop up.

The results of the Architect's Journal 2016 annual student survey in Great Britain clearly show student fears over - in particular - financial debt and workload. 'Just over a quarter of students surveyed (26%) said they were receiving or had received medical help for mental health problems…' 'Just over nine in ten (91%) students reported working through the night for their studies at some point - and almost one in three (29%) said they did it on a regular basis' (Waite and Braidwood, 2016). In the Netherlands, Tilman (2016), the editor in chief of the Architect magazine, reflects in his blog on this study. He calls the field of architecture 'a profession that never sleeps' and he presents the mirror that this culture is present in both education and practice, with all its negative consequences for the health and wellbeing of both students and practitioners.

In 2013 the Graduate Architecture, Landscape and Design Student Union (GALDSU, 2013) at the University of Toronto published the results of its first mental health survey. The report shows a worrisome picture of the unhealthy and stressful design student experience: gigantic workload, unhealthy lifestyles (skipping meals, irregular sleep schedules, rarely exercising), faculty disorganization, stressful days and weeks before the crits, unhealthy working environment in the studios (noise, air quality, lighting etc), and the faculty's administration not doing enough to address these issues. On the ArchDaily website, Whelan (2014) gives a to-the-point perspective on those GALDSU findings. '… to keep up with the stressful and demanding workload, survey respondents confessed to having developed many bad habits…' '…Bad habits are formed when a specific behavior results in a favorable outcome, leading to the conditioned repetition of these actions.'

DELFT DESIGN EDUCATION

In our two monthly project team meetings, as well as in our validation interviews with the student counselors, design tutors, and faculty education management, we discussed the features and characteristics of our TU Delft IDE and ABE design education and learning environment, in particular from a student experience, study success, and well-being point of view. We came to a set of more positive and more critical characteristics (Table 1) focusing on the themes of 'community', 'assignment', 'pedagogy', 'design process', 'assessment', and 'ambition'.

Table 1. Characteristics TU Delft IDE and ABE design education from a student experience, study success, and well-being point of view

Positive side	**Characteristic**	**Negative side**
Many small groups increase the visibility of individual students. Students meet a variety of helpful tutors during their studies. The involvement and commitment of both students and tutors are high.	Community	The large diversity of students and tutors working closely together and interacting intensively makes the learning environment more vulnerable to social safety issues. Sometimes there is competition between students (awards, prizes, student contests).
Studio activities are both synthetic *and* analytical, and both creative *and* reflective. Assignments are hands-on, pragmatic, applied, derived from practice, and oriented towards solving (a) concrete problem(s).	Design assignment	Design assignments are (on purpose!) complex, open-ended, ill-defined resulting in an endless solution space. The workload is high.
There is an activating and challenging studio 'vibe': curiosity, exploration, idea development, lateral thinking, and working with alternatives are stimulated. Sharing ideas among students is stimulated.	Studio pedagogy	Feedback and crits are very often 'in the open'. Students can feel 'attacked'. Oral presentations, expert and peer reviews, mid-term assessments, deadlines, milestones, deliverables: there are many obstacles and/or hurdles to take for students.
Students get a lot of freedom and responsibility to develop their process, style, and design language.	Design process	It can be not clear for (undergraduate) students what a (good) design process should look like, and when a design process is done or finished satisfactorily.
The final design product is something that the student makes: concrete, tangible, visible.	Assessment	The level of performance can be unclear to students; it might be not clear if the learning, the learning or design process, or the design product is assessed (or all?). Assessment may sometimes feel more subjective.
Programs teach value-centered design approaches to improve the world (more	Ambition	Students are quite often highly talented, ambitious, and self-critical perfectionists; and

sustainable, juster, more healthy, more inclusive, more resilient, etc). A designer is seen in Delft as a team player.		uncertain as they do this for the 'first' time. Tutors might see the potential of a very interesting design idea/concept, and stimulate/push the student to work even harder. Design is never finished.

INDICATION OF STRESS LEVELS

To get an indication of the perceived stress levels among the students of IDE and ABE in the design projects, we used the regular faculty evaluation moments to ask a few additional well-being questions. In the project team, we intensively discussed which kinds of questions and which kind of tone of voice would be best to use in the student questionnaires. We wanted to avoid notions such as 'stress', 'health', 'well-being', and 'burnout' as they might bring students in a less neutral mood. In the end, we developed six questions using the perspective of 'study experience' (Appendix 1). We included in our first question four sub-questions from the Perceived Stress Scale (Cohen, Kamarck & Mermelstein, 1983), the most widely used psychological test for measuring the perception of stress. This scale has been validated in different contexts and is therefore both reliable and valid. Here, stress is defined as high perceived helplessness and low perceived self-efficacy. To limit the length of the total questionnaire, we used the four item-scale (PSS-4). Additionally, the other five study experience questions are closely connected to the self-determination way of thinking (Ryan & Deci, 2000; Linnenbrink, Patall, & Pekrun, 2016) which focuses on competence development, autonomy, and relatedness from a more positive and a more negative point of view.

In this paper we present a small part of the results of the online questionnaires which were sent to our first-year students in the academic year 2020-2021. Both faculties have a numerus fixus (IDE 350 students, ABE 400 students), which means that the total amounts of students in the first first-year projects are around these numbers. During the year a small number of students drop out (eg wrong study choice), so the total amounts of students in the second first-year projects are a bit lower. For our study we had 456 valid entrees.

Table 2 shows the PSS-4 results per studio from the 2020-2021 surveys in the IDE and ABE faculties. From reference research (Vallejo et al., 2018; Lesage et al., 2012) we know that an average score around 5 is 'healthy stressful' and from 6 on it becomes more (and more) unhealthy. The average score for the four studios is 6.1, but about half of all participants scores 6 or higher. For the IDE1, IDE2, and ABE1 cohorts, we can conclude that the average score is 'healthy positive', although a large number of individuals scores go beyond 6. The ABE2 studio has a significantly higher and more worrisome average PSS-4 score of 8.3. This confirms earlier course evaluations by the ABE faculty's Quality Assurance department where students shared their concerns on (among others) the workload of this studio.

Table 2. PSS-4 scores first-year TU Delft design studios Industrial Design Engineering (IDE1 and IDE2) and Architecture and the Built Environment (ABE1 and ABE2)

Project	**Period**	**Number of participants (n=456)**	**Average score**	**Standard deviation**	**% with score >= 6**
IDE1	Autumn '20	101	5.4	2.5	41%
IDE2	Spring '21	126	5.5	2.9	47%
ABE1	Autumn '20	159	5.2	3.3	43%
ABE2	Spring '21	70	8.3	3.4	76%

SPHERES OF INFLUENCE

The open remarks in the questionnaires and the follow-up panel talks gave us the input for our model ‘Spheres of influence’ (Figure 3 and Table 3) which we developed during our project team meetings in co-creation. Our validation talks with tutors, student counselors, and education management told us that these five spheres were ‘recognizable’, ‘distinctive’, and ‘usable’ to explain the complex nature of the well-being issue in design education. For our model we used the metaphor of a mountain climber, i.e. the student (self (1)), who is secured by a teacher, supervisor, mentor, or coach (design tutor (2)), does not climb alone (classmates (3)), climbs in a challenging, rocky environment (faculty learning environment (4)) and in a wider setting and scenery (societal context (5)). Each sphere consists of various potentially stressful factors or situations (Table 3).

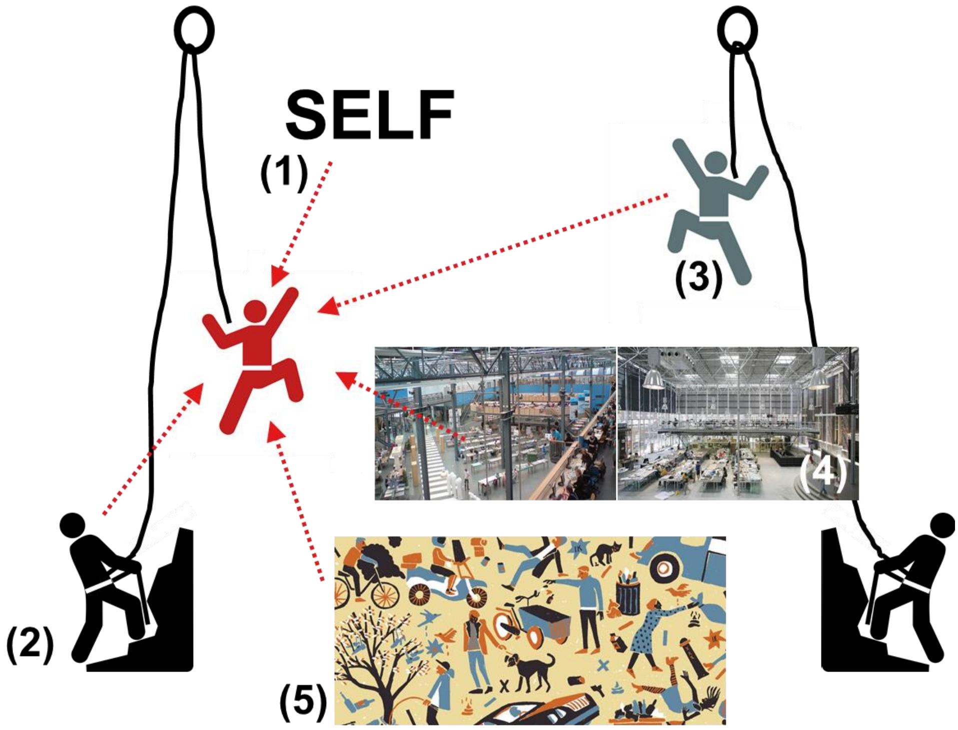

Figure 3. Five Spheres of influence: (1) Self, (2) Tutor, (3) Classmates, (4) Learning Environment, (5) Society

Table 3. Potential stressors within the five Spheres of influence

Sphere	Potential stressors
(1) Self	The degree to which the student him- or herself takes responsibility for • balancing study efforts vs relaxation • having realistic expectations • meeting personal needs • developing self-insight and making choices • maintaining focus and setting standards for him- or herself • reflecting on and learning to deal with external influences • …
(2) Tutor	The way the design tutor • communicates and gives feedback • inspires and motivates • coaches, supports, and steers • organizes supervision, facilitates, and moderates • assesses and uses assessment criteria • …
(3) Classmates	Other students are points of reference for • co-operation, peer-learning, and community building • performance level • working attitude, approach, and opinion development • inspiration and motivation • …
(4) Learning environment	Important, determinative factors • (intended) learning objectives and course contents • assessment strategy and assessment criteria • progress requirements • schedule, deadlines, and deliverables • ateliers, studios, rooms, facilities • sense of community and belonging • …
(5) Society	Various societal factors have various kinds of impacts which students have to deal with • starting at a university means a new life phase, new living conditions, new friends, and new social activities • financial arrangements, such as loans • diploma pressure of society • family and friends with their expectations and hopes • (social) media and the (societal, perceived) image of 'success and failure' • the thought that study is a right instead of a privilege • …

COPING STRATEGIES FOR STUDENTS AND TUTORS

Society, faculty, tutors, and students themselves should try to avoid destructive, unnecessary, unrealistic, and/or unproductive (for learning) stressors in the learning process of students. But an important notion (for all stakeholders involved) is that meeting stressors is not at all bad for students. Students 'just' have to learn to deal with them constructively. Stressors are 'simply' part of life, study, or design education. We put 'just' and 'simply' between hyphenation marks as this is easier said than done. Also in the questionnaire, some potential stressors, e.g. deadlines, were (also) indicated by the students as contributing to a positive experience.

So, we argue that when a certain potentially stressful *event, situation, or observation* happens, it is first and foremost important to understand what kind of *meaning* a student gives to it, and which *feelings* and *thoughts* build that meaning. From that step, students will show certain more or less constructive behaviors. And those behaviors will have both more short-term, pragmatic kinds of consequences and more long-term, emotional kinds of consequences. From a more positive or negative approach and mindset towards a certain stressful situation, completely different patterns might result in the daily lives of students an in their attitudes. See the following two examples of a student facing an overcrowded, noisy studio space as a stressor and a tutor who gives a bit unclear feedback (Tables 4 and 5).

Table 4. Noisy, overcrowded studio coping example (Main spheres of influence: student – learning environment)

+ **Positive approach and mindset**	**Steps**	- **Negative approach and mindset**
A student enters an overcrowded and noisy design studio room.	Event, situation, observation	A student enters an overcrowded and noisy design studio room.
"Wow, what a hive, a huge source of inspiration, creativity, and liveliness. A lot of people to get feedback from and to give feedback to. This gives me energy." Or: "O boy, I need a place to work in silence now, so I will get to this creative hive later today when I have something to show and discuss myself."	Thoughts and feelings: giving meaning	"Whaaa! What a mess here. In this environment I cannot work, let alone learn. This does not work for me. What was I thinking this morning when I had good hopes for working in the studio?"
The student discusses and exchanges thoughts and ideas, and a lot of peer feedback takes place. Or: the students looks for a more quiet place, for now, produces materials, and goes back to the studio later.	Behavior	The student leaves the studio, goes home with good intentions to work there, but with some distractions around, only partly does what (s)he should do.
The student makes a lot of progress and due to the feedback develops a better plan. But the student also learned a lot from the design (processes) of others. Or: student has been able to make progress, and discusses it briefly with other students. Gets (limited) feedback.	Short-term consequences (practical)	Too little progress, some procrastination, a bit tired (mentally in particular) from traveling back and forth to the faculty for nothing. Student missed the opportunity for exchange, bonding, and peer learning.
A positive feeling towards the studio as a learning environment. Students want to come here more often. Or: Student has experienced and learned how to take into account one's own needs, and behave accordingly.	Long-term consequences (emotional)	The student is reluctant to work in the studio, will miss the studio learning experience as it is meant. Student shuts off from others and disentangles from the community.

Table 5. Tutor feedback coping example (Main spheres of influence: student – tutor)

+ **Positive approach and mindset**	**Steps**	- **Negative approach and mindset**
My tutor says I have to do things differently.	Event, situation, observation	My tutor says I have to do things differently.
"I have to learn something which I have not done nor shown yet. And my tutor invites me to explore further, and develop more design alternatives. That is new to me, so that is both interesting and exciting."	Thoughts and feelings: giving meaning	"O boy, my tutor tells me (again, sigh) I did a bad job and that my ideas are misplaced. Perhaps I should stop putting so much energy into it, and just do what I think my tutor wants me to do. I could also quit and do the studio next year when I get a tutor with whom I can easier communicate."
The student starts to explore.	Behavior	The student limits efforts and stops exploring.
The student develops a better-underpinned design proposal and has experienced more perspectives towards the design (process).	Short-term consequences (practical)	Learning slows down, and the creative, explorative, divergent, and lateral thinking stops. Weaker results, perhaps even a fail.
The student's confidence has grown in design (processes). The student has learned to deal with comments and (re)interpret feedback.	Long-term consequences (emotional)	The student's confidence has decreased in design (processes). The student developed a more negative attitude ('see, this is too difficult for me') and has not learned how to deal with feedback.

Important questions which derive from here are about the role of design tutors in all of this. For example, can a tutor stimulate and support students towards (more) constructive behavior (see Table 6)? Usually, design tutors are not trained as psychologists, social workers, or professional coaches. Tenured academic TU Delft staff, both lecturers and professors, should have at least a University Teaching Qualification, but the themes of student-wellbeing and coaching are addressed only to a limited extent in that kind of course. Additionally, many of the TU Delft IDE and ABE design tutors in our undergraduate programs have a position in practice or industry and help us with educating our large number of students; our so-called part-time (e.g. 0.2fte) practice teachers, sometimes with limited formal pedagogical training. We do offer them a series of (short) workshops on design pedagogies. But our validation talks with the design tutors told us that many tutors are open to hearing and learning more about this. One colleague even said: '…and we might also learn a thing or two for balancing our own lives better." And whenever there is a really sensitive well-being issue, tutors should refer a student to a student counselor and/or a general practitioner.

Table 6. Tutor feedback coping example: tutor perspective

<table>
<tr><td colspan="2">Objective of tutor
I would like this students to explore more design alternatives, to look for different directions, and to do some more lateral thinking.</td></tr>
<tr><td colspan="2">What the tutor says
“You have to do things differently.”</td></tr>
<tr><td>Observation by the tutor (+)
The student looks positively aroused, surprised, curious.
The student asks questions about Why? How? When?
The student looks up, continues making eye contact.
The student remains open, communicative, and enthusiastic.
The student’s posture is active and open.</td><td>Observation by the tutor (-)
The student looks shocked.
The student stops speaking.
The student looks downwards, avoids eye contact.
The student is less open, less communicative, less enthusiastic.
The student’s posture is passive and closed.</td></tr>
<tr><td colspan="2">Coaching on meaning
Offer support, but leave responsibility where it belongs: that is, with the student!
Name what you observe (can also later; an hour, a day, a week). Check if you observed correctly.
Rephrase original feedback. Be congruent yourself in your language, mimics, posture, thoughts, and feeling.
Speak out your confidence when appropriate. Speak out your concerns when appropriate.
Encourage the student to make the next steps, because without action there will be no result.
Show that exploring and experimenting is the core of design (processes): fall and rise are okay, actually: it is the intention of design (processes) (and design education).</td></tr>
</table>

CONCLUSIONS, RECOMMENDATIONS, DISCUSSION

Better understanding of what is at stake is helpful for all involved: change of culture

The objective of this research project was to understand better the conditions that make design education more or less stressful and find ways how students and teachers can cope with these conditions in a constructive, positive way. Our ‘answer’ to these challenging ambitions are our Healthy Challenging Design Education models which show that the three pillars – *Spheres of influence* – *Student coping strategies* – *Tutor coaching skills* mutually influence and strengthen each other in a positive or negative process towards a(n) (un)healthy challenging design education *culture*. The positives of the design education characteristics will prevail when students constructively face the challenges within the spheres. But also tutors need to help students in facing those challenges; only then the culture can change for the better. But it could also go the other way around towards a more unhealthy culture, when students, tutors, and faculty staff do not feel empowered nor supported to change things for the better. And as cultures are not made nor changed overnight, all stakeholders involved have a role to play.

How to make next steps?

In our project team meetings and our talks with students, tutors, student counselors, and faculty management we always asked if people had suggestions about concrete and feasible steps to improve things for as many students as possible. Additionally, we addressed the kind of style and *tone of voice* which would be helpful. It became clear to us that a multi-layered, multi-stakeholder approach is needed, addressing all involved in various ways and formats: from a logical (academic) point of view but also an empathetic, relational point of view.

That is why we have started in co-creation to develop an accessible and education practice-oriented booklet for both students and staff. We have asked several students, tutors, coordinators, and student counselors to write anecdotally from their own experiences about situations in and/or observations on design education. Thereafter we analyze these anecdotes from the point of view of our model. By doing so, we aim to create awareness of the audience first ('hey, I know/recognize this situation. I have been there myself.') before giving the reader more handles and levers to cope and more theoretical backing. We are discussing how we can integrate the booklet and our experiences in the faculties' student mentoring approaches and workshops for design tutors.

In the tutor validation talks, several suggestions were given to improve design education, design learning, and design teaching. We were surprised that the tutors were extremely positive about the talk itself – and missed it in their normal lives as tutors – to take a step back and discuss more intensively (for about 90 minutes) a certain topic relevant for their educational practice. They said that it is the exception rather than the rule to have peer discussions and/or peer feedback (such as intervision among teachers). They made a distinction between 'normal' tutor instructions and assessment alignment sessions on the one hand (which happen a lot), and this kind of more reflective discussion and exchange of thought and ideas we had during the validation talks. An interesting suggestion that was given was about more explicitly rewarding students – in the assessment strategy – who dare to experiment, be pro-active, and be divergent. The idea here was to both challenge and support students to feel okay when feeling less comfortable.

Limitations of the study and special circumstances

In our project, we only looked at the first year's IDE and ABE undergraduate's design programs. Of course, the relations to and the impact of/on the other first year's courses are also interesting and relevant to consider. Additionally, reviewing what happens in the follow-up years in the design curriculums is also worthwhile to research, as we expect increasing stress levels when students have become an integral part of a certain teaching and learning culture. But with our limited resources, we thought it made sense to start at the beginning of the beginning: the first-year design education programs.

In the course of the 2019-2020 academic year we all, students and staff, experienced the uncertainty and stress of the Covid-19 pandemic. This impacted the students, tutors, educational management, the learning environment, and society in unprecedented ways. In our questionnaire, we immediately integrated questions on how the pandemic influenced the study experiences. Logically most of the students told us that studying design became more stressful, harder, and less fun. But, also some students told us the positives; several technical tools that support exchange and presentation, visual feedback, and peer assessment were highly appreciated. They improved and stimulated design learning. From that point of view, it will be interesting to observe if and how our 'traditional' studio model for learning and teaching design will (not) change into a more blended one in the future, as it became clear to many that design education benefits a lot from informal peer-to-peer and expert-to-peer learning when students and tutors are sitting together physically.

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APPENDIX 1 STUDENT QUESTIONNAIRE QUESTIONS

Question 1: During your design project, how often (5-points scale from 'never' to 'very often'):

- Have you felt confident about your ability to handle your personal problems?
- Have you felt that you were unable to control the important things in your life?
- Have you felt that things were going your way?
- Have you felt difficulties were piling up so high that you could not overcome them?

Question 2: In the next question we would like to know if there are factors that influenced your study experience positively (more answers are possible):

- I can keep myself on track according to my planning
- The ateliers/studio spaces
- The way my tutor organized the tutoring sessions
- I experienced moments of success
- There were enough possibilities for my input in my project
- The atmosphere in my group invited me to ask questions
- The presence of deadlines
- The module was manageable within the given time
- The way my tutor gave feedback on my performance
- It was sufficiently clear for me what was expected from me
- I got inspired by my fellow students

Question 3: Please explain your answers to the previous question (open question)?

Question 4: In the next question we would like to know if there are factors that influenced your study experience negatively (more answers are possible):

- I tend to procrastinate
- The way my tutor organized the tutoring sessions
- The ateliers/studio spaces
- The level of the module is too high
- I experienced too little freedom for my design choices
- I had the feeling that I never do good enough
- The presence of deadlines
- The lack of enough time (the workload was too heavy
- The way my tutor gave feedback on my performance
- Unrealistic expectations from my tutor
- The feeling of competition among students

Question 5: Please explain your answers to the previous question (open question)?

Question 6: What could have strengthened your study experience during the design project (open question)?

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HOW TO MAKE GOOD TEACHERS GREAT IN CHALLENGE-BASED LEARNING

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ABSTRACT

This paper aims to analyze what roles are needed in the team that organizes a challenge-based learning (CBL) course or event. We also aimed to share our experience and provide advice on working with CBL in entrepreneurship courses. To fulfil this aim, we have analyzed four courses in the Erasmus+ project ScaleUp4Sustainability where CBL is used, using theories on experience-based learning models in general and the literature on CBL in particular. Our main finding is that for CBL to work, three main roles are required: (1) the teacher role, which is knowledge-oriented; (2) the role of the coach, which is oriented toward skills; and (3) the role of the organizer, which is oriented towards the context in which the learning takes place – the challenges. Together, these three roles can be labelled "teamcher". According to our own experience working with CBL, the teamcher role is preferably shared by a multi-disciplinary team of educators. CBL is resource-demanding education; hence, cooperation with actors such as tech transfer offices, innovation facilities and the regional innovation system can benefit this work. This is especially true as CBL has the ambition to contribute to society, something which also underlines the importance of regional triple helix collaboration.

KEYWORDS

challenge-based learning, experiential learning, enhancement of teaching methods, challenge-based innovation, entrepreneurship education, sustainability

Standards: 1, 2, 7, 8, 9, 10

INTRODUCTION

Challenge-driven innovation is high up on the agenda of initiatives such as HEInnovate and Horizon 2020 (European Commission, 2015). Challenge-based Learning (CBL) – also called Challenge-Driven Education (CDE) – is a relatively new way of working with entrepreneurial learning and entrepreneurship courses. Working with wicked, external and societal challenges that need innovation is a great way to set the stage and add relevance for students also in CDIO-based courses.

Today, more than a thousand higher education institutions within the EU educate tens of thousands of engineering students in the theory and skill of entrepreneurship (HEInnovate, 2021). The EU has distinguished entrepreneurship competences as one of the eight key competences for lifelong learning (Bacigalupo et al., 2016), defining entrepreneurial education to cover all activities "that seek to prepare people to be responsible, enterprising individuals who have the skills, knowledge and attitudes needed to prepare them to achieve the goals they set for themselves to live a fulfilled life" (Erkkilä, K. 2000, p 229).

Searching through the literature on CBL and related learning approaches shows much evidence regarding how CBL benefits students in higher education (Kohn Rådberg et al., 2020). However, less is written on didactical issues and on what is required by teachers that are, or want to be, engaged in CBL activities.

This paper aims to analyze what roles are needed in the team that organizes a CBL course or event, share our experiences, and provide advice on working with CBL in entrepreneurship courses.

The paper is outlined as follows: First, we build a frame of reference from the relevant literature on CBL to underpin our analysis. Next, we give a brief description of the methods used in the paper, followed by our data and our analysis. Finally, we give our conclusions and advice to those who want to engage in CBL.

CBL ACCORDING TO THE LITERATURE

CBL is a pedagogical approach with roots in the evolution of experience-based learning practices, which originated from the work of John Dewey (1938;1963) and later was further developed in pedagogical approaches such as problem-based learning (PBL), action learning, adventure education, simulation, and gaming (Kolb & Kolb, 2017). The tradition of PBL has deep roots in medical education programs, whereas project-based learning, which probably also could be seen as one in the above-mentioned family, has deep roots in engineering education (Biggs & Tang, 2011). CBL has been described by authors such as Malmqvist et al. (2015) as an evolution of PBL, although with the difference that CBL is more open and has a value-driven and entrepreneurial approach to solving societal concerns.

CBL is both applied and defined in various ways, and there seems to be no single and accepted definition or exact way of how it should be defined and run (Gallagher & Savage, 2020). According to Apple (2008), which was relatively early out in CBL, it can be described as an engaging and multidisciplinary TD learning approach, where students work collaboratively and solve authentic problems. Perez-Sanches et al. (2020) describe CBL as a pedagogical approach that “actively involves students in real-life, meaningful and context-related situations” (p. 6). According to a literature review by Gallagher and Savage (2020), CBL is characterized by (1) global themes, (2) real-world challenges, (3) collaboration, (4) technology, (5) flexibility, (6) multi-disciplinarity and discipline specificity, (7) creativity and innovation and (8) challenge definition.

In recent years, CBL has found its way into our education system, not least due to the formation of the ECIU – the European Consortium of Innovative Universities[1] – in 1997, of

[1] https://www.eciu.org

which Linköping University is a part (Gunnarsson & Swartz, 2021). In the few years, challenge-based innovation and CBL have been advocated as the main approach within the ECIU. On its website, the following citation can be found: *"The core of the ECIU University is the challenge-based approach – a model where learners, teachers and researchers cooperate with business and society to solve real-life challenges."*[2]

Norrman et al. (2022) define CBL as an experiential learning approach that starts with wicked, open and sustainability-related real-life challenges that students, in cross-disciplinary teams, take on in their own way and develop into innovative and creative solutions presented in open forums.

CBL has also been related to the CDIO framework, which has been used at Linköping University since 2006 (Ouctherlony, 2006), and there are several similarities between these approaches. As an example, the paper by Gunnarsson and Swartz (2021) could be mentioned. In this work, the CDIO framework is used as a template when the authors develop and suggest a framework for education among the ECIU universities. Also, Kohn-Rådberg et al. (2020) compares the frameworks and finds them compatible.

Regarding the benefits of experiential learning approaches such as CBL, the literature is extensive in describing them – especially regarding those for students – and factors such as networking, real-life practice and skills related to technical, managerial, and organisational aspects are emphasized (Gallagher & Savage, 2020). Apple (2008) lifts forward that CBL enables 21st-century skills and creates active learning and motivation in the classroom. Lackéus (2020) finds that value-creation pedagogy (which is close to CBL) showed the highest development of both entrepreneurial skills and development of curricular knowledge and skills. In addition, the students' motivation was high, probably because of the connection to the real-world problems they solved.

Within the education system, a great palette of teaching methods facilitating student-centered learning like CBL and CDIO is present. Examples include active learning, action learning and self-directed learning. According to O'Neill and McMahon (2005), the term "student-centered learning" can be interpreted in many ways. However, one uncommon aspect is "that knowledge is constructed by students and that the lecturer is a facilitator of learning rather than a presenter of information" (O'Neill & McMahon, 2005, p. 28). Irrespective of how student-centered learning is applied, it entails requirements for a change in the teacher's role towards facilitation of the process to gain knowledge and skills rather than being a source of theoretical knowledge.

The didactic competence of the teacher regarding how education is planned and organized is important for the student's learning process. According to Børte et al. (2020), there has been a change in what is included in the teaching practice in higher education, and mainly toward a more student-centred approach. However, the same authors stress that the pedagogy (i.e., how teaching is conducted) is still stable, although new technology is utilised. This is despite it being shown (cf. Leong et al., 2016) that the pedagogic competence of the teacher influences the learning among the students.

The purpose of the course and its learning goals are of great importance in working with the students to support their ability to reach these goals. Lelong et al. (2016) advocate that even

[2] https://www.eciu.org/for-learners/about#challenges

if the technical knowledge and skills as such are important, other skills are essential, and so also the issues of motivation to learn, develop and innovate. In CDIO, one of the mantras is that engineers must be able to engineer (Crawley et al., 2007), and hence education needs to foster both knowledge and skills, which also were the idea of the early thinkers (see Dewey 1963;1938). This is also supported in later works such as Kans (2016), Rotherham & Willingham (2010) and Olivares et al. (2019), who put forward the so-called 21st-century skills, which include analytical-, communicational, and teamwork abilities. According to the above studies, these skills can be obtained through pedagogical approaches such as CBL.

CHALLENGES IN TEACHING EXPERIENTIAL PEDAGOGICS

Olivares et al. (2019) claim that although the benefits of CBL are recognized, few educators have turned real-life challenges into practice in their teaching, probably because this type of pedagogy is “expensive” both with regard to effort and competence of the teachers. In this section, therefore, we will investigate the area of teacher skills and new pedagogies for CBL in general but also in the context of CDIO.

In the literature we can find two different challenges for teachers in CBL:

First, as the projects are based on problems from *stakeholders outside of academia*, students become very dependent on these stakeholders for information and feedback (Norrman & Hjelm, 2017). The teacher might have to take on a nontraditional role to help the student groups in this work (Hero & Lindfors, 2019). Not all external challenge providers engage the way they were expected, and the recruitment and retainment of external stakeholders are time-consuming (Norrman & Hjelm, 2017).

Secondly, teamwork and team members also become a major factor in the success of the work, which might both be a strength and a weakness in the progression of the course (Hauer & Daniels, 2008; Hero & Lindfors, 2019).

As CBL and CDIO are closely connected, as we have discussed earlier, we look to the literature concerning CDIO for discussions on the role of teachers:

Flarup and Wivel (2018), who have investigated mechanical engineering students engaging in CDIO courses in Aarhus, find that the teacher moved from giving answers to giving questions and from directing to supporting. They distinguish three different roles taken by teachers: (1) traditional teaching, (2) supervising the proceeding teamwork and (3) tutorial supervising – i.e., supporting students in, for example, exercises and the use of tools.

Hauer and Daniels (2008) describe the works with open-ended group projects (OEGP) in computer science education, pointing out that teachers are acting more as facilitators or consultants – supporting the students in making sense of the ill-structured problems they endeavor into in the course. “The general idea is that currently well-structured problems, at some point, probably started out as ill-structured problems, and this is part of the OEGP process: provide an ill-structured problem, with balanced scaffolding so students learn how to resolve such problems” (Hauer & Daniels, 2008, p. 90).

According to Kolb and Kolb (2017), the educator should take on as many as *four* roles during the process of experiential learning: the “Coach,” who helps in initiating and starting the project; the “Facilitator,” who encourages experiencing, imagining and reflecting; and the “Subject Expert” who supports in analyzing but also concrete thinking about the project together with the “Evaluator,” who supports in deciding and acting upon what is learned.

The supporting role of the coach has also been highlighted by Klofsten and Öberg (2012), who describe a coach as someone with a strong connection to the program content who guides the team to develop a platform and a structured way of working forward in an entrepreneurial project.

We compare these authors and the teacher roles in CDIO they are describing in Table 1. Regarding Voogt et al. (2016), we distinguish between coaching/supporting students in their work and taking on the role of subject expertise, calling it “expert in practice”.

Table 1. Comparison of teacher roles in CDIO

	Traditional teaching	**Coaching/support the students**	**Expert in practice**
Flarup and Wivel (2018)	Traditional teaching	Supervising the proceeding teamwork & Tutorial supervising	
Hauer and Daniels (2008)		Facilitator	Consultant
Kolb and Kolb (2017)	The Evaluator	The Coach (for teamwork) and the Facilitator (for practical use of methods)	The Subject Expert
Klofsten and Öberg (2012)		The Coach	The Mentor

To understand this multi-faceted role of the teacher, we must understand that the student, while being adult and mature, lacks the experience of context to be truly reflective about her/his actions and skills (Norrman & Hjelm, 2017; Hägg & Kurczewska, 2016). This means that when the student enters a setting well prepared for theory, practicing the theory will be problematic. This relates both to teamwork and aspects of the field that are practiced (Hägg & Kurczewska, 2016; Klofsten & Öberg, 2012).

All this complicates the role of the teacher and the situation of students even more, something we will look deeper into in the empirical findings.

METHOD

We have worked with CBL on two projects: an internal pedagogical project financed by Linköping University and the EU ERASMUS+ project ScaleUp4Sustainability (hereafter mentioned as “the S4S project;” see Acknowledgement for further details). In this work, we recognized that the areas where most efforts were needed were in the role of teachers and how to work with challenge providers. To deal with this, we decided to write two papers. Hence, this paper share parts of its frame of reference and data with Norrman et al. (2022).

This paper is based on four main sources of information. Firstly, we have reviewed the literature on experiential learning in general and CBL in particular. We have also regarded different frameworks for learning, such as CDIO. Secondly, we have used data collected from student and teacher reflections and from questionnaires that have been sent out to courses investigated in the S4S project. Additionally, we have held an interview with a CBL teacher active within the ECIU community, focusing on the teacher role (for more background on the ECIU, see Norrman et al., 2022). Finally, we used our own experience of arranging and running CBL courses and activities for several years. This research approach is by Lewin (1946) described as “action research” and by Hayano (1979) as “autoethnographic.” If we go back to the roots, Dewey (1938), who advocated experience as the “means and goal of education,” utilising our own practice and reflecting on it to move forward is, in practice, what CBL is about.

Background and Data collection within the S4S project (Courses A to D)

The partnership within the S4S project consists of two universities, one academic institute and seven companies. The project aims to develop new teaching modules in close collaboration with leading enterprises, using the ability of students to develop and assess new business solutions for a more sustainable world (Fichter et al., 2020). All courses in the project are challenge-driven, either by an external challenge provided or by aiming at one of the Sustainable Development Goals (SDG) or similar known societal challenges.

The S4S project started in 2018 as a result of a gap analysis made by Fichter et al. (2016). This analysis pointed out the need to further build on good examples and develop new courses for sustainable entrepreneurship and eco-innovation. In university courses, the aim for educators, using students as change agents for companies, is to develop students’ skills and knowledge and, at the same time, make innovative, viable solutions for challenge providers. The four main courses included in the S4S project are described in Table 2 below.

The data from courses A to C were collected by an extensive evaluation, including interviews with students and teaching personnel and a quantitative survey. More detail about the interviews and surveys can be found in the report for Work Package 2, “Evaluating leading approaches and tools in collaborative green venturing,” of the S4S project by Fichter et al. (2020). Course D was included in the S4S project but not part of the evaluation performed in Work Package 2. The data we present for course D was instead collected from the written student reflections submitted at the end of each run of the course. In total, 120 reflections were analyzed from 13 course runs in the period 2014-2020, and the main points are highlighted in this paper.

Table 2. The four main courses included in the S4S project and from which experiences are presented in this paper.

Course A:	***Eco-Venturing at the University of Oldenburg***
Start year:	2009 (ongoing)
Duration:	24 weeks (one semester)
ECTS:	6
Description:	The main target of the course is to develop entrepreneurial skills for the development and implementation of environmental innovations and sustainable business ideas.
Course B:	***Environmentally Driven Business Development at Linköping University***
Start year:	2013 (ongoing)
Duration:	20 weeks (one semester)
ECTS:	6
Description:	The course aim is to develop the capabilities to formulate and plan a desirable, viable and feasible business solution for an environmental problem.
Course C:	***Fujifilm Future Challenge at Avans University of Applied Sciences***
Start year:	2016 (ongoing)
Duration:	10 weeks
ECTS:	2
Description:	The students are to generate new sustainable businesses for the external challenge provider (in this case, Fujifilm). In this, they learn theory and practice in both ideation and validation of business cases.
Course D:	***InGenious Cross disciplinary project***
Start year:	2014 (ongoing)
Duration:	20 weeks (one semester)
ECTS:	8
Description:	This cross-disciplinary course is open for all students through ECIU having 90 or more ECTS in whichever discipline. It is a collaboration between Linköping University, Region Östergötland and the region's two largest municipalities, Linköping and Norrköping, aiming to build bridges between the region and the students at the university. Through this partnership challenge providers are found, supplying the challenges students take on in the course.

DATA

Student experiences from CBL (data from courses A, B, C and D)

Positive experiences

Students in all three courses lifted the challenge-based learning and real-life experiences as something very positive. In courses A, C and D, the opinions were very positive regarding the challenge provider and the support that students received from the external parties – a "taste of real work," as one student said. In course B, students have the option to come up with their own solutions, often based on broader societal challenges. This freedom is by some students considered as good, for some, a bit unclear. The personal development attained in the courses is lifted by several students, both in group work aspects as well as skills in pitching and contacting customers.

Students lifted that the teachers did not only work in a traditional way. The teachers were perceived "more as coaches or mentors," working together with the students and people from external parties. Students reacted very positively to this change in the teacher's role in supporting, brainstorming and guiding. In all four courses, the teachers' commitment was lifted as something positive.

According to the students, the main learning outcomes were hands-on, practical experience in entrepreneurship and teamwork, as well as new insights into sustainability challenges. As an example, self-evaluations taken before and after course B show that students significantly change their knowledge in both the practical and strategic field of sustainability during the course. Learning from peers is also lifted, as students are required to work with students from different programs and specializations.

Subjects for improvement

The open-end group project setting for all courses was seen as something inherently positive by the students but also challenging and demanding. In all courses, students lifted the need for more coaching – either by teachers or external parties. The need for coaching was related to three different areas:

1) Assistance in practical questions: Students requested more support in time management of the project and selection and using the theoretical tools, and sometimes needed help when encountering setbacks in the development of the innovative solution.

2) Assistance in team-related questions: Some student groups found the team constellation challenging. Group contracts and constant teamwork development take time, and some teams needed more time with teachers to help get the group together.

3) Expectation management: Especially in courses A and B, where the challenge providers were not as clear as in courses C and D, some students requested more help in setting the right level for the group work. The evaluations showed that students felt all three courses took more work per credit than other university courses.

Teacher experiences from CBL (data from courses A, B, C, D and the ECIU)

Positive experiences

All teachers involved in all three courses see the setup with challenge-based learning as something positive. They all express the impressive solutions that students arrive at within the limited time given.

All courses have more than one teacher involved. In courses B, C and D, the roles of the teachers are also pre-defined: one as a teacher and one as a coach. But all teachers also express the feeling that they take on a non-traditional role of coaching the students rather than teaching them. This is seen as something both positive and challenging at the same time.

Teachers in courses with external challenge providers (A, C and D) are very content with the engaged external parties.

Subjects for improvement

Time is the major limitation of all courses. According to the teachers, managing the external challenge providers, the normal course administration and the students' group work takes time and creates a sense of "split vision." Even in courses with set roles (teacher and coach), time is the greatest delimitator.

Some student groups work without needing much support, but in some groups, teachers must help quite a lot to ensure progress regarding both teamwork and the actual development of the project. This makes time management hard. There are suggestions that skills in team building should be added to the learning goals and assessed – thus lifting its importance.

Communication between all parties (teachers, students and external parties) is also lifted as a challenge during the course. The challenge providers can open many doors for students, giving them access to interviewees and information needed, but they also have their own time management to think of, and the teacher then often becomes the fallback for students who are unable to reach their challenge providers when needed.

Finding and onboarding external challenge providers is also a time-consuming task. Most external parties are engaged through the personal network of the teachers and coaches involved. Here, support from universities' technology transfer offices is mentioned as a desire for managing and finding challenge providers.

ANALYSIS AND DISCUSSION

According to our empirical findings and with support from the literature, there are three main overarching themes that we would like to highlight in the analysis:

Theme 1: Freedom vs. ambiguity

CBL, like all entrepreneurial learning initiatives, really stresses the "free," innovative approach to a challenge (or problem). This way of learning is, according to our data, highly rated among the students as well as teachers. This is connected to what we have found to be one of the most important strengths of CBL: It simulates real work-life situations for students in a way that more traditional teaching never does. This corresponds well to the analysis of CBL made by Gallagher and Savage (2020), the findings of Perez-Sanches et al. (2020) and the assessment of Lackéus (2020).

This freedom also comes with a high dose of ambiguity. Students might find the way forward unclear, the criteria for grading vauge, or the demands for subject-specific knowledge demanding. Teachers have adapted to this ambiguity by setting time and resources for coaching, feedback sessions and other types of support for the student teams. Keep in mind that contact with challenge providers will take time and could be demanding as it requires a contact network that not all university teachers have. A complicating factor is that the challenge providers have their day job schedules to heed and hence cannot always pay full attention. Teachers often work hard with *transparency*: both in the case of clear descriptions of the process and what will happen in each step and the case of criteria for judgement and grading. Still, the ambiguity in the context created through the challenge can be demanding for students. Although this is mentioned by some authors (cf. Malmqvist et al., 2015; Norrman & Hjelm, 2017), this ambiguity is rarely elaborated on in the literature. However, it is mentioned that students must be mature and take great responsibility (cf. Hägg & Kurczewska, 2020; O'Neil & McMahon, 2005).

Theme 2: Teamwork

In CBL, as well as other OEGP disciplines, the student team is a major factor for success. Students express many favorable aspects of the need for teamwork, both as a source of personal development and preparation for work-life and learning from other students with different skills and backgrounds.

Both students and teachers highlight the downside of teamwork: If the team does not work well together, the advancement of the whole project can be threatened. Therefore, CBL teachers often put a great deal of work into forming groups of students and coaching them regarding teamwork progress during the courses. Most students have been working in teams before, but our analysis as teachers shows that CBL pedagogics puts a higher demand on teams being fully functional than other courses do.

The relevance of functioning teamwork between students is presented in the literature on several occasions, as well as the downside of non-functioning teams (cf. Hauer & Daniels, 2008; Kolb & Kolb, 2017).

Teamwork among teachers is something that is seldom elaborated on, but when it comes to CBL, it could be beneficial since this kind of learning approach requires that the teachers can take on different roles that could hence be difficult to manage for a single individual.

Theme 3: Time management

This third theme is strongly connected to the other two. Working with free and ambiguous projects in teams takes time. In our student evaluations, most students note that they work more hours per credit than they usually do. And still, they also wish for *more time for external contacts and teacher support*.

Teachers also find the courses demanding, as they plan for teaching, coaching and supporting. Keeping student teams aligned, communicating with external parties, and dealing with expectations management on all frontiers is taxing, and the work is also hard to foresee and plan.

There are some cases raised in the literature on this topic, for example, the time needed for external participation (Norrman & Hjelm, 2017), the time limitations in open-ended group work projects (Hauer & Daniels, 2008) and the teacher being split between tasks (Klofsten & Öberg, 2012).

The Role of the Teacher

From the literature on CDIO, we found three different roles that were defined by several authors (see Table 1):

- The Traditional Teacher – The academic teacher role, which includes course creation and development of formal course plans, including formulation of learning goals and clear assessment criteria. This role also includes being the examiner of the course. This role is mainly oriented towards enabling the students to acquire knowledge.
- The Coach, supporting the students – Facilitating and coaching students in their development project, support in group dynamics and support to overcome problems along the way. This role is mainly oriented toward enabling students to acquire skills.

- The Expert in Practice – Guiding students in their studies of the challenge and supporting them in finding empirical evidence, interviewees and data to test and validate their solutions to the challenge. This role is fully oriented to practice and work-related knowledge.

Comparing these roles to our empirical findings, we see that the teacher with the academic responsibility is needed for studies in higher education and CBL, which is very important in helping students tackle ambiguity. Teachers supply clear learning goals, a well-formulated curriculum and the theoretical frameworks for analysis that are applied within the CBL process.

The Coach is an equally important role, as it encompasses supporting students in both the important teamwork and the sometimes waxing degrees of freedom that they experience. The coach also handles group dynamics issues and encourages the students through asking questions that move their innovation process forward.

The role of the Expert in Practice is not as present in CBL as it is in CDIO. However, in CBL, the Expert in Practice is equal to the external challenge provider. This is because the teachers and coaches are not the subject experts on the external challenges. The challenge provider supplies the students with context and information on their challenge and works as a sounding board in their development work.

Finally, putting the pieces together calls for a fourth role, which must be included in the teacher team: the Organizer. The Organizer role is about finding challenge providers, creating challenge briefs that suit the purpose of the CBL course and benefit the challenge provider and handling immaterial property rights issues and contracts (if used) between challenge providers and students.

Our suggestions for teacher roles in CBL

As we have put the context expert role on the challenge provider, three roles remain for the teacher in CBL. Through our analysis, where we have compared the literature with our empirical findings and experience, we have distinguished three main roles needed in the teacher team of a CBL course:

1. **The Academic Teacher**
   Enabling the students to acquire knowledge.
   Includes course creation and development of formal course plans, including formulation of learning goals and clear assessment criteria as well as examination.
2. **The Coach**
   Enabling students to acquire skills.
   Includes matching students to projects, coaching of the students in their development project, support in group dynamics and support to overcome problems along the way.
3. **The Organizer**
   Facilitating interaction and work with external parties.
   Includes finding challenge providers, the creation of challenge briefs, the handling immaterial property rights issues and contracts.

Toward a definition of TEAMCHER

In CBL, the learning goals are oriented toward both knowledge and skills – that is, it combines theory and practice. Hence CBL incorporates more than traditional courses and consequently requires more than what is included in the traditional teacher role.

To find a proper denomination, "teamcher" has become a rather commonly used etiquette to describe the different requirements of leaders in CBL. Teamcher is mentioned in papers such as Gunnarsson & Swartz (2021) and within the ECIU-sphere; however, no explicit and clear definition of the concept is given.

Based on this research, we therefore suggest that the teamcher role includes both enabling knowledge and skills and the ability to set the scene for this. Hence, we define a teamcher as an individual who, either on their own or as a part of a team, arranges, leads and supports CBL activities. Teamchers take, and often also slide between, the roles of being teacher, coach and organizer of CBL activities.

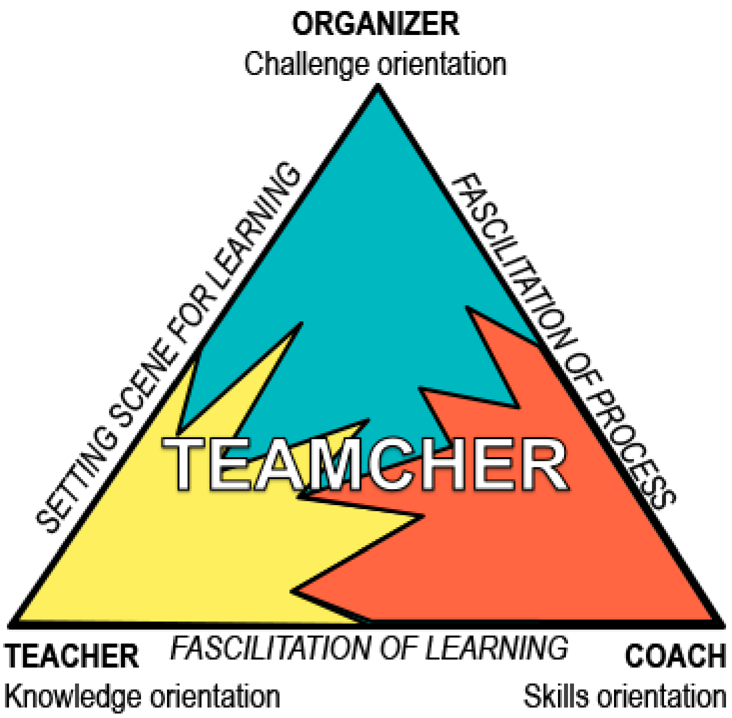

Figure 1: The Teamcher, own design

CONCLUSIONS

This paper aimed to analyze what roles are needed in the team that organizes a CBL course or event and to share our experiences and provide advice on working with CBL in entrepreneurship courses.

We have reached the following conclusions:

- For challenge-based learning to work, three main roles are required: the academic teacher, the coach and the organizer.

- If taken together, these three roles could be labeled as “teamcher,” which we define as an individual that, either on their own or as a part of a team, arranges, leads and supports CBL activities.
- From a teamcher perspective, CBL can be seen as both demanding, especially regarding resources, and rewarding. Hence, our recommendation is to start small and add on until a full CBL setup is reached.

In the paper, we have reflected upon our own practice and shared our experience regarding teaching and organizing CBL courses.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

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This paper is co-produced with the paper “Making Good Challenges Great - Engaging External Parties in CBL-Activities” by Norrman et al. (2022), which entails that it shares parts of the frame of reference and the empirical base.

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DO ENGINEERING STUDENTS FROM VOCATIONAL AND ACADEMIC BACKGROUNDS THINK DIFFERENTLY?

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ABSTRACT

This work describes an experimental study to try to better understand the natural and previously evolved problem solving strategies used by entrants to undergraduate engineering programmes. New entrants to degree and pre-degree programmes were presented with a range of brain-teaser and practical problems requiring no specific prior knowledge to answer. Some would have unique answers with others being more open ended. Students worked in pairs to solve the problems and their discussions, notes and where relevant physical interactions with props were recorded and observed. The results were then coded and conclusions drawn based on both general approaches and whether particular types of student educational backgrounds influenced their approaches to problem solving.

KEYWORDS

Problem solving, entry standards, qualifications, experimental. Standards: 4, 5, 8, 12

INTRODUCTION

This research is to determine the natural tendencies in numerical and visual logic type problem solving of new entrant students to degrees in engineering.

The aim is to establish if there is a difference in the way students in the English educational system think and learn in these types of problems and whether there is a notable difference between those entering from an academic (typically A-Levels) or vocational (BTEC) route. This type of problem solving is often key to becoming an effective practical engineer and will help us better understand student preferences and diversity in approach to tackling these problems, so helping us better develop engineering problem solving in our students.

While A-level students are still dominant, students with BTECs or a BTEC combined with an A-level are becoming increasingly common at University entry and make up a significant part of entry cohorts in many institutions particularly those with low to middle level entry tariffs. The uptake of students taking BTECs has grown dramatically over the last decade growing from 50,000 to 150,000 between 2006 and 2014 (Richards 2016). For the 2016 application cycle 54% of students accepted onto a University course nationally held only A-levels with 18% holding only BTECs and a further 8% holding a combination of the two. (Gicheva N, Petrie K, (2018), Havergal, C., (2016)) It should also be noted that there are notable socio-economic differences in the characteristics of many students taking vocational over academic qualifications with factors such as parental occupations and historic participation of the community in University education also linked to choice of qualification taken.

Students being offered places at University nationally are more likely to have done so via vocational qualifications if they have come from low participation areas or their parents have manual rather than professional occupations. (Gicheva N, Petrie K, 2018). Similar indicators can also be found for the greater likelihood of vocational qualifications among students receiving free school meals, a common proxy for low income family background (Richards (2016)). Related to this are concerns that students entering University with vocational qualifications, even if nominally equivalent in tariff to their academic counterparts, very noticeably do not perform so well once on their degree, whether due to syllabus mismatch, learning and assessment modes, preparation, perception of self, or socio-economic factors. (Shields, R & Masardo, A, (2018), HEFCE (2018), Gill T., (2018)).

In the engineering field much of the focus of this transition gap has focussed on conventional academic deficiencies, most notably mathematics (Gallimore & Stewart (2014)), however we are also keen to formally investigate to see if there are differences in the way students think about and tackle more applied visual and practical problems. Problem solving is a key aspect of becoming an engineer and much has been written on it in relation to students own understanding of the role of problem solving ((Kim (2018), McNeill et al. (2017), Koro-Ljunberg (2016)), placing the work in context (Wolff (2017)), categorization of problems (Scheulke-Leech et.al. (2020)), competence of graduates (Clegg (2019 et.al))Burkholder et.al. 2021) and so on.

The overall methodology used here will be a meta-analysis making use of existing literature, historical data of the performance of students on different module types, interviews and experimental observations. These will then be analysed to draw up proposals to support vocational and academic entrants which will be trialled, and the outcomes disseminated as advice, guidelines and best practice. The focus of the work presented here is however the experimental work.

METHODOLOGY

The approach here involves a mix of problem solving observations and questionnaires with students on the first year or foundation year of engineering degree programmes at an English University.

Participants

Students were asked to volunteer via open calls in classes hosting students on relevant programmes and those taking part in the work were provided with a ‘thank you’ in the form of a shopping voucher in return for participation. Participant responses to questionnaires and problem solving exercises were anonymized at start of participation.

Ethical approval

The research approach and the use of the volunteers was approved via the Aston University ethics committee (Ref. 1550).

Questionnaires

The questionnaires were used to determine the demographics and educational background of the individuals and their perceived preferences when solving problems or on confidence levels when solving particular types of problem eg.

“I like to draw diagrams to help me progress toward a solution” (agree-disagree Lickert scale)

“On a 1-5 scale with 1 being least confident and 5 being most confident, how confident would you feel answering the following types of problems ?

- Estimation (eg. number of bricks to build a shed to within 20%)
- Optimisation (eg. working out whether best to buy or rent)”

Problem Solving Exercises

Students were paired together to solve practical problems. Pairing was used to help encourage verbalization of ideas and approaches to solving the problems, so enabling recording of the methods used. Pairings were set up based on student availability for a given session and where possible those with similar pre-University qualifications were paired up.

Problem sessions were of a nominal two hours with around 90 minutes spent on activity and the remainder explanations and formalities. Sessions were video recorded with the focus of the camera on the workspace, avoiding student faces to retain anonymity. Participants would attend up to two sessions with different problems presented in each session.

The aim of the exercise was to look at problem solving methodologies rather than technical knowledge and given the participants were new students, each problem was designed such that there would be no specific engineering or scientific prerequisite knowledge though basic high school arithmetic, trigonometry and algebra skills would be assumed.

A range of problems were presented, covering a variety of different challenge types. For example :

- Logic problems – eg. determine the correct combination of terms to be compatible with a set of verbal expressions.
- Visual problems – eg. Fitting tiles into a particular shape
- Open problems – eg. design a concept to solve a practical problem
- ‘Out of the box’ problems – eg. problems with a non-apparent approach

Problems were generally designed to be able to be achieved in in around 15 minutes. If students were unable to complete these in the time allotted the tests would move on to the next problem.

Students were also provided with large sheets of paper to work on and these were recovered following the tests to help understand the approaches used. Students were also allowed to use calculators if they felt it might help in some problems. Certain problems also featured physical props – such as tiles or blocks - which could be used as part of the problem solving.

Post testing

To help with analysis of the problem solving approaches a coding system was used to record the content of the videos and the approaches to problem solving in a systematic manner. Table 1 describes this coding.

Also recorded will be any tools used to help visualise or support solving the problem:

- Numerical / Algebraic Model: NM
- Graphics - Sketch / Drawing: GR
- Artefacts – provided (tools, components, blocks etc): AP
- Artefacts – improvised (pen tops, erasers, components used abstractly): AI

Table 1 . Coding structure for recording approaches used

CODE	DESCRIPTION	VERBAL EXEMPLAR TO TRIGGER CODING (typical expressions - physical and graphical equivalents also permissible)
Clarifying (clr)	Clarifying initial problem or current state of solution	"So the key thing is…" "We are limited in how much…" "…is important but *that* is not…"
Exploring / proposing (exp)	Generating (and selecting) possible pathways for solution	"Can we brainstorm…" "How about *this* or *that*…" "We could…."
Trialling (tri)	Testing suppositions, physically, numerically or otherwise	"Could we play around to see if…." "So we should be able to…." "Can we see if we can add these up it should give…"
Progressing (prg)	Following a logic step wise path toward particular solution stage	"If we can first work out…" "Now we know *this* then we can …."
Questioning (que)	Checking and quearying proposal	"Are we sure it would be strong enough?" "Are we missing something ?"
Adapting (ada)	Modifying a solution stage which is seen to be promising if not fully appropriate	"If we changed this…" "Rather than……how about….."
Retracing (rtr)	Going back to last assumed 'good' state	"So we are confident up to here…?" "If we go back to…."
Abandoning (abd)	Abandoning possible pathway	"This isn't going to work"
Presenting (prs)	Confirmation and presentation of proposed solution	"I think we've got it…" "Just checking but looks good…"

ANALYSIS

Figure 1 shows a graphical representation of the questionnaire results in which self-reported problem-solving strategies were explored. The students were responding on a five-point Likert scale covering the sort of methods or tools students felt helped them to solve problems.

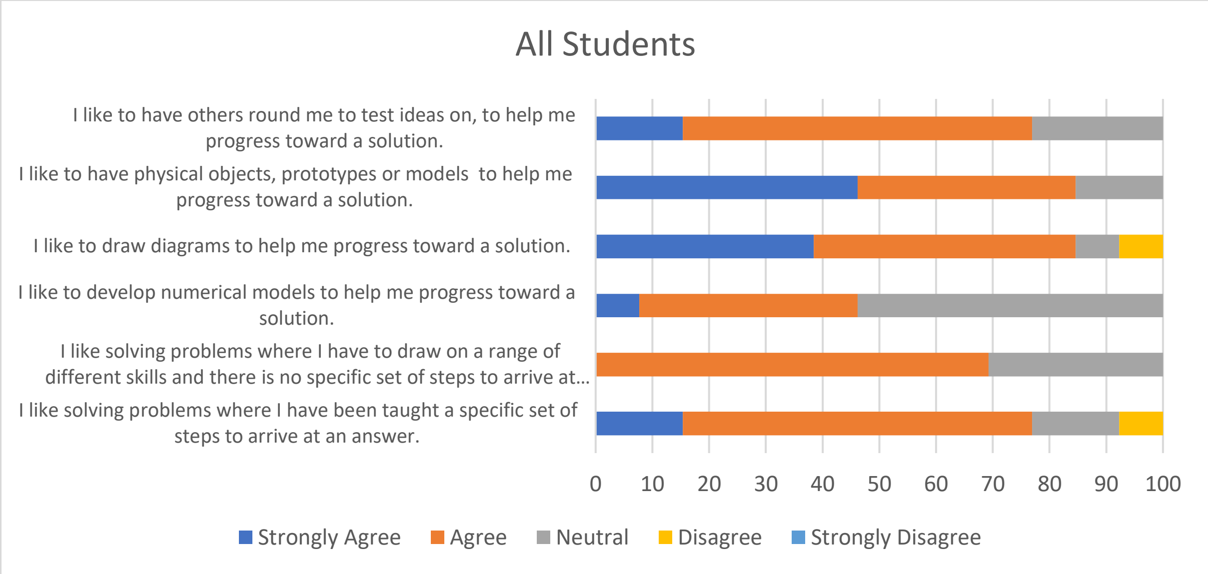


Figure 1 : Student's declared preferences in problem solving

Splitting some of the questions into those from A-level and from less traditional routes showed some differences (Figures 2 & 3).

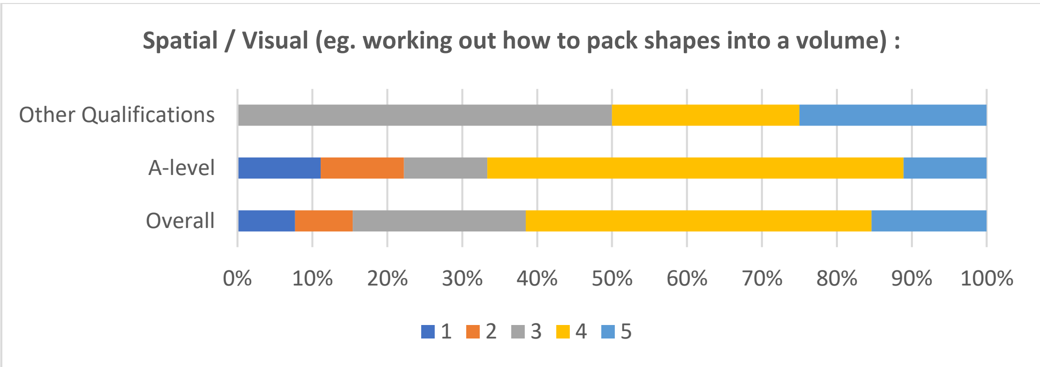


Figure 2: Student Confidence Levels for Spatial / Visual Problems – 1=Low, 5-High

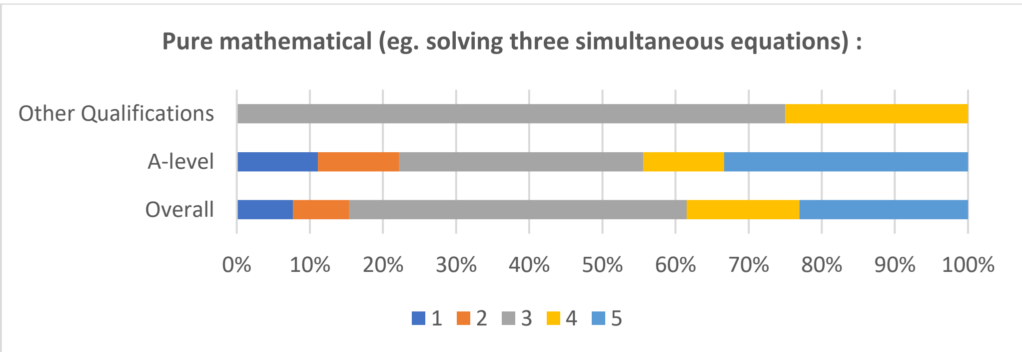


Figure 3: Student Confidence Levels for Mathematical Problems – 1=Low, 5=High

The results from the practical problem-solving trials were rich and are likely to require significant further review to fully draw out the learning which can be gained from these. Logic problems and those with a definite leaning to needing some form of undefined mathematical approach seemed to prove the most problematic for students to grasp and self-develop a strategy.

By contrast those with visual elements seemed to give students more to grasp and even where the approach used may not have been optimum, students seemed to be more willing to keep trying and were less likely to hit a dead end.

A number of problems were designed to have non-obvious and indirect solutions – eg. An apparent 2d problem which could only be solved by using 3d methods and this 'out of the box' type thinking stumped many unless prompted with clues as to the approaches used though neither group of students seemed more favoured by these types of challenges.

Some problems were couched as mini design challenges eg. – "Come up with 3 concepts to help doctors safely extract sweetcorn from childrens' ears" and so had no fixed solution. Students tended to tackle these problems with confidence, though as might be expected not necessarily following a process or critical review of the concepts. While most categories of problem showed little difference between the student types, these problems seemed to particularly appeal to those from vocational backgrounds.

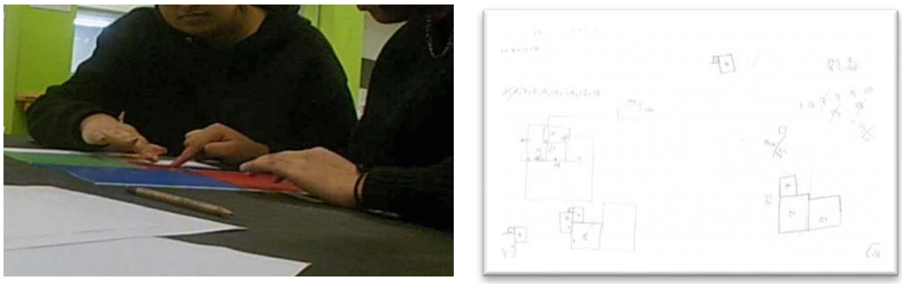
Practical Problem Solving Example: Carpet Fitting – Spatial Geometry

In this problem students were given a list of carpet tile sections ranging from 1m x 1m up to 18m x 18m and asked to join these to create a perfect rectangular shape using all the sections and with no overlaps, gaps or protrusions. Initially students were not provided with any physical tiles to work with, nor were they told these would be provided at some stage.

With the physical tiles to hand this can lead to a simple case of manual assembly and trial and error and would preclude any other options.

There is however potential for some logic and mathematical approaches to help support the decision-making process in this problem though not all groups identified this. Primarily the realisation that the area of the carpet elements will be the same as the assembled rectangle. In addition, groups should generally identify that the shortest side must exceed the size of the largest tile (18m x 18m) and that only certain combinations of widths and breadths will match the total area. This then gives a potential tool to identify how the tiles could combine to give these dimensions.

Figures 4 & 5 show exemplar results from a couple of the student trials on this problem. In this case the students in Group 14, 16 came through a traditional A-level entry route, while students in Group 1,2 had a broader educational background.

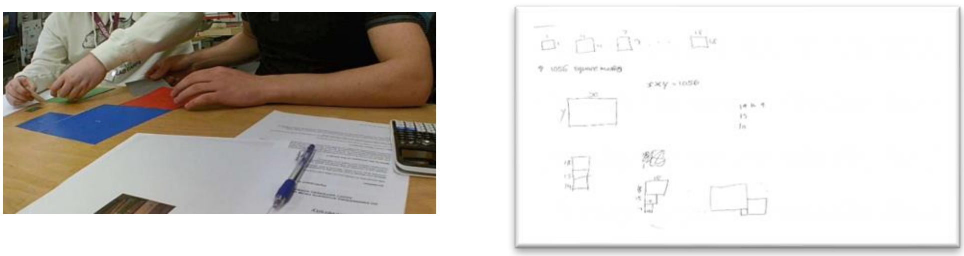


Exemplar Trial Record Following Transcription and Coding

Date : 26.01.22
Location : LG36
Problem set : TileFitting
Participants : 14,16
File : C:\Users\thomsoga\Desktop\Trial Data\220126-14-16\SUNP007
File : C:\Users\thomsoga\Desktop\Trial Data\220126-14-16\SUNP008

Time		Code	Tool	Notes
14:44:50		CLR		Problem sheet issued - read through
14:45:36	00:00:46	CLR		Tutor clarification
14:49:30	00:03:54	PRG	paper	start with one - some attempt at logical progression
14:50:40	00:01:10	PRG	paper	Some use of maths "even number needed" - drawing out
14:52:00	00:01:20	TRI	tiles	tiles released
14:53:08	00:01:08	TRI	tiles	playing with tiles but trying to add values
14:54:56	00:01:48	PRE		presenting and checking
	00:10:06			

Figure 4 : Group 14,16 (A-level background) video still, working sheet and encoded process sheet for the carpet tile fitting problem



Exemplar Trial Record Following Transcription and Coding

Date : 21.12.21
Location : LG36
Problem set : TileFitting
Participants : 1,2
C:\Users\thomsoga\Desktop\Trial Data\211221-01-02\SUNP003

Time		Code	Tool	Notes
11:05:37		CLR		Clarification of Problem - largely silent, no writing or sketching
11:06:56	00:01:19	CLR		Tutor clarification,
11:08:10	00:01:14	PRG	Calc	Total area calculation
11:09:23	00:01:13	TRI		Trying to determine next step
11:10:00	00:00:37	TRI/PRG		Realisation that need whole numbered sides to give area of combined rectangle "So if width is 18, length is 58. something, something, so let's try...."
11:11:21	00:01:21	PRG		Tring to find combinations of tiles to meet values
11:13:57	00:02:36	PRG		Continuing to trial combinations
11:16:31	00:02:34	TRI	Paper	Sketching out ideas
11:17:40	00:01:09	TRI	Tiles	Tiles issued
11:18:50	00:01:10	TRI	Tiles	"It's not going to work" - using tiles to trial options
11:23:16	00:04:26	PRE	Tiles	"That is it"
	00:17:39			

Figure 5 : Group 1, 2 (Mixed background) video still, working sheet and encoded process sheet for the carpet tile fitting problem

In this case, as with many of the problems, the two student groups appeared to follow similar processes regardless of student background. Group 1, 2 picked up on the fixed area constraint early on and appeared to follow a more logical approach. Group 14, 16 appeared slower to pick up on this issue and did make extensive use of sketching to help flesh out their ideas.

DISCUSSION & CONCLUSIONS

It has to be recognized that the activities and problems set were relatively small scale – 15 minutes typically, and so not necessarily the complex, multi-dimensional problems they will have to tackle in the future while the number of students involved was modest. This and the fact that students were not being asked to use formal engineering knowledge or skills due to by nature being focused on untrained entrant students means it does not necessarily correlate to those students later in their education or careers.

This work has highlighted however some of the key factors in the approach of engineering students to problem solving.

With physical problems we seemed to observe an eagerness to get involved though a goal focused approach tended to mean a drive to deliver a solution early, often through trial and error, rather than perhaps reframing the problem early to eliminate options and give direction to the solution route.

Logic type problems can often require a systematic approach – having a structured method to hone in on an answer by continually tightening the goal requirements through analysis of the data and eliminating those options which do not meet these. Keeping track of both the tightening specification and the list of options was not always done and not always in harmony.

Problem solving is and is likely to always be a key part of an engineer's skill set and the engineer needs to be able to apply a range of strategies to solve a diverse variety of problems. Understanding how to build on the latent capabilities of students to solve problems while offering workable and practical support to develop strategies to optimize their ability to develop viable solutions is a key skill of graduate engineers and a key area for educators to work on to support their students.

Some recommendations which come from this work are as follows:

- The work shows students on engineering programmes want to solve problems and capability in this is independent of background. Therefore, ensure all students and in particular those from a vocational background are fully supported in all aspects of their degree and scrutinise carefully syllabi to ensure hurdles are not placed unnecessarily – eg. Complex engineering science or mathematical theory taught but then never used elsewhere in the curriculum. Without this type of thinking we risk losing highly capable problem solvers from the discipline.

- Encourage students and support students to use the problem-solving approaches which suit them best but ensure opportunities are given to explore other methods as their underpinning skill sets evolve and the problems and projects they work on become more complex.

- Consider incorporating short form, non-linear problems into the element of the curriculum to support and stimulate creative solution finding among students beyond the long form major complex projects.

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DO ACADEMIC RECRUITMENT POLICIES UNDER REPRESENT TEACHING AND LEARNING COMPETENCES?

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ABSTRACT

CDIO standards 9 and 10 focus on the technical and teaching competences of staff delivering engineering education programmes. For most Universities, whether CDIO or otherwise teaching and learning are the key financial and reputational activities which ensure the institution can thrive. To ensure academic degrees can be delivered in a progressive, student centered and active manner such as that championed by CDIO it is essential that staff with the capabilities to deliver and develop strong teaching and learning approaches are recruited and trained. This paper looks at recruitment practices for Engineering academics in the UK and France. It examines how research and teaching criteria are framed in the hiring process examining recruitment advertisements and job details to examine both the numbers and types of terms used to describe these two types of core academic activities. This tends to show that, while anecdotally it has always been reported, for many of the more established Universities there is a significantly greater emphasis on research over teaching competences though the picture is not uniform and while the picture in France and the UK overall is similar the degree of emphasis of research over teaching in France appears lower.

KEYWORDS

academic recruitment, faculty development, teaching and learning competencies, CDIO Standards 9 & 10

INTRODUCTION

CDIO standards 9 and 10 focus on the technical and teaching competences of staff delivering engineering education programmes but these standards can be amongst the most tricky to systematically address and appraise. Staff training and mentoring can obviously be delivered to existing staff to develop and grow these skills however this takes time and resource.

Previous work has indicated the provision of this training is often patchy with expectations and opportunities very limited beyond basic thresholds (Thomson & Clark, 2018). Staff are also mobile in academia and will move to posts in other institutions for career progression or family reasons. Having a marketable resume is therefore important and for those seeking a move, a match to expected hiring metrics is a key aspect of career building. These metrics not only influence the teaching / research balance of those recruited but also the ideal profile of those seeking to be hired.

While most institutions in the UK, France and elsewhere will offer research only or teaching only posts, most staff are appointed on contracts where academics are expected to take part in teaching, research and general administration. The balance between these roles can be contentious however in terms of workload and career progression (Pilcher et al., 2017; Richardson and Zikic, 2007; Fahnert, 2015).

As an indicator of the relative funding importance of research and teaching to institutions, in England, the income from teaching fees and grants in the sector in 2017/18 was approaching £18 billion with research income approaching £7 billion. Much of the teaching income comes from student fees which has seen a shift in students becoming much more consumer minded with expectations of quality learning opportunities for their investment (Bates, E and Kaye, L., 2014-1). Given the relative financial and reputational importance to Universities of teaching, a question asked is "Do academic recruitment policies under represent teaching and learning competencies?"

UNIVERSITY LEVEL ENGINEERING EDUCATION EMPLOYMENT LANDSCAPE IN FRANCE AND THE UK

Academic hiring policies in EE institutions in France

For historical reasons, the majority of engineering education institutions (EEI) in France, called "Grandes Écoles", are in the public sector (85% in 2018). These institutions depend on the French Ministry of Education (or in certain case on others, Ministries like Industry, Defense of Agriculture). To give the "title of engineers" to their graduated students, they have to certify their engineering training via the CTI (Commission des Titres d'Ingénieurs - Commission of Engineering Title) requiring a high level of quality teaching.

In France, the academic profession include three different positions:

1. Tenured academic staff with two positions:
    a. teaching-researching position with a worktime division: 50% for teaching activities and 50% for research activities,
    b. teaching position: 100% of worktime for teaching.
2. Non-tenured academic staff position: generally young academic people waiting for a tenured position and employed on fixed-term contract.
3. Academic staff employed on hourly bases (external peoples employed for giving courses and payed for their teaching hours, have no administrative tasks to do).

Academic hiring policies are very different at Universities (always in the public sector) and at Grande Ecoles (could be in the public and private sector).

(1) <u>The hiring process at Universities</u> is based on a "recruitment agenda" published each year in advance at the beginning of the academic year.

In this process, the first step is to obtain the qualification of the CNU (Conseil National des Universités – National Council of Universities)[1]. For applying to the qualification that is called "qualification concours" in French, candidates are required to hold a PhD degree. The objective of this qualification process is to select the better-qualified candidates for tenured academic position at the national level. The second step of the hiring process is at the institutional level: concerning public HE institutions who have vacant positions for tenured academic staff. To apply to a tenured position, candidates have to be qualified by the CNU (this qualification is valid for four years). Each intuitions set up "recruitment committees" by disciplines for hiring tenured academic staff for their vacant positions. These committees choose a limited number of candidates for interview. Based on the results of interview, they rank candidates (on an ordinal scale) and propose the positions for the better ranked.

(2) The hiring process at Grand Écoles (in the public or private sector) is less regulated and gives more flexibility for these institutions. They are not obliged to adapt their hiring process to the official recruitment agenda and do not require candidates to be qualified by the CNU (or in certain cases not event hold a PhD degree). They apply a one-step hiring process and the decision at the institutional level is by a recruitment committee set up in the institution after the selection and interview of candidates. This hiring process gives much more liberty and adaptability (the possibility to make immediate adjustment of human resources for these institutions). As well as, it does not oblige the limitation of candidates for only qualified persons (could accept candidates from foreign countries who are not qualified by the French CNU).

In EE most of the engineering school are of the "Grande École" type applying the second hiring process with the possibility to employ a more diversified body of tenured lecturers (e.g.: people from research institutes, lecturer from foreign countries or practical teacher with a strong industrial experience).

Academic hiring policies in Engineering Education institutions in the UK

In the UK, Higher Education is not formally divided into different classes of provider as is the case in France and some other parts of Europe. Despite this there are a number of different informal categories. Until the 1950s there were around 25 Universities in the UK, a blend of ancient and civic Universities generally based in major cities. Many of these now form the self-selected 'Russell Group' of research intensive Universities. The numbers of Universities in the country were approximately doubled through to the late 1960s following government impetus. Colleges of existing Universities gained independent status while several former trade and technical schools and new entrants to the field gained University status. University numbers then underwent a further major expansion in 1992 when a large number of former polytechnics converted, again following the paving of the way by government policy. Since that time a number of further Universities have also emerged. While all Universities have equal status in the formal sense, the Ancient and Civic Universities ('Historics' for the purpose of this paper) and 1960s Universities have tended to have a strong research component which the post-92 Universities as a whole do not match (Bates and Kaye 2014-2, Hunt 2016).

[1] The French National Council of University is divided into 72 specific sections by academic disciplines and many of them subdivided into subsections.

Universities in the UK are essentially independent bodies and have a recruitment process similar to that of the French Grand Écoles with the institutions largely having a free hand in the recruitment process. In general a staffing need will be identified and the recruitment process triggered. A "*person specification"* will be drawn up itemising the skills, competence, experience and knowledge required for the role. The criteria in this specification will commonly be defined as either 'essential' or 'desirable' with these being used to formally draw up the shortlist of those applicants invited to interview state. A candidate not demonstrating all the essential criteria via their written application is unlikely to be called for interview. These criteria therefore play a crucial role in framing the type of candidates shortlisted for roles.

Within the UK, academic posts may be purely teaching or purely research but classically most permanent posts are as lecturer, senior lecturer, reader or professorial chair and expect post-holders to have a commitment to both research and teaching alongside administrative duties.

METHODOLOGY

Data Collection

To review the situation in the UK, details of academic posts in engineering education advertised via a major specialist recruitment website (jobs.ac.uk) were gathered over a number of months to see how recruitment documentation described the teaching and research requirements of prospective staff. This website is the standard recruitment site for academic posts in the UK. Excluded from the study were posts such as teaching fellow or research fellow which were clearly focused to specific activities. Also excluded were posts based overseas or at international campuses of UK institutions as were colleges without degree awarding capabilities. 101 engineering academic posts were surveyed in total spread between historic (n=26), 1960s (n=27) and post-92 (n=48) institutions.

In France, academic posts in engineering education are advertised in two ways. For public positions at the University, requiring the CNU qualification as a prerequisite for applying to a position, all advertisements are in an official website called "Galaxy" of the French Ministry of Higher Education, Research and Innovation. On this website, academic positions advertisements are classified according to their specific sections of academic disciplines. Their hiring process follows the "Recruitment Agenda" of the year published in the website. Every year, there is only one national hiring process with an application period between mid-February and March, and ends with the publication of the results in June. For private positions, there are several online websites from where advertisements for academic position in engineering education were gathered. For the private academic position, there is no hiring agenda, they are available as functions of the need of engineering schools making data collection easier. 41 engineering academic posts were surveyed in France.

Collected Data

For each case in the UK, details of the post were gathered; post title, discipline, university and seniority of post. The "person specification" for each post was also gathered.

For France data gathering was limited to private Universities recruitment due to the annual public University recruitment round falling inconveniently with regard to the conference time frame.

Data Analysis

With an aim to see how universities framed and prioritized teaching and research competences, the person specification criteria which had a specific teaching or research focus were isolated for each post advertised.

The numbers of criteria which focused on teaching or on research were then used as an initial approximate measure for the emphasis placed by the Universities on each area.

A word count analysis was then applied to the text used to describe the criteria to determine the type of language used predominantly in describing the teaching and research roles.

RESULTS

Quantitative Data

For each post, a number of essential and desirable criteria were listed in the person specification by the hiring institution. Typically there may be around 6 essential and 6 desirable criteria listed. The numbers of criteria in the person specification which could be attributed specifically to teaching or research activity were recorded. These were also collated depending on University types and whether the criteria were essential or desirable.

Summaries of this data for UK posts can be seen in Table 1.

In all cases, for essential criteria there appears to be a statistically significant (T-test <0.05) difference in the average numbers of research versus teaching criteria listed for each job, though for post-92 Universities this is notably biased in favour of teaching with the 1960s institutions and historic biased toward research.

This can also be seen graphically in figure 1.

Table 1 : Mean criteria count for teaching and research competencies as specified in person specifications for engineering academic posts at three UK University types.

	Historics (n=26 posts reviewed)				1960s (n=27 posts reviewed)				Post-92s (n=48 posts reviewed)			
	Essential Criteria		Desirable Criteria		Essential Criteria		Desirable Criteria		Essential Criteria		Desirable Criteria	
	Teach.	Res.	Teach.	Res.	Teach.	Res.	Teach.	Res.	Teach.	Res.	Teach.	Res.
Mean	1.73	3.27	0.54	0.35	1.70	3.26	0.74	0.67	2.46	1.65	0.77	0.65
St. Dev.	0.83	1.48	0.76	0.63	1.23	1.56	1.10	1.04	1.29	1.18	1.06	0.93
% split T/R	34.62	65.38	60.87	39.13	34.33	65.67	52.63	47.37	59.90	40.10	54.41	45.59
T-test Research v Teaching	7.30E-05		0.169961		2.90E-05		0.663224		0.00152		0.55799	

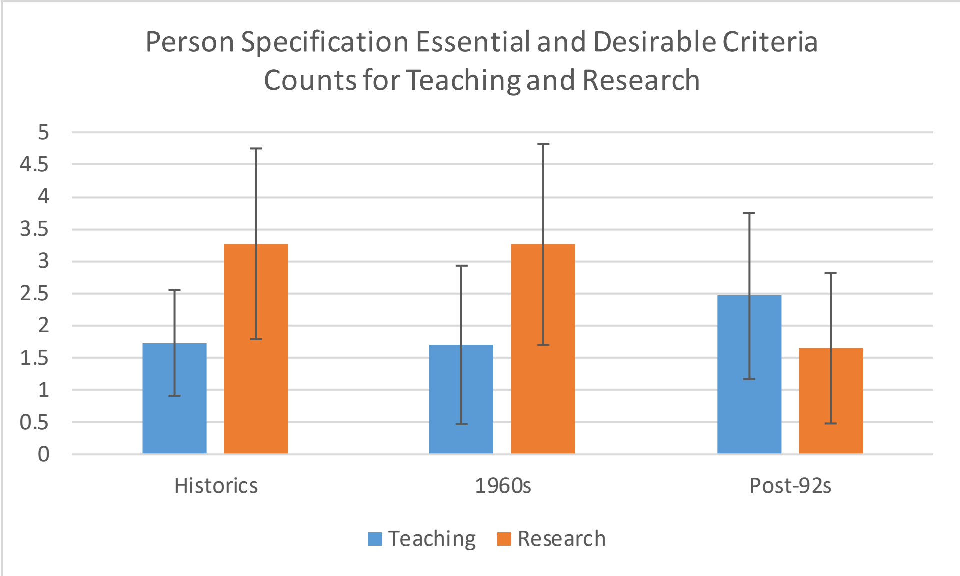

Figure 1 : Mean Person Specification Criteria Counts by Teaching and Research and UK University type

An alternative approach to this same data can also be seen in the table 2 below where a T-test comparing the mean numbers of criteria specified for teaching and those specified for research by each of the University types. This shows no significant difference in person specification criteria counts between the historic and 1960s Universities but both differ notably to the newer post-92 Universities in how they define job candidate specifications.

Table 2 : Criteria comparisons between different University Types

	Teaching Essential	**Research Essential**
T.test Post-92-Historics	0.004335	1.9E-05
T.test 1960s-Historics	0.925467	0.981065
T.test 1960s-Post-92	0.015311	2.87E-05

Qualitative Data

The tables shown below (Table 3) summarise the wording used in the ‘essential criteria’ for criteria deemed as addressing teaching and research activities respectively in the UK posts surveyed. The count is the number of times a word was used with the %age indicating this as a fraction of the accumulated number of criteria for each activity – a proxy for the likelihood a given word would appear in a given criteria. In each case the top 20 words found have been presented.

While many of the words are simple functional terms related to each activity, others relate to qualifiers which either demonstrate a basic level of evidence of engagement or competency in a specific aspect of the activity (highlighted in orange) and others where a certain higher level of recognition or mastery might be implied (highlighted in green).

It can be seen that the teaching expectations for academic staff hirings appear to be set at a much lower level than those for research with fewer base evidence terms being used and no evidence of higher level terms being used on a consistent basis.

Table 3 : Word frequency analysis of popular terms in teaching and research person specification criteria for UK posts

Words used to describe Teaching Criteria (All University Types)

Count	%age	Word
151	72	Teaching
87	41	Experience
70	33	Student
58	28	Ability
53	25	Learning
46	22	Levels
41	20	Postgraduate
37	18	Undergraduate
31	15	Evidence
30	14	Education
29	14	Higher
24	11	Qualification
23	11	Assessment
23	11	Programme
21	10	Development
20	10	Engineering
19	9	Support
18	9	Delivery
17	8	Contribute
16	8	Commitment

Words used to describe Research Criteria (All University Types)

Count	%age	Word
243	97	Research
73	29	Record
56	22	Evidence
55	22	Publications
53	21	Experience
48	19	Ability
47	19	Funding
42	17	International
41	16	Track
39	16	Quality
36	14	Journals
31	12	Successfully
28	11	High
25	10	Area
25	10	Outputs
21	8	Projects
20	8	Developing
20	8	External
20	8	Relevant
19	8	Activities

Table 4 : Word frequency analysis of popular terms in teaching and research advertisement criteria for French posts

Teaching Criteria (All University Types)

Count	%age	Word
38	12.06%	Teaching
37	11.75%	Pedagogical
32	10.16%	Training
26	8.25%	Experience
25	7.94%	Project
22	6.98%	Domain
16	5.08%	English
13	4.13%	Course
13	4.13%	Participate
11	3.49%	Competences
12	3.81%	Team
10	3.17%	Student
9	2.86%	Capacity
9	2.86%	Responsibility
7	2.22%	Multi-tasking
7	2.22%	Communicate
7	2.22%	Design
7	2.22%	Learning
7	2.22%	Aptitude
7	2.22%	Team

Research Criteria (All University Types)

Count	%age	Word
59	20.07%	Research
27	9.18%	Project
17	5.78%	Level
16	5.44%	Experience
14	4.76%	Publication
14	4.76%	Activities
13	4.42%	International
12	4.08%	National
12	4.08%	Scientist
12	4.08%	Development
12	4.08%	Participation
11	3.74%	Team
11	3.74%	Partnership
10	3.40%	Collaboration
10	3.40%	Competences
10	3.40%	Academic
9	3.06%	Domain
9	3.06%	Develop
8	2.72%	English
8	2.72%	Contract

Table 4 shows a similar analysis carried out for French posts which shows a similar but less clearly defined degree of emphasis between teaching and research.

DISCUSSION & CONCLUSION

This work has shown that that the language and emphasis used in the advertisement of jobs in the engineering education field shows statistically significant emphasis toward research in both the UK and perhaps to a lesser extent in France. In many cases, despite the nominal joint teaching and research role to which the academics would be appointed, for established universities there were typically twice as many references to research achievements and competencies as there were to those associated with teaching and learning. In many cases the threshold criteria for teaching, at least as expressed in the recruitment literature, was often very perfunctory – 'experience' and 'ability' being among the most common terms used with little in terms of qualifiers to suggest the standard which might be expected or the potential to develop in this area. By contrast the criteria descriptors associated with research were often augmented with aspirational or advanced expectations – 'internationally', 'leading', 'external'. In other words, an outstanding researcher with basic competence in teaching would meet the hiring criteria but an outstanding teaching academic with competence in research would not.

Effective engineering education requires well motivated and skilled staff to ensure that the students being developed through the programmes emerge with an education which provides not only the core skills needed to embark on a career in engineering but also and increasingly the qualities needed to grow and develop over a lifetime in the profession.

CDIO aims to address this and alongside the standards associated directly with the active learning of the students are key standards – 9 & 10 - related to the development of faculty.

This task however is likely to be significantly harder if progression criteria via internal promotion and external opportunities do not require more advanced levels of engagement in the learning process and where research achievements and targets are set at a higher level.

While the institutions and posts reviewed here were not necessarily those associated with CDIO institutions, they are representative of the labour market from which we recruit and hope to retain the brightest and best of our educators.

The relative paucity of emphasis on learning and teaching in recruitment advertisements and supporting information allows CDIO based institutions to be more targeted and differentiated in the hiring process, using appropriate language to emphasise the teaching and learning opportunities available which may not be present elsewhere. It does however also pose challenges in helping staff develop as per standards 9 and 10 if the drivers which brought them into the role and the expectations of their next role do not necessarily require or reward high achievement in learning and teaching.

This paper does however hold up a mirror and fact check on hiring policies and should act as a stimulus to open up debate on progressive approaches to staff recruitment.

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LEARNING MECHATRONICS USING DIGITAL LIVE LABS

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ABSTRACT

Practical skills training in laboratories are important elements and learning outcomes in engineering education, where leaners, through exploration, experimentation and reflection engage in inquiry-based learning that stimulate the acquisition of deep conceptual domain knowledge and inquiry skills. Traditional lab environments are very costly to maintain, partly unsafe and often require proximity of instructors and/or students that is in conflict with the Covid-19-driven need for physical/social distancing. In this paper, we describe and evaluate a course in logic control that used online labs both in pure online and in hybrid format. Students reported very high satisfaction with all three formats and achieved similar learning performances. However, qualitative analyses indicate that student learning is deeper and more authentic in the on-campus and hybrid formats compared to the pure online format. Teacher reflections show an overall positive impression of online labs. In conclusion, we recommend the hybrid format as it combines the benefits of online and physical labs, i.e., the flexibility of online laboratory work and realism of hands-on physical laboratory work.

KEYWORDS

Online learning, Online labs, Digital live labs, Hybrid teaching, Logic control, Standards 5, 6, 8

INTRODUCTION

Laboratory work are key elements in engineering education providing students with opportunities for enhancing understanding of theories and concepts as well as preparing them for engineering profession tasks such as, experimentation, and testing (e.g., Hofstein & Lunetta, 2004). Physical labs have obvious benefits for learning but also drawbacks as they are expensive, have limited accessibility and potential safety concerns. New technology offers new possibilities to arrange laboratory learning activities in hybrid or in online formats with opportunities to participate from distance. However, the effects on students' experiences and learning using online and hybrid labs are not fully understood and there is a need for learning design recommendations.

In this study we contribute to close this gap by examining a course in logic control at Chalmers University of Technology. The project-based course has recently been delivered in three different formats: campus, online and hybrid. Data on student learning, satisfaction, and experienced workload together with teacher reflections are used for comparative analyses of the three formats.

CONTEXT: THE LOGIC CONTROL COURSE

The 7.5 ECTS course named “Logic Control” (Chalmers University of Technology, 2021) is given as a project-based course at the end of the first year of the BSc programs in Electrical Engineering and Mechatronics Engineering for a total of 100 students. The intended learning outcomes include programming of an industrial PLC (Programmable Logic Controller) system, programming of a microcontroller and to use electronic components for communication between the two control systems.

The students work in pairs to solve one of three similarly complex project tasks, where PLC programming, programming of a microcontroller and use of electronic components are trained. They have studied courses in computer engineering (including Boolean algebra), electric circuits and programming in C during their first year. This knowledge from previous courses is needed in the projects. The course adds new information through seven two-hour lectures early in the course. The course literature consists of two compendia, manuals, and datasheets.

Assessment of the student knowledge and skills is done in four parts: solved project task, written report, individual short written test, and oral presentation of the project. The oral presentation includes individual questions to test the understanding of fundamental parts of the course.

During the years 2019 – 2021, the course has been given three times in three different formats. In 2019, and the years before, on-campus formats were used. In 2020, the course was given in pure online format and in 2021 in hybrid format.

STATE-OF-THE ART

Online labs have been examined as a viable alternative to physical labs, where the benefits - realistic data, the interaction with real equipment and the opportunity to collaborate and interact with other students and the teacher – stand against the high costs, time, and place restrictions as well as scheduling and supervision requirements (Nedic et al., 2003). The literature generally distinguishes two types of online laboratories – virtual and remote (Chen et al., 2010). Virtual laboratories refer to simulated lab environments based on software such as Matlab/Simulink, LabView, Java Applets or others. Remote labs are lab experiments with real instruments and/or components that are remotely controlled with the help of the internet - either directly or via instructions to staff on site. Both types of online labs have been investigated in terms of their strengths and weaknesses and regarding their effect on student learning. Research has thereby provided case studies reporting on the design and evaluation of numerous virtual and remote lab environments of varying levels of technical complexity (e.g., Wang et al., 2015; de Jong et al., 2014; Potkonjak et al., 2016).

Several potential benefits of virtual and remote labs over traditional labs have been identified (e.g., Potkonjak et al., 2016; Chen et al., 2010; Post et al., 2019; Nedic et al., 2003; Lynch & Ghergulescu, 2017; de Jong et al., 2014). The most cited reasons to integrate both remote and virtual labs in higher education are the expected cost reduction and simplified maintenance of lab facilities, while providing students with a safe learning environment that can be accessed from anywhere. Both forms of online labs are more cost-efficient because virtual labs are easier to set up and maintain and involve comparatively low equipment costs, whereas remote labs can be used much more efficiently through tight scheduling, shorter time slots and non-stop scheduling. Access and set-up are more flexible as online labs can be available 24/7 and offer geographically distributed learners the possibility to remotely collaborate and cooperate with each other and the instructor. Remote labs allow for interaction with real equipment. Virtual labs on the other hand enable a variety of experiments with different components and changes in system configurations. Experiments can easily be repeated, and the inner mechanics of lab devices can be observed with greater transparency and without damage or impact risk. The very nature of virtual environments is also its main disadvantage – they do not actually exist which may result in a lack of real-life feel and seriousness for students that might experience virtual lab more as a game, making impactful teaching about health and safety issues difficult. Even in remote labs, students are only virtually present in the lab. Further, depending on the technology used in virtual labs there are risks of oversimplifications and a lack of natural variation – adapting virtual labs to class contexts requires advanced understanding of the underlying software. In addition, the necessary professional development of teachers to enable them to create well-designed inquiry environments can be a major challenge.

With regard to learning, Brinson (2015) in a review of 56 studies concludes that learning outcomes were equal or better from virtual or remote labs compared to traditional labs. For example, Wang et al. (2015) found that compared with traditional lab environments, the use of a virtual physics lab provided students with more in-depth practice of process skills, comprehensive skills, and reflection skills of scientific inquiry. In another review paper focusing on learning outcomes of remote labs, Post et al. (2019) found positive results with respect to gain of conceptual knowledge, student engagement and student satisfaction. However, they also argue that the review of learning outcomes was superficial as most articles do not focus on that aspect and more research is needed in that regard. Similarly, Potkonjak et al. (2016) point at the fact that most online labs are adapted to a specific educational context with very limited degrees of generalizability. On a more critical note, some authors point at the need to improve learning in online labs through more careful design and the coordination of group and individual activities (Corter et al., 2011). Others argue that online labs - while providing value to education – should and cannot replace traditional lab environments completely and its usage should be governed by the teaching goals balancing the simplicity and physical experience of the student with the appeal and convenience of digital learning environments (e.g., Scheckler, 2003; Sicker et al., 2005).

Some authors have suggested to overcome some of the drawbacks of simulations and remote labs by combining both into hybrid labs (e.g., Rodriguez-Gil et al., 2017; Henke et al., 2013; Lei et al., 2018). In this format, the scalability and cost-effectiveness of virtual simulations are combined with the higher authenticity of remote labs. While being relatively new, tentative evidence suggests that this format is interesting and engaging to the students and has educational potential (Rodriguez-Gil et al., 2017). Little attention has been paid to combinations of online and real lab sessions. This learning design attempts to provide students with the flexibility of remote or virtual labs as well as the real-world hands-on experiences (Zhu, 2010). A recent study in chemistry (Enneking et al., 2019) reported that compared to traditional labs, this format provided similar results regarding the students' cognitive and psychomotor development. On the other hand, students were less able to see real-world connections and spend less time reflecting upon the underlying concepts.

In sum, we conclude that while there is increasing evidence that virtual and remote labs can effectively replace physical labs at least in part, the mixed results point to the importance of adapting online learning environments to the educational context, in which the potential of hybrid solutions has been recognized but needs further exploration and validation.

THREE DIFFERENT COURSE FORMATS

The same course has been given in three different formats. All three formats had the same intended learning outcomes and students had the same preceding courses. Three of the preceding courses are considered vital for the Logic Control course but the students were eligible to take the Logic Control course without having passed these courses.

In the on-campus format, all seven lectures were given live in a classroom and the students were provided with pdfs of the lecture notes. All project work was conducted in labs with physical equipment for direct testing and trouble shooting. The students had each 48 hours scheduled in the lab for their project work, more if needed. The scheduled lab time was mandatory to attend until the project was finished. Assessment of the solved project task was done in the lab, by presenting the solution to the teacher.

In the pure online format, the three PLC lectures were given as short, pre-recorded films. The scheduled online lecture sessions were used for a short overview and time for discussion and questions about the films. The three lectures on microcontroller and the lecture on electrical components and troubleshooting were given live online. All lectures were recorded and were made available to the students after the lecture. All project work was conducted at home in simulation models and the groups had 48 hours online to ask questions. Each week, the groups had to send in a progress report and their code. The teachers read the progress reports, answered unsolved questions, and gave a few comments on the code. Assessment of the solved project task was done online at two 30 minutes sessions per group.

In the hybrid format, all lectures were given online, and the structure of the lectures was maintained from the online format. The students were given 24 scheduled hours in the lab for their project work. The scheduled lab time was mandatory to attend until the project was finished. The students had the possibility to attend 8 hours of the mandatory lab time remotely. They were provided with simulation models for preparation at home and 20 hours of online sessions for questions between the scheduled times in the lab. Assessment of the solved project task was done in the lab, by presenting the solution to the teacher.

THE DIGITAL LIVE LAB SETUP (ONLINE AND HYBRID)

In both the pure online format and the hybrid format, the students had to prepare and work outside of the scheduled lab hours. The preparations were made using simulation models.

For the PLC part, a simulation model of the physical system was developed in the PLC programming environment Codesys. The program code can be tested in the simulated environment on a PC and transferred to the PLC systems in the lab. Codesys is free of charge and can be downloaded to any PC with a Windows operating system (Codesys, 2022).

The microcontroller used was a PIC processor in the on-campus format and in the pure online format. For the hybrid format, the microcontroller was changed to the developing platform Arduino Uno. The PIC processor can be programmed and simulated in MPLABX (MPLABX, 2022), which is free of charge and can be downloaded to any PC and any operating system.

The Arduino Uno and electrical components can be simulated in the web-based program Tinkercad (Tinkercad, 2022).

The hybrid learning set-ups were guided by the pandemic restrictions, i.e., the maximum students in rooms, and the need for students to stay at home when experiencing symptoms. In the hybrid format it was possible for both students in a pair to be on campus for the labs, and it was possible for one student to be on campus and the other student to be online and work together. An example of the setup for one student online is seen in Figure 1. The setup facilitated one web camera (encircled in yellow) and one conference mic (encircled in red). The students were communicating online through Zoom, where the student in the lab could share the screen and give control to the other student. Through the conference microphone, the teacher could talk to and discuss with both students at the same time, as if they were both in the lab.

Figure 1. Lab setup for lab session with one student on campus and one student online in hybrid format. The web camera is marked in yellow, and the conference mic is marked in red.

For the pure online format, the assessment of the function was conducted in two steps. The first function test was made halfway through the project, when the students had made most of the PLC code and had started to connect the PLC system to the microcontroller system. This first test was made for the students to gain a better understanding of the total project and to check their understanding. The second test was a function test of the entire system. In both tests, one teacher was in the lab with the physical equipment and the students participated through Zoom. The lab setup for the function tests is seen in Figure 2. One web camera (encircled in yellow) and a headset for the teacher were used. All communication was through Zoom, where the teacher could share the screen.

Before the function tests, the students had to submit their code and their circuit diagram schematics. The teacher had prepared some of the circuits on a breadboard. The teacher had checked that the schematics resembled the prepared breadboard circuits and checked that the programs could work with some minor adjustments. If the criteria for preparations were not met, the students had to make changes and resubmit for the function test.

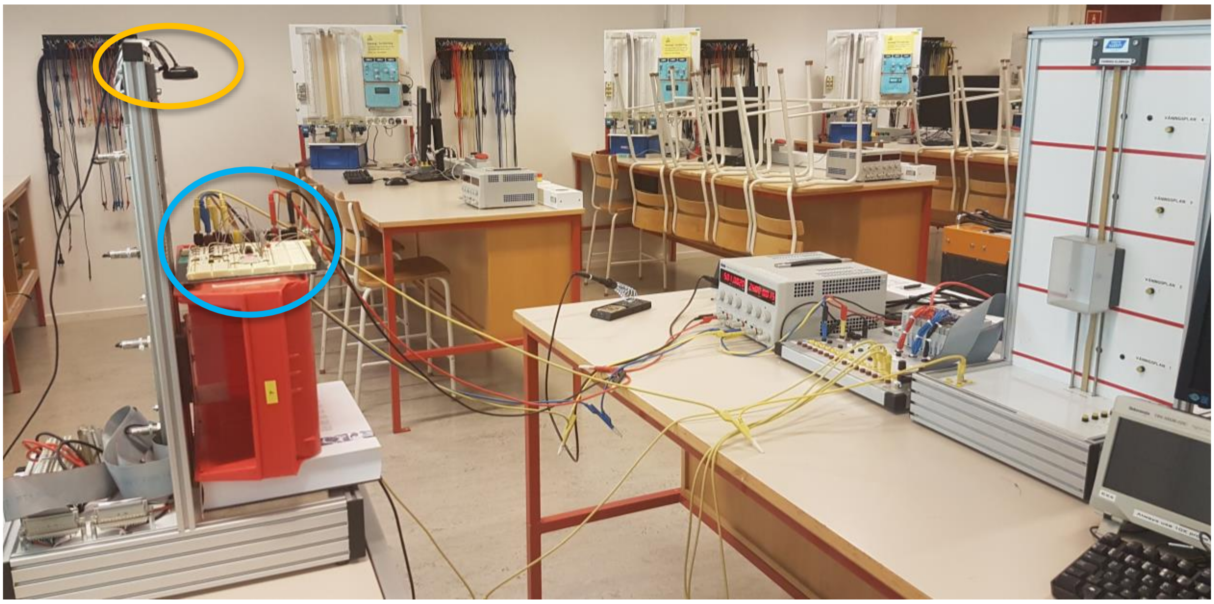

Figure 2. Lab setup for function test in the case of pure online format. The web camera is marked in yellow and can be angled to show the breadboard, marked in blue or the controlled system

During the test, the teacher showed the prepared breadboard and asked the students about the components, and where to connect about eight missing wires. Figure 2 shows the web camera encircled in yellow and angled to show the breadboard, that is marked in blue. The teacher showed the download of the code to the PLC and the microcontroller and made function tests from the students' instructions.

In order to pass the function test, the students needed to prove that their programs and designs worked, and that the hardware could be controlled to specifications. They also needed to answer questions about the electric components and their programs. The questions served the purpose of ensuring that both students had been working with the preparations and had understood what they had done. The discussion also gave an opportunity to sort out any misunderstandings.

RESEARCH METHOD

This is a comparative case study based on three different course formats (on-campus 51 students, on-line 62 students, and hybrid 46 students). Data was collected from:

- student throughput data,
- end-of-course evaluation questionnaire, and
- teacher observations and reflections.

Quantitative comparisons have been made of student throughput, student satisfaction ratings and self-reported student workload. We used standard statistical test procedures for determining the significance of the observed differences, namely one-sample t-tests for comparing observed course means with the program averages and one-way ANOVA for comparing the course formats with each other (e.g., Acton et al., 2009).

As a follow up analysis, we also analyzed the effect of student participation in preceding courses on their likelihood to pass this course as a controlling factor. We used binary logistic regression (e.g., Bewick et al. 2005) with the number of completed preceding courses (between none and three) as regressor variable. The predictor variable, *number of passed preceding courses*, was tested a priori to verify there was no violation of the assumption of the linearity of the logit. The output analyses involved the Wald test at a 95% level of significance. The model's reliability was verified by analyses of chi-square omnibus, Nagelkerke R^2, and Hosmer and Lemeshow tests (Cleff, 2019).

Finally, qualitative analyses have been made based on teacher reflections and student free-text comments from end-of-course evaluation questionnaires, using inductive thematic analysis (Braun and Clarke, 2012).

RESULTS

Student throughput

As outlined in Table A1 (see Appendix A), the student throughput was approximately the same in the on-campus format (75%) as in the pure online format (74%). However, in the hybrid format, the throughput had decreased to 67%. An one way analysis of variance (ANOVA) showed nevertheless that the difference between course formats regarding student throughput was not significant, $F(2,156) = .389$, $p = .678$ (see Table A2). Further, the average student throughput for all courses in the two programs is 77%. None of the three course formats differs significantly from that (see Table A3).

As a controlling factor, we also studied the student throughput in preceding courses, where the same decrease for students in the hybrid format was observed. Figure 3 shows the correlation between passing the Logic Control course and the three preceding courses: Introduction to Computer Engineering, Electrical Circuits, and Programming in C. The coloring goes from dark blue for passing all three preceding courses to white for not passing any of the three preceding courses. Figure 3 illustrates that passing all three preceding courses gives a high probability of passing the Logic Control course. Almost everyone who passed the three preceding courses also passed the Logic Control course regardless of the format. Furthermore, the figure shows that not passing any of the preceding courses gives a low likelihood of passing the course in Logic Control. Hence, the lower throughput in the preceding courses is the most probable cause of the lower throughput in the Logic Control course in the hybrid format 2021.

To confirm this observed effect, a binary logistic regression analysis was conducted to investigate the relationship between the *number of passed preceding cours*es and *passing the Logic Control course*. The logistic regression model (Table A4) with only this one regressor correctly predicted 87.4% of the passing or non-passing students, with significant chi-square value (96.788, p = .000, Table A5). The Hosmer and Lemeshow test indicated the model consistency (1.964, p = .375, Table A6), and the Nagelkerke R^2 performed a very good overall fit (.658, Table A7). In terms of effect size, the model shows an 'odds ratio' of 6.312 (see Table A8), which is significant (Wald = 49.487, p = .000) and suggests that with each passed preceding course, the odds of a student to belong to the passing group of the Logic Control course increases by that factor. The coefficient on the *number of passed preceding cours*es variable has a Wald statistic equal to 49.49 which is significant at the .001 level.

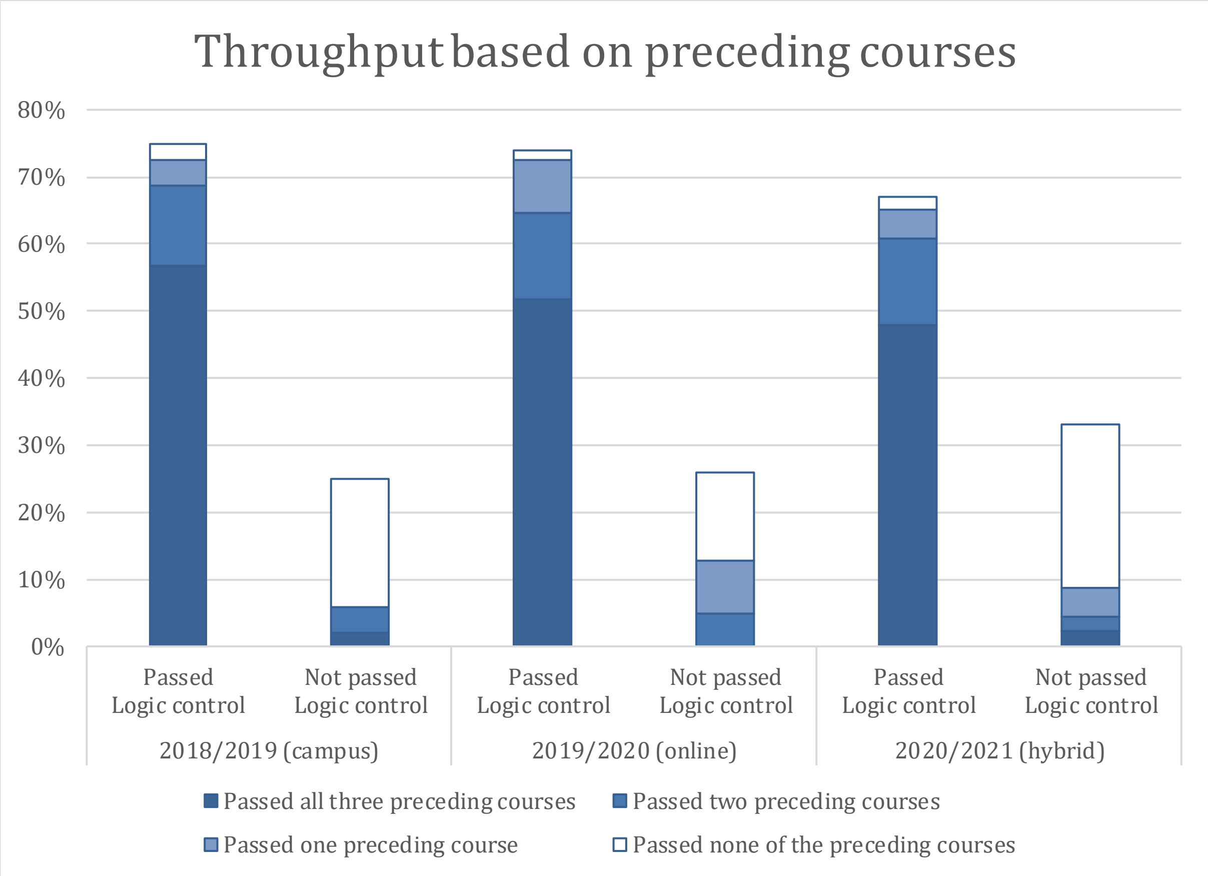

Figure 3. Throughput in the logic control course in relation to success in preceding courses

Student learning

Apart from student throughput, information about student learning is limited. The online format and the hybrid format gave the students working conditions, that can be more like the working conditions they will face as engineers. In most development projects of automation or control systems, continuous testing on the physical system is too costly. Therefore, most development and programming are tested in simulation models. Both formats also put higher demands on preparations and time management.

Some of the questionnaire answers indicate that the students gained much of their understanding of the systems in the lab, where they could see how everything was connected and worked together. In the pure online format, some students did not reach that understanding until the first function test. In both the on-campus format and hybrid format, the answers showed appreciation for the time to work in the lab.
One important step of the course is troubleshooting of the electrical circuits. For many students, that was also the most time-consuming step in the on-campus format. Troubleshooting can be trained in the simulation environment of Tinkercad but not fully. That could be observed in the hybrid format course, where students had made preparations of their circuits in Tinkercad but still had trouble to work out in their circuits on the breadboards in the lab. That more extensive troubleshooting was unfortunately not a part of the pure online course.

Student satisfaction

Course evaluations have been made each year from questionnaires and a course evaluation meeting. The student satisfaction has been high in all three formats, but slightly higher in the on-campus format (4.86 for on-campus and 4.33 for both online and hybrid, in a scale 1-5, poor to excellent, Table A9). The ANOVA did not show any significant differences between the three formats, $F(2,25) = 1.562$, $p = .229$ (see Table A10).

The average student satisfaction for all courses in the two programs is 3.7, which is lower than in all three of the formats examined here. A one-way t-test confirms that the difference is significant for all three formats (Table A11).

Student workload

Students reported the same workload in the on-campus format as in the pure online format. However, they reported higher workload in the hybrid format. The higher workload is a consequence of working both in the simulators and the physical hardware. Several groups struggled with transferring their simulated results to the lab setup. From a teacher perspective, that is important training but from a student perspective, it takes time. Some student groups also struggled with troubleshooting the same problem twice, first in Tinkercad and then on their breadboard.

Consultation sessions were used between the lab sessions in the hybrid format to aid the students in their work. However, many students did not come to the online consultation sessions. They reported that they were working at other times and had solved their questions before the consultation sessions. Working on their own helps in learning but can increase the workload.

Teacher reflections

The teachers reported the highest workload in the pure online format. The higher workload was mostly due to the progress reports and the function tests.

From a teacher perspective, online consultation sessions are effective. One teacher can meet and guide more students in an online session than in a lab session. Using more consultation sessions, as in the hybrid format, can therefore reduce the teacher workload.

In both the pure online format and in the hybrid format, the students plan their work themselves, in contrast to the on-campus format when they could come and work at scheduled times in the lab. Most students handled the planning very well. However, the quieter students and the less motivated students had a tendency not to come to the consultation sessions, they asked fewer questions and finished their project later or not at all. As a teacher, it is easier to see and motivate these students in the lab.

The individual work of each student in a group is harder to see in an online format. Therefore, the small written test and the oral discussions at the end of the course are more important in the pure online format but also in the hybrid format. In all three formats, they are one tool for explaining the individual grading of two students in a pair.

In the pure online format, the students are guiding the teacher through their code and their electrical circuits in the function tests. The function tests are a part of the assessment of the course and meanwhile they were the only time the students could use the physical hardware. The duality of the sessions sometimes made it hard to balance between explaining and assessing the students' knowledge.

From teachers' perspective the hardware and software set-ups functioned very well and supported student learning as well as student-to-student interaction and student-teacher interaction.

DISCUSSION

This study was set out to examine student experiences and learning in a lab course conducted in three different formats. Our results confirm earlier studies in that students achieved similar throughputs in online, hybrid and traditional learning environments (e.g. Brinson, 2015; Enneking et al., 2017) and expressed high levels of satisfaction in each format (Post et al., 2019; Corter et al. 2007). The slight preference of students for the hands-on format in our results is also mirrored in other studies and has been explained with the fact that students can work with actual equipment (Post et al., 2019).

However, especially from the teacher reflections, we could also identify potential issues. As others (e.g., Potkonjak et al, 2016) we identify the transfer of knowledge from the online to the physical lab environment as something that needs to be carefully considered in the learning design. Another challenge relates to what Stöhr et al. (2020) call the "polarization effect" of online learning. While offering more flexibility, online learning environments tend to put higher demands on students' ability to regulate and organize their learning compared to campus-based education with the effect that strong students might benefit from online learning while weaker students struggle even more.

Further, in difference to earlier studies, the introduction of the pure online format and the hybrid format has been driven by the Covid-19 pandemic with potentially profound effects on delivery and student experiences in the lab environments (Gamage et al., 2020). Thus, the pandemic and some changes in the teaching staff have influenced our results. In the presented results, these influences have been filtered out as far as possible for the purpose of comparison, but some effects remain.

The short time for preparations and restrictions due to Covid-19 prevented recording of a lecture in the lab about the hardware. A lecture like that would have helped student understanding of the physical systems and how they would work together. We also needed to reduce the number of alternative projects from three to one.

A change was made in the teacher staff before the hybrid format round of the course, resulting in fewer available teacher hours. Restrictions due to the pandemic put limits on the number of students in the lab at the same time. Both these changes resulted in the lower number of hours where the students could get help from a teacher in the hybrid format. That put higher demands on the students and is one reason for the reported higher student workload. Without restrictions from the pandemic, the students can have more hours in the lab.

The change in teacher staff before the hybrid format resulted in two hand-in assignments and a change of focus in the first lab session. The addition of two hand-in assignments resulted in a higher workload for both teachers and students but also in higher student learning. The shift of the first lab session took time from the project and the students fell behind their plan early in the project. The hand-in assignments helped in understanding and will be kept but adjusted to resemble the project more. The first lab session will be shifted back to understanding the physical systems and start of the project. It will also be used to show how to ease the time-consuming transition between preparations and lab work.

Preparations between the labs have been hard and time consuming for the students. However, they are given the possibility to learn both time management and a more realistic way of working as an engineer. The simulation tools and online consultation sessions can be kept, and the job can be less time consuming for the students if they are guided through how to transfer their simulated results to the physical hardware.

The students were not allowed to bring the equipment home to prepare due to limited number of lab kits. To continue developing the on-line format to satisfy all learning outcomes it is necessary to invest in enough lab kits, so that each student can work individually with circuit set-up from home. This can also solve the problem of balancing explanation and assessment as well as providing more hands-on training.

The possibility to work from home has opened an opportunity for students to participate also with a minor illness. Furthermore, the setup can be used for collaborations between students from different universities taking the same course or lab.

CONCLUSIONS

Digital labs have been used in both a pure online format and in a hybrid format. Both formats have been compared to the same course in an on-campus format. The students in the pure online format gained less training in trouble shooting compared to the other formats and the pure online format was more time consuming from a teacher's perspective. Therefore, the pure online format is not the primary recommendation from this study.

The hybrid format on the other hand, has proven to work well. With some modifications to lower the student workload, the hybrid format can be recommended for this type of course. From a teacher's perspective, online consultation sessions are more efficient than meeting the students in the lab. The possibility to follow physical labs online if needed, provides extra flexibility in the hybrid format compared to the on-campus format. The same format can be used in collaborations between universities for both students and teachers.

An extra benefit from the hybrid format is that the students train in a more authentic set-up as engineers, where they must make preparations before testing the theories on the physical system.

This study has focused on one specific course and some of the positive effects of the hybrid format may be limited to labs that show similarities to this course. The use of simulation model has been crucial to the digital labs. Following physical labs online is likely to work better if much of the lab is by use of a computer and observations of the physical systems, in contrast to labs where hands-on operation of the equipment is a vital part.

As many other studies, this has been a single-case study. To gain more insight in the area, meta studies and comparison of all single-case studies are needed.

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APPENDIX A

Table A1. Descriptive statistics for student throughput for on-campus, online and hybrid format

	N	Mean	Std. Deviation	Std. Error
On-campus	51	.75	.440	.062
Online	62	.74	.441	.056
Hybrid	46	.67	.474	.070

Table A2. ANOVA comparing student throughput in on-campus, online and hybrid format

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.158	2	.079	.389	.678
Within Groups	31.666	156	.203		
Total	31.824	158			

Table A3. One sample t-test of student throughput in on-campus, online and hybrid format versus the program average of 77%

	Test Value = .77					
					95% Confidence Interval of the Difference	
Format	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hybrid	-1.375	45	.176	-.096	-.24	.04
On campus	-.404	50	.688	-.025	-.15	.10
Online	-.501	61	.618	-.028	-.14	.08

Table A4: Classification Table[a]

			Predicted		
			Pass		Percentage
	Observed		0	1	Correct
Step 1	Pass	0	36	8	81.8
		1	12	103	89.6
	Overall Percentage				87.4

a. The cut value is .500

Table A5: Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	96.788	1	.000
	Block	96.788	1	.000
	Model	96.788	1	.000

Table A6: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.964	2	.375

Table A7: Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	90.780[a]	.456	.658

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table A8: Variables in the equation

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Number of preceding courses	1.842	.262	49.487	1	.000	6.312	3.778	10.545
	Constant	-2.052	.458	20.056	1	.000	.128		

a. Variable(s) entered on step 1: Number of preceding courses.

Table A9: Descriptive statistics for student satisfaction for on-campus, online and hybrid format

Format	N	Mean	Std. Deviation	Std. Error
Hybrid	12	4.33	.778	.225
On campus	7	4.86	.378	.143
Online	9	4.33	.707	.236

Table A10. ANOVA comparing student satisfaction in on-campus, online and hybrid format

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.440	2	.720	1.562	.229
Within Groups	11.524	25	.461		
Total	12.964	27			

Table A11. One sample t-test of student satisfaction in on-campus, online and hybrid format versus the program average of 3.7

	Test Value = 3.7					
					95% Confidence Interval of the Difference	
Format	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hybrid	2.818	11	.017	.633	.14	1.13
On campus	8.100	6	.000	1.157	.81	1.51
Online	2.687	8	.028	.633	.09	1.18

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DESIGN PROCESS REPORTING TOOL FOR MAPPING AND PERFORMANCE OPTIMIZATION

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ABSTRACT

The integrative design process is becoming a fundamental part of courses offered at the Construction engineering and Lighting Sciences at Jönköping University, especially in the Architecture-engineering program. Various design processes are known, but the employed concept-test model is a good fit for the integrative design process. This study aimed to investigate how design learners' integrative design process works, and it was hypothesized that this approach fosters students' creativity. The integrative design process was separated into five tasks: Conceptualization with a mood board, Volume study, Floor-plans, Work in progress, and Poster. The quality of the design process was assessed in a Building renovation course using an online assessment platform called Design Process Reporting Tool (DIEGO). This tool measured hours spent on tasks, level of enjoyment, appraisal of the task's difficulty, perceived openness, control over the task performance, and perceived helpfulness of the peer. The results show that students suffer from performative tunnel vision and focus on the quantitative aspects rather than quality. Shortcomings in conceptual preparation and volume studies create frustration and place themselves in an uncomfortable zone. Two-thirds of the students could reach the creative zone with their peer in the process, and in the meantime control, opennes and enjoyment were experienced positively. The need to refine the conceptualization and volume study was made to unlock the full potential of the integrative design approach. Additionally, higher course grades were attainable for those individuals whose ratings on task enjoyment, effort, openness, control, and groupmate evaluation were less exaggerated.

KEYWORDS

Design process, Openness, Control, Creativity, Standards: 3, 5, 7, 8, 9, 11

INTRODUCTION

A design process can be described in many ways, and it is often reflecting the professional's own problem-solving and problem-setting approaches in a combination of personal factors, educational backgrounds, and levels of experience. In the case of a practicing professional, the vast amount of images, examples, precedents, typologies, and situations collected over the years contribute to defining a concept and testing its functionality. "*This repertoire seems to be the product of lectures, library research, site visits, precedent analysis, behavioral studies, and personal experience and preference*" (p. 50, Milburn and Brown, 2003). One of the reviewed relationships between research and design by Milburn and Brown (2003) is the concept-test model of a design process which is a good fit for an educational situation, wherein the design learners face a never-before-experienced situation, and they need to be able to develop concepts and test their functionality. The cyclical process of this development may give rise to an analytic activity enhanced with intuitive leaps when it is successful. The concept-test model can be traced back to Schön's philosophy of a reflective practice called reflection-in-action (Schön, 1983). As Visser (2010) explains, the most important character of reflection-in-action in professionals' practice (the educational situation was the primary practice of Schön at MIT) is the reflective conversations with design situations (just like in a concept-test model). The designers "*frame*" and "*reframe*" problems so that the practitioner exerts mental effort to reframe the design situation, which leads to discoveries and therefore calls for new reflection-in-action. These conversations occur in an open dialogue (usually in a design-studio situation) wherein the successful design process involves appreciation, action, and re-appreciation stages. With every framing and reframing of the design problem, the uncertain situation is more understood through the cognitive attempt of control. Furthermore, the unintended changes create new meanings that render different understanding that may contribute to the project. As Schön (1983) explains, this situation talks back to the practitioner, and if that listens and "*appreciates what he hears, he reframes the situation once again*" (Schön, 1983, p. 131-132).

For an architecture-engineering student, this dialog about framing and reframing can be frustrating since the design teacher may raise new concerns about the so-called problem setting and problem-solving. Nevertheless, the repertoire of uncertainty should not overwhelm the students but maintain a high complexity that can be accomplished in a cyclical design process constructed to encounter intuitive solutions within the course limits. This cyclical design process introduces the complexity gradually, tailoring the project complexity to the student's learning process - with the goal that the course's objectives must be fulfilled – and eventually delivering the integrative design approach.

We know about the integrated design process from the building industry's bottom-up development (Kolarevic, 2009). It started with the complex forms and surfaces with structural consequences bringing architects closer to other disciplines, which became integrated into the design process. These other professionals were still related to the building industry that used digitalization as a tool in the integration process. From integrated to integrative design process, the difference is palpable in how the disciplines work together or collaborate to achieve the goal of a building project. In terms of integrative design, the collaborating agents are creating concepts that are being tested during the design process, just like in the concept-test design model. For instance, the goal of a building project will not be merely to accommodate the families but also to reduce waste and promote healthy living with environmental performance that is no longer a burden on the city infrastructure. By elevating the conceptualization of a project to a higher level than in the integrated design, for instance, the aesthetical appeal or standard solutions are not as doctrinaire as before. In other words, the students of the integrative design process are not simply fulfilling the course requirements, the given outline for completion but achieving an individual problem-setting and problem-solving activity closely related to research by design. As Nyka, Cudzik, & Urbanowicz (2020) refers to this, "*Blurring the borders between learning and researching not only inspires students, but also fosters their creativity*" (p. 86).

Within the Concieve-Design-Implement-Operate (CDIO) community (Edström & Kolmos, 2014), the term project-based learning (PBL) curriculum is used to describe the projects as a "*platform for students to achieve competences, and to relate disciplines to each other in analysis and identification of problems as well as the problem-solving process*" (p. 541). The process skills of PBL refer to an integrated approach of self-directed learning, project management, collaboration, communication, and collaborative knowledge construction where students can reflect on their practices. By comparing PBL to the integrative design process, the difference can be highlighted in the discourse of how design learners and design practitioners communicate with each other. The integrative design approach necessitates that the design learners set the project problem-level first, which they gradually increase to a complexity that fulfills the course requirement during the discourse. In practical terms, the design learners cannot manage an integrated approach at the beginning of their design skills since their *design identity* is not yet developed, and reading the course curriculum is not prioritized when the project evolves. As Edström & Kolmos (2014) pointed out the differences between the PBL and CDIO approaches and stated that the PBL is more conductive and evidence-based; meanwhile, the CDIO approach is formal and codifiable. The integrative design process has its origin in the PBL process, in which the design learners may exceed the prescribed and pre-set goals (by CDIO standards) of the course by being able to express their creativity and design identity. The CDIO standards are valuable tools for benchmarking and curriculum development (Rosén, Hermansson, Finnveden, and Edström, 2021). The refined CDIO Standards 3.0 compared to the earlier version includes sustainability, digitalization, services, and faculty competencies (Malmqvist, Edström & Rosén, 2020). These changes align with an evolving topic on engineering education as it involves other disciplines, like social sciences and architecture.

From the perspective of architecture-engineering, the integrative design process is a pedagogical technique that was tested in a Building renovation course. This course is a design course focusing on the three different areas of renovation: reuse renovation, restoration, and conservation of an existing or historical building. The objective of the course for the students is to work on an actual building by conducting an analysis of the given building both historically and culturally and determining its reuse value, and creating a proposal for sustainable reuse architecture with a new addition to the building. The project is conceived through integrative design. This study aimed to understand how design learners' integrative design process worked. The integrative design process employed the concept-test model, and it was hypothesized that an integrative design process boosts students' perceived control and positions their learning styles to a more open preference.

METHOD

The method of investigation relied on an online design process reporting tool which included subjective assessments. Additionally, course results were added for further analysis.

Participants

Altogether, there were 59 participants out of 68 students in the second-year bachelor's program in architecture engineering. The majority were female (n=42, 71%). Participants were rewarded with two extra points in their project examination when they fulfilled the minimum of 15 data inputs (three on each of the five tasks). This way, the study rewarded 39 students with 5% of the total score on the project examination.

Data collection instruments

The Design Process Reporting Tool (DIEGO) was a quick online questionnaire that recorded items such as hours spent on tasks, level of enjoyment, appraisal of the task's difficulty, perceived openness, control over the task performance, and perceived helpfulness of the peer. The subjective assessments were recorded on a five-point Likert scale (Strongly disagree to Strongly agree), except for the enjoyment (seven-point Likert scale). Furthermore, the questionnaire included an informed consent which the participant had to accept each time and identify themselves with their email address. After reviewing the input data, n=951 reported cases were kept in the database for investigation.

Procedure

The course of Building renovation at the University of Jönköping, Department of Construction Engineering, five specific tasks were given and followed up. The students were introduced to DIEGO and the reward system during a lecture. They were asked to visit the reporting tool at least fifteen times during the group design exercise and record their answers at least three times in each design task (Conceptualization with a mood board, Volume study, Floor-plans, Work in progress, and Poster).

Task one involved an initial research stage about the given historical building and renovation project area. The students worked in a group of two and had to gather information about historical and cultural values and then write a program and put together a mood board showing the initial design concept and program requirements. The objective of task two was to follow the design process and frame and reframe the initial ideas while creating a site plan and volume study sketches for the project. This task also included a written report on historical constructions and materials. Students were required to elaborate on the concept and match the floorplans and facades in task three. These drawings had to be in scale and as presentation drawings submitted for review and criticism. The fourth task involved presenting and submitting the work in progress of specific illustration drawings and written reports, including site plans, floorplans, sections, elevations, renderings, and mood boards. All the drawings had to be in scale. A summarized architectural poster was made to communicate the students' overall and final ideas in task five.

Data Analysis

The raw input data of DIEGO responses is visualized on a time axis, showing the clusters and overlappings of the five tasks. Participants' data (including the course result) were further organized, and mean values of visits, hours spent, enjoyment, openness, perceived difficulty, control, and peer helpfulness were calculated task-wise. Parametric statistical differences and correlations were explored using SPSS 27 and MS Excel.

An individual scattergram shows the perceived openness and control in a quadrant format. This scattergram builts upon an earlier investigation by Fischl *et al.* (2018), Fischl & Wännström-Lidh (2020) and Fischl & Erlandsson (2021). The openness relates to the perception of the undefined-defined project form, while the control measures relate to the perceived control one feels over the actual task. The corresponding first quadrant is the *Comfortable zone*, wherein students perceive low control and a more defined task. This zone is adequate for external demands and external support for completing a task. The second quadrant is the *Uncomfortable zone,* and the students perceive an open task with a lack of control. This combination may result in helplessness or frustration. The third quadrant is the *Performative zone.* Students are driven, quantity oriented, and able to produce results. However, the qualitative component of the task is lacking. Finally, the fourth quadrant is called the *Creative zone* because this quadrant is well desired; it combines perceived control with preference to open tasks.

RESULTS

The study followed a group design exercise to understand how students perceive their integrative design process. On average, participants (n=59) visited 14,69 (SD=6,56) times the DIEGO tool and reported 77,69 (SD=44,95) hours for the five tasks. The distribution of task hours across the course span is shown in Figure 1. The values over 15 hours might be several days of combined working hours registered instead of a single-day activity. The task-specific hours are increasing as the design exercise gets more complex. The reported hours are the highest for the Work in progress task ($T4_N$=51; $T4_{mean}$=31,43; $T4_{SD}$=17,71) , which indicates that in the design process, this is where most of the design iterations are done. The second-highest hours are reported for the poster presentation ($T5_N$=51; $T5_{mean}$=23,3; $T5_{SD}$=16,95), and it is somewhat an interesting finding since this much attention was not supposed to be given to a task that is a compilation of the earlier results. The least hours are stated for the concept with mood board ($T1_N$=55; $T1_{mean}$=9,58; $T1_{SD}$=1,59), volume study ($T2_N$=50; $T2_{mean}$=12,02; $T2_{SD}$=6,95) and floor plans ($T3_N$=53; $T3_{mean}$=15,49; $T3_{SD}$=9,04). The performative impetus of the students may explain this finding. In the beginning, the students are unfamiliar with the integrative design process, and therefore, they do not pay much attention to a well-developed concept with the corresponding mood board. Furthermore, they do not understand the importance of a volume study, as it is often seen as an unnecessary task submission, which hinders them from focusing on the floor plans' main issue, such as functionality. This *performative tunnel vision* may be one of the main issues in our integrative design process development. By spending more task hours on understanding the qualitative aspects of a design exercise, the quantitative perspective on task accomplishment has to be rejected. The distribution of hours invested in each task is reported in Figure 2.

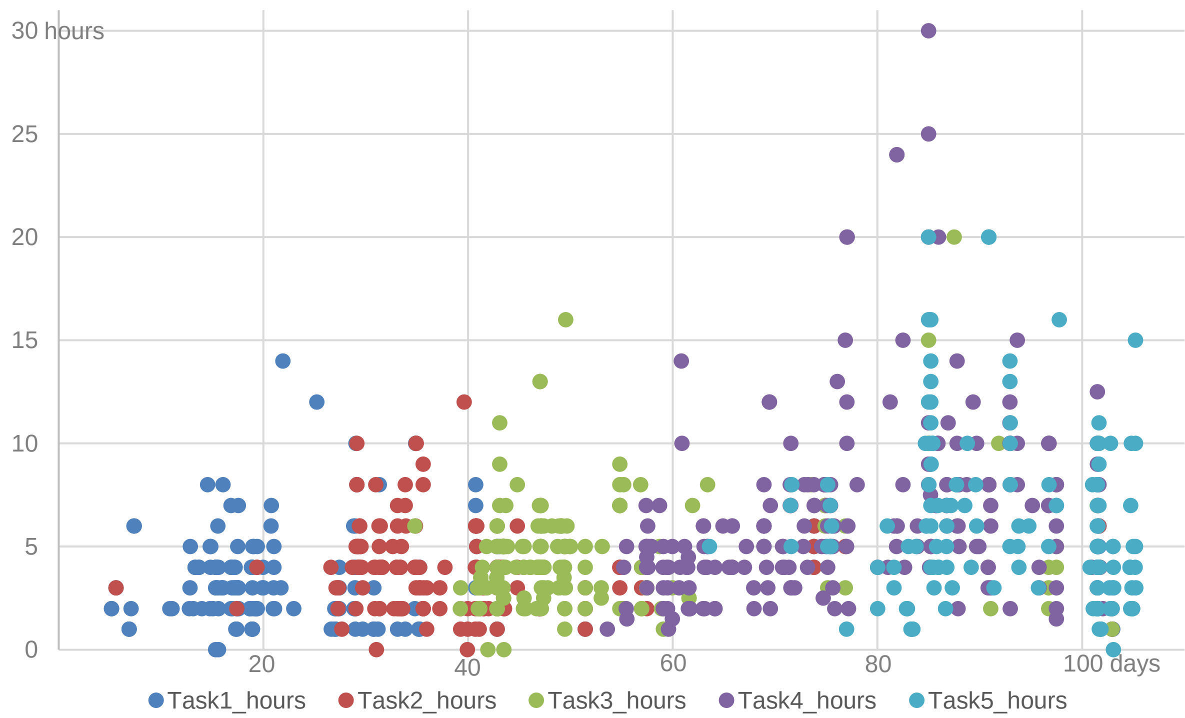

Figure 1. Scattergram of task hours reported (n=951) (Task1=Concept with moodboards, Task2=Volume study, Task3=Floor-plans, Task4=Work in progress, Task5=Poster).

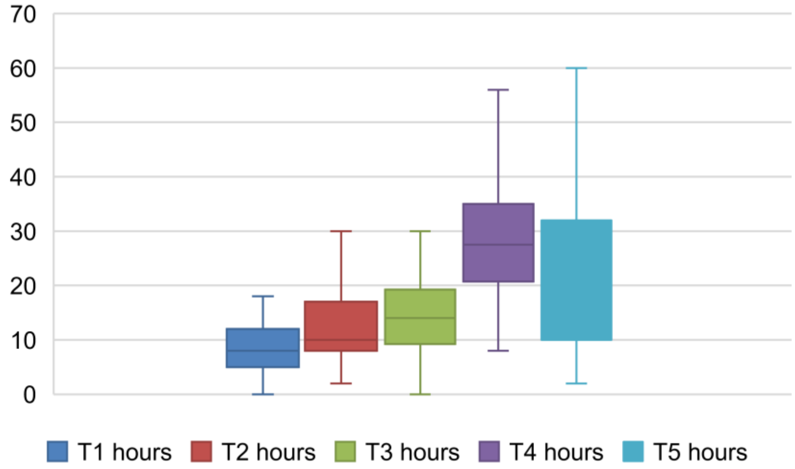

Figure 2. The minimum, maximum and the median hours reported for each task (T1=Concept with mood boards, T2=Volume study, T3=Floor-plans, T4=Work in progress, T5=Poster).

It was hypothesized that an integrative design process boost students' perceived control and positions learning styles to a more open preference. The mean values of perceived control and openness are presented for the participants in Figure 3. This shows that most of the students could find the creative zone during the group design exercises; however, one-third (n=17) of the student group failed to position themselves clearly in this zone.

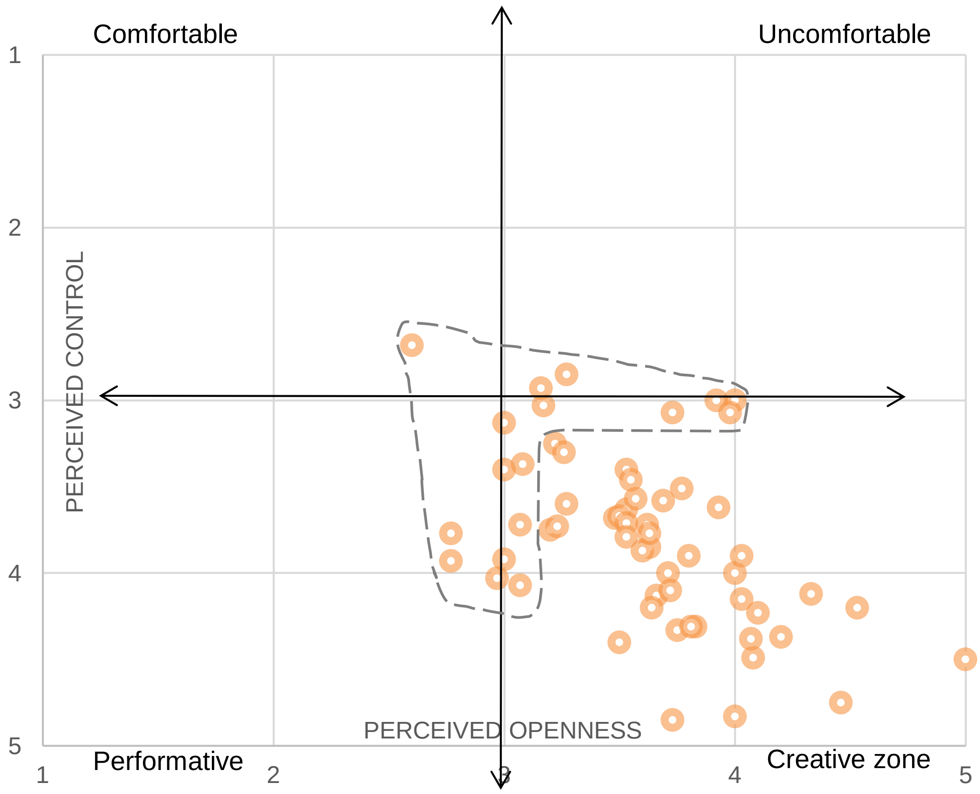

Figure 3. The participants' individual scattergram (n=59) on the perceived openness and control concerning the overall mean task performances. Note: The openness and control neutral position is located at the mean level of 3 (Control>3 more internal, control<3 more external). The project definition axis is at a neutral position (3) due to its 5-point scale (1=More open to 5=More closed).

A closer inspection of the tasks reveals how the perceived control and openness propagates throughout the project phases (Figure 4). The clusters show variation across the quadrants and display the most dispersed image for Work in progress (T4). Meanwhile, the most concentrated position for the Creative zone was the Concept development (T1). The finding for T1 seemingly contradicts the previous explanation of performative tunnel vision. This task required the least effort ($T1_{N}$=52; $T1_{Mean}$=2,99 ; $T1_{SD}$=0,63) and was perceived as the most enjoyable ($T1_{N}$=56; $T1_{Mean}$=5,57; $T1_{SD}$=1,02). It is probably because the students had not investigated many alternative concepts and mood boards; instead, they were satisfied with the first solution. Later on, this lack of exploration resulted in task confusion for T3 (Floor-plan) and T4 (Work in progress) when the concept did not match the produced drawings.

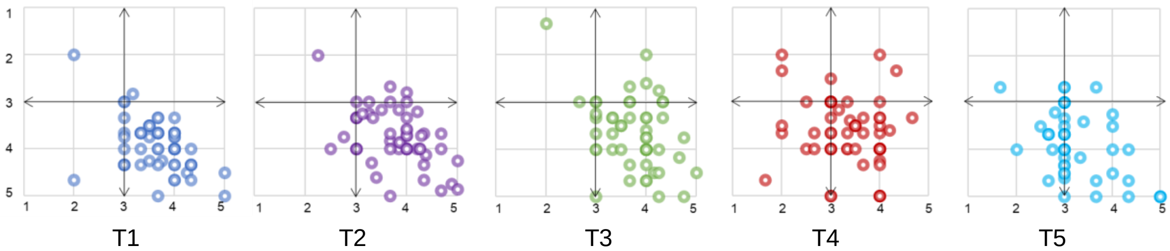

Figure 4. The variation of perceived openness and control during the different tasks (N=59; T1=Concept with mood boards, T2=Volume study, T3=Floor-plans, T4=Work in progress, T5=Poster). Note: The openness and control neutral position is located at the mean level of 3 (Control>3 more internal, control<3 more external). The project definition axis is at a neutral position (3), due to its 5-point scale (1=More open to 5=More closed).

Pearson correlation was performed between enjoyment, effort, openness, control, and groupmate ratings. The most correlation was found for groupmate rating, suggesting that satisfaction with a well-performing peer has a moderate positive correlation to task enjoyment (r(57)=.45; p<.001), and slightly negatively correlation to effort (r(57)=-.32; p<.05) exerted. In terms of openness (r(57)=.35; p<.05) and perceived control (r(57)=.34; p<.05), groupmates were slightly positively correlated. Thus, the more open and controllable the task seemed, the higher the groupmate's rating was. It was also found that as the perception of control increased, the tasks were seen as more open (r(57)=.50; p<.001) and enjoyable (r(57)=.30; p<.05).

Finally, the different course grading levels are described by the mean values of the subjective assessments, the reported hours spent on the project, and the number of visits to account for these data (Table 1). The frequencies of the higher grades (4 or 5) indicate a successful course accomplishment, and only a minority could not pass the course. Interestingly, higher values for the number of visits, hours spent on the project, and the perceived level of enjoyment, effort, and openness were reported among those who failed. These values tend to decrease as higher grades are achieved, strengthening the assumption that getting a good grade in a design project cannot be obtained by overestimating one's effort, enjoyment, and openness of the project. On the contrary, these students struggled to retain control over the project complexities and appreciate their groupmates.

Table 1. Descriptive statistics of the final grades and the mean values of the number of visits and hours spent on the project, as well as the reported subjective assessments (Enjoyment, Effort, Openness, Control, and Groupmate evaluation)

	Failed	3	4	5
N	4	7	13	35
Visits	16,75	15,14	14,38	14,49
Hours	124,50	84,43	76,73	71,34
Enjoyment	5,84	5,16	5,24	5,17
Effort	3,91	3,35	3,52	3,29
Openness	3,82	3,60	3,62	3,58
Control	3,67	3,69	3,72	3,86
Groupmate	3,89	4,32	4,54	4,49

Note: The subjective assessments are rated on a 5-point Likert scale (1=Strongly disagree, 5=Strongly agree), except for Enjoyment (1=Not at all, 7=Very much). The mean values are presented for the number of occasions (Visits) for reporting data and invested Hours in the project.

DISCUSSION

This study used the Design Process Reporting Tool (DIEGO) for collecting relevant information about the subjective appraisal of personal control and perceived project openness. The study aimed to understand how design learners' integrative design process worked.

An integrative design process as a pedagogical approach to project-based learning was introduced to the Building renovation course. The main distinction between integrated and integrative design approaches is how the disciplines work together to achieve the goal of a building project. By linking the integrative design process to the concept-test design model that has an origin in the reflection-in-action practice, using framing and reframing discourse between the design learners and the practitioners, the cyclical design process is promoted. Interpretation of the results for task distributions on the timeline shows overlaps and frequent revisits between the different tasks. Although the reflection-in-action method was new to the students, and many of them seemed not to comprehend the design practitioners' discourse at first, they slowly learned to see the freedom and creativity within the ever-increasing complexity. The students' learning process produced this complexity as they encountered design details connected to neighboring disciplines. The key to a successful design project was to develop an integrative and flexible concept for incorporating multiple objectives while being visionary. From an initial performative tunnel vision that narrowed down the design opportunities, two-thirds of the students were able to rebound. In the visualization of the control and openness quadrants, the students' positions showed when they were in a comfortable-uncomfortable, performative and creative phase. It was hypothesized that an integrative design process boosts students' perceived control and positions their learning styles to a more open preference. The hypothesis was accepted when two-thirds of the students became in the creative position of the openness-control quadrant. Further analysis could reveal each individual's journey during the course, and tailored discussion might take place for a deeper assessment. However, personalized feedback and discussions are common in the architecture discipline; it is less appreciated among architectural engineering students.

Overall, the correlations between the subjective assessments revealed that a well-performing peer is essential to the project's success. Not only because the peer supports, moderates, and is a source of project enjoyment, but because the peer helps in the reflection-in-action design process and contributes to additional discourse. The discourse-based cyclical design processes are the fundamentals of the concept-test model and for an integrative design approach. In a dysfunctional group, students report more project hours and overestimate the freedom they might possess. These can lead to a false sense of mastery of the project, being overtly positive and, in the meantime, concluding that the project cannot live up to the expectations. Consequently, the student may lose interest in the design process, start blaming the circumstances and try to find a scapegoat.

Methodologically, this study showed a promising way of encouraging students to participate in evaluating one's own design processes. The high response rate and follow-through in the administration of the questionnaire showed engagement and interest from the students. The inbuilt reward mechanism was attractive enough to maintain this behavior.

CONCLUSION

This study employed the Design Process Reporting Tool (DIEGO) to gain insight into the integrative design process. The results showed high engagement from the students and revealed the bottleneck of this integrative design process. Namely, students need to focus more on the concept building and preparatory work before starting with the floor plans because there will be more confusion and uncomfortable experiences. Gaining control and understanding of an open or undefined project would ease the performance tunnel vision that is predominantly quantitative and does not support creativity. Modifications were made during the design process to rebound from this problem. To further emphasize the concept-test model characteristics of the integrative design process, the first two tasks must be more iterative or cyclical to give rise to an analytic activity enhanced with intuitive leaps. The hypothesis that an integrative design process boosts students' perceived control and positions learning styles to a more open preference was proven true for two-thirds of the participants.

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7 YEAR ITERATIVE IMPROVEMENTS IN LABORATORY WORK - CONSTRUCTIVE ALIGNMENT

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ABSTRACT

Most agree that laboratory work is essential for engineering learning. The purpose of laboratory work is usually to the deepen understanding of the material and/or to prepare students for the workforce. However, having well thought out experiments certainly does not guarantee that those goals are met. In order to meet those goals constructive alignment is of utmost importance. Having appropriate learning outcomes, appropriate assignments corresponding to the laboratory work and having it aligned to coverage in lectures is crucial to reach constructive alignment. Having an appropriate group size in the laboratory work is also vital. The group size needs to fit the number of tasks in each experiment but also to fit the assignment format to ensure active engagement of all members. This paper presents an experiment on improving laboratory work component of an undergraduate Fluid Mechanics course in Mechanical and Chemical Engineering at University of Iceland. The experiment spans the years from 2015 to 2021, where several adjustments in the laboratory were tested. The measurements tools include i) midterm and ii) end of term student teaching quality surveys with Likert scale questions and open-ended replies, iii) a survey specially made by the author to target the laboratory work (with Likert scale questions and open-ended replies) and iv) a focus group interview on the same subject. The experiment sparked because a large portion of students complained that the workload of the laboratory work was immense and in no correlation to the ECTS units given for the course. This turned out to be a valid point. More seriously students also complained that they did not see the purpose of the laboratory work and that they learned nothing from it. By making adjustments to the alignment of material coverage and laboratory work, by reducing idle time in the laboratory, by adjusting the laboratory work assignment, by making sure the group size was manageable and more significant improvements were seen in reduced student workload perception, student perceived learning, student enjoyment of the laboratory and students saw the purpose of the laboratory. Since workload perception may differ from actual workload it may be assumed that with better structure and learning, workload perception was reduced with the same learning objectives. Some of those results have been published in two papers in the journal International Journal of Engineering Education but this paper emphasizes the newest developments since their publications and more detailed cumulative analysis.

KEYWORDS

Laboratory Work, Formative Assessment, Assignments, Group work, Constructive alignment, Standards: 1, 2, 3, 6, 7, 8, 10, 11, 12.

INTRODUCTION

The laboratory work in an undergraduate Fluid Mechanics course in Mechanical and Chemical Engineering at the University of Iceland had been the same for decades when the author of this paper started teaching the course. She initially just taught the course as traditionally done but heard students complain about immense workload and not seeing the purpose of the laboratory work. This surprised her since she considered the laboratory work crucial to help students gain deeper understanding and intuition on Fluid Mechanics. Simultaneously she was being introduced to student centered learning and the vast literature on scholarship of teaching of learning, so she was determined to find the reason for this mismatch in instructor's intensions and students experience and fix it all. Little did she know that 7 years later that journey was still ongoing. This paper shortly discusses this journey with the emphasis on the newest improvements.

LITERATURE REVIEW

Laboratory work is considered essential for engineering studies (Feisel & Rose, 2005) as by doing properly designed hands-on experimentation students learning is aided (Buntine et al., 2007). Constructive alignment i.e., having appropriate learning outcomes, assessment that supports learning and learning activities that support learning, is essential for learning to occur (Biggs, 1996). The purpose of laboratory work is either to support learning or prepare students for working in the industry or in many cases covers both aims. Where the purpose is to aid learning (as is in this case) it is of utmost importance that the laboratory work is linked with the coverage of material in the course (Hunsu, Abdul, Wie, O. Adesope, & Brown, 2015). If it does not, then the learning activity of laboratory work is ill fit to support learning.

Lack of alignment in material coverage in a course and in its laboratory work is common. This is due to logistical reasons i.e., laboratory equipment is expensive meaning few or only one set of each is available, and laboratory work requires more time involvement of instructors and lab technicians than other forms of learning, meaning laboratory hours are limited and difficult to fit into an already packed schedule. Most deal with this lack of alignment by having thorough laboratory instructions (Lal et al., 2020; Nikolic, Ritz, Vial, Ros, & Stirling, 2014) but many experience that they are useful but insufficient (Helgadottir, Palsson, & Geirsdottir, 2022). Whittle and Bickerdike (2015) used online multimedia sources followed by quizzes, Cranston and Lock (2012) use three plenary minilectures during the laboratory session and Rodgers et al. (2020) use 6-9 minute videos to successfully prepare students for laboratory work on material not covered yet in lectures. However, it must be best, if possible, that students have been acquainted with the material beforehand and those preparation videos can rather be used as a further support for students. COVID-19 has sped up some technological improvements in teaching and now videos have become the new norm. Chew et al. (2021) report making 450 short videos to prepare students for laboratory work with good success. 80% of students were pleased with this format. This was done to make up for school closures due to COVID-19, but post COVID-19 could be used to supplement onsite laboratory work and particularly to aid preparation for students for laboratory work.

Usually, laboratory reports are the assignment formats due after each laboratory session, however, homework (Hunsu, Abdul, van Wie, Adesope, & Brown, 2015), quizzes or assignments (Kresta, 1998) based on experiments, real time visual comparison of students' results and results from other students (Cranston & Lock, 2012), oral presentations (Grant, 1995), blogging (Hicks, Bruner, & Kaya, 2017), turning in single sections of lab reports (Heslop, 2017), synopsis reports (Hoffa & Freeman, 2007) and portfolios (Chen, DeMara, Salehi, & Hartshorne, 2018), have been reported in the literature. Mastering report writing is essential for graduating engineering students but their learning in field of the laboratory work is not increased by writing a report on it rather than completing other well thought out assignments forms (Helgadottir, Palsson, & Geirsdottir, 2020).

Manageable workload is crucial for students to be able to acquire the material covered in a course (Entwistle, 2009; Kember, 2004). Workload prediction is complicated but a well-studied field (Chamber, 1992), with the exception that there is a gap in the literature when it comes to workload in laboratory work. One can assume though that most alternative assignment formats to report writing reduce the workload of students (Chen et al., 2018; Heslop, 2017; Hoffa & Freeman, 2007). Workload perception is not necessary the same as actual workload even though having time is crucial for feeling manageable workload (Chamber, 1992; Prosser & Trigwell, 1999). Other factors like well-structured courses, students being able to ask questions, examples students can relate to, even workload, and more have shown to lead to students experiencing lower workload even though the time they spend on the course might be higher.

METHOD

Student teaching evaluation surveys are used at University of Iceland both midterm (formative) and end of term (summative for administrators, promotions and tenure and formative to improve the course next year). The multiple Likert scale questions there are not tailored to the laboratory work which is only part of the course so only the open-ended replies in those surveys have turned out to be useful in exploring the effects of making changes in the laboratory work of the course. Students tend to only address what they are particularly pleased or dissatisfied with in open-ended replies so those give an indication of what brings up strong emotion among students. More detailed answers are only achievable by asking them specifically which is why in 2015-2021 (apart from 2020 since COVID-19 restrictions greatly affected laboratory work) the author of this paper made a special laboratory work focused survey for students. The number of students in the course in each year varied from 29 to 76 with 43 being the average. The participation in the laboratory focused survey varied from 40.8% to 61.1% during that time. In 2018 to get more detailed analysis a one-time five student focus group interview was held and analyzed with a thematic approach, which results confirm other results but will not be presented in detail here. In this paper the results of the laboratory work focused survey of all years is combined getting a more detailed analysis of the effects of each change in the laboratory and significantly more replies than results only based on each year. The focus is also on new additions in 2021. The interested reader is pointed to Helgadottir et al. (2020) for more detailed analysis, year by year, of the effects of different assignment format used in 2014-2018 and pointed to (Helgadottir et al., 2022) for more detailed analysis, year by year, of the alignment of lecture and laboratory work in 2014-2019.

A list of how the laboratory work was in each year is given in Figure 1. To explain, 2015 represents previous setup but 2016 and later altered setup, with the exception that in 2020 due to COVID-19 restrictions the laboratory was altered so much it is not considered beneficial to include the results in this study. In the old schedule 5 sessions, each 3 hour long were held every week in October (so starting in week 6 or 7 of a 14-week semester). Five groups worked concurrently, each on separate experiments, rotating each week. Students often worked on experiment covering material that had not been introduced in lecture beforehand. Online PDF instructions were, however, available. In the new set up 6 sessions were held, each 1 hour long, only one group at a time meaning idle time waiting for instructor to assist was eliminated. This meant the content of the experiments was not reduced in the new schedule. All groups worked on the same experiment in the same week that was 1-2 weeks after coverage of the material connected to the experiment in lecture. This meant students had been familiarized with the material before working on an assignment based upon it as is crucial for constructive alignment as is known to be essential to support learning (Biggs, 1996). This also meant the experiments were not evenly distributed during the semester but rather in weeks 3, 4, 9, 10, 11 and 12 of a 14-week semester. In the new laboratory schedule adding a new group means adding one hour to the time the laboratory technician and instructor need to be present. In the new schedule the time needed for laboratory instructions, therefore, fluctuates more with enrollment. Making sure the number of students in each group fits tasks in experiment and is appropriate for the assignment due after each experiment, is essential for student learning.

2015	2016	2017	2018	2019	2020	2021
5 sessions	6 sessions	6 sessions	6 sessions	6 sessions	Not in this study included due to COVID-19 restriction effects	6 sessions
3 h each	1 h each	1 h each	1 h each	1 h each		1 h each
Each group working on separate exp. per session	All groups work-ing on the same exp. in the same week	All groups work-ing on the same exp. in the same week	All groups work-ing on the same exp. in the same week	All groups work-ing on the same exp. in the same week		All groups work-ing on the same exp. in the same week
5 groups working concurrently	1 group working at a time	1 group working at a time	1 group working at a time	1 group working at a time		1 group working at a time
Timing of exp. not linked to coverage in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture	Exp. 1-2 weeks after coverage of material in lecture		Exp. 1-2 weeks after coverage of material in lecture
		Postlab	Postlab	Postlab		Postlab
Reports	Worksheets, 1 report	Short reports	Excel sheets	Excel sheets		Excel sheets
				Reflective questions		Reflective questions
						Preparation and postprocessing videos

Figure 1. Summary of the arrangement in laboratory work in each year.

A few changes were made after the initial changes in 2016. A postlab discussion was added in 2017 and later, where the results of all groups were compared in a lecture following each experiment. This meant constructive alignment was further improved and by adding discussion and reflection, so students' learning was likely to be deepened (McKeachie & Svinicki, 2014). Reflective questions were added to the postprocessing in 2019 and later to further push students to the higher level of thinking according to Blooms taxonomy (Bloom, 1989). The search for the most fitting assignment output for analyzing the results has led us from full reports (2015) to worksheets (2016), to short reports (2017), to Excel sheets (2018 and later). The full reports were traditional laboratory reports. The worksheets had the same contents as the lab reports without the continuous text i.e., it was premade by instructor with blanks for students to fill in. The short reports put the focus on analysis of results, but other traditional laboratory chapters could be incomplete. The excel sheet was premade by instructors, students filled in their results and special emphasis was on analysis. This made it easy for instructors to write a Python code that automatically compared the results of all groups and did statistical analysis of their results. This was essential to efficiently prepare the postlab discussions previously mentioned. In 2021 at most 4-minute-long preparation videos for each laboratory session were added to Canvas as additional laboratory preparation for those that considered the laboratory PDF instructions insufficient. In addition, at most 2-minute-long videos on postprocessing of each experiment were added to supplement the previously mentioned laboratory instructions.

RESULTS AND DISCUSSION

Overall results 2015 – 2021 combined

The estimated time students needed to spend on the course in the previous format was 180 hours before the change in the laboratory work and 170 after the change (Sigurdsson, 2011). A 6 ECTS unit course, as Fluid Mechanics is, should be between 150 and 180 hours of work for students. It was, therefore, before the change right on the maximum limit but below it after the change. This is reflected in students' perception of workload. Before the change 28% of students considered the workload too much, 44% a lot and 28% just right. After the change in 2016 17% considered it too much but also only 17% considered it just right, the rest considered it a lot. The change in setup, therefore, reduced the number of students that considered it too much but also those that considered it just right. This turned out to be because the worksheets were considered too time consuming. So, the reduced attendance requirement which should have led to lower workload did not lead to an overall workload reduction in the laboratory work because the worksheets surprisingly took longer to complete than full laboratory reports. In all the following years the percentage of students considering the workload fitting ranged from 64 – 87% and even a few students reported it being low. The new schedule, therefore, is experienced as appropriate workload for students. Students in 2018, 2019 and 2021 were asked how much time it took them to complete each Excel sheet and on average it took them less than 2 hours.

Before the change students wanted to spread experiments more evenly over the semester and few realized aligning them with lectures was beneficial. Many wanted a numerical project, i.e. computational simulations of flow, instead of experiments since they did not see its purpose. After the change (in total 103 replies) over 93% of students prefer the new schedule, less than 3% would like some other form with alignment of lectures and laboratory, and less than 4% of students mention some other schedule without alignment but rather having the laboratory work more evenly spread out over the semester. After the change, no student suggested numerical work instead of laboratory work, indicating that they now see its purpose. I believe the reason all students realized the purpose of the laboratory work after the alignment, but some did not before the alignment, is because now students had learned about the material in class prior to the experiment and could, therefore, relate to it. Prior to the alignment they just followed a recipe, often without understanding, making it hard for them to fully grasp the purpose of the laboratory. In the focus group students particularly mentioned that they felt they learned more from this set up rather than laboratory work in other courses where this alignment was missing.

Using two sided Welch t-test (Derrick, Toher, & White, 2016) it can be stated with 5% certainty that students report learning more in 2016 than 2015 and more in 2017 than in any other year. They also enjoyed the laboratory work more in the improved laboratory schedule than previously except for 2016 when the worksheets were too time consuming. When asked if they learned from the assignment format there is not any statistical significance between the replies in all years even though the assignment formats altered significantly. Students in 2018, 2019 and 2021 were asked if they believed they learned more Fluid Mechanics from the Excel sheets than writing a report and they moderately agreed (3,29 on a 5-point Likert scale with sample variance 1,03). It can, therefore, be stated that the new schedule is an improvement and preferred by students. However, the assignment format has little impact on how much students perceive learning but does impact how much workload they perceive and how much they enjoy the laboratory work.

The assignment format also impacts how easily the instructor can compare the results of all groups which is essential for a successful postlab discussion. After the postlab discussion was added (in total 92 reply) students reported learning from the combined analysis of all groups and discussion i.e., it received 3.97 with a sample variance 0.8 on a 5-point Likert scale. The students in 2019 and 2021 (in total 47 answers) very much agreed to learn from the thought-provoking reflections for each experiment (Likert score 4.53 out of 5 with standard variance 0.34) and enjoying them (Likert score 4,06 out of 5 with standard variance 0,76).

Taking the average over all years (total 136 replies) of the number of students they consider ideal in a group is 3.87 which is consistent with the number of tasks in the experiment and with the consensus in the literature of an ideal group size between 3 and 4. Being able to make sure the group sizes don't exceed this is sometimes challenging but essential for student learning.

In addition to the quantitative data presented here numerous open-ended replies support that the changes in the laboratory work were significant improvements to students experience and learning.

To emphasize, constructive alignment is achieved by having learning outcomes that fit the course and the curriculum, assessment that supports learning, and learning activities that support learning. In this paper the learning outcomes of the laboratory work are not covered, but they have been scrutinized. The assignments of the laboratory work were also iterated to better support learning as explained above and in detail by Helgadottir et al. (2020). The largest gap needed to be bridged to reach constructive alignment in the course, however, was to make sure that the learning activities of the laboratory work supported learning of the material covered in the course. When students had not learned about the material before participating in an experiment (as in the previous set up) then the laboratory work did not support their learning and a learning opportunity was missed. When they had been familiarized with the material the laboratory work covered then, contrary to previously, the laboratory work further enhanced their learning. The postlab discussions were an additional learning activity that further supported their learning on the material covered in each experiment by digging deeper and giving them a different perspective. Therefore, aligning the coverage in lecture and the laboratory work schedule was essential to make the learning activity, i.e. laboratory work, support learning, and therefore crucial for reaching constructive alignment.

Analysis of additional developments in 2021

In 2021 short preparation videos for the laboratory work and analysis were added to the PDF instructions over 74% of students in 2021 felt the preparation videos for the laboratory work were very useful, just over 16% found it rather useful and less than 10% were neutral. No student did agree with finding it not useful. In 2021, just over 45% of students found the videos explaining the analysis of the results very helpful, 35.5% rather helpful, just over 16% were neutral and just over 3% found them rather useless. Students were also asked if the online

PDF instructions were useful. Over 45% strongly agreed, over 45% rather agreed, 6.5% were neutral and just over 3% found them rather useless.

The focus group of 2018 said one of the benefits of the laboratory was that the instructor was present during the laboratory work. They said this was because then the link between lectures and laboratory work was stronger and, therefore, their learning. In 2021 due to a significant increase in number of students (the total hours of the laboratory were 96 hours) the instructor did not attend the laboratory work but rather an excellent teaching assistant. Students were asked if they thought it would have been better if the instructor had attended the laboratory work and 2/3 of students either strongly or moderately agreed with this statement even though over 80% of all students found the teaching assistant either very or moderately helpful. Having an instructor rather than a teaching assistant attend laboratory work is uncommon so this is an issue that needs to be further investigated in the literature.

LIMITATIONS AND FUTURE DEVELOPMENTS

The main limitation of this study is that even though this study covers many years the total number of students is rather low, it has not been applied to other courses, the statistical analysis is basic and learning and workload measures are based on students' perceptions rather than concrete measures. Despite this it is a solid foundation for future research on this subject.

Shibl, Anwar, Wegdan Wagdi, and Ali (2020) describe how they use the CDIO approach to alter laboratory in Fluid Mechanics to enhance learning. In the future it would be interesting to make similar adjustments to this laboratory work component and rigorously measure its effects and compare to the previously acquired data.

As brilliantly suggested by one of the reviewers it would be beneficial learning experience for students to let them prepare their own worksheets. Then they would need to think about what would be the clearest way to present the material for a user and that would push them to a higher level of learning according to Bloom's taxonomy (Bloom, 1989). This would, however, mean that the automatic extraction of data using the python code script to read the Excel sheets, which was essential to make preparation of the postlab sessions fast and efficient, would fail and the preparation would become much more time consuming. However, a middle ground could be found i.e., letting students prepare their own worksheets for some of the experiments and giving them standardized forms for other experiments. Thus, a balance in workload of the teacher and challenging students could be reached.

CONCLUSION

In this paper a 7-year long journey of improving a laboratory work section of a course and monitoring its effects, is analyzed. Teachers experienced that students felt the laboratory work component too time consuming, that their learning was minimal and undervalued its purpose. By minimizing workload yet maintaining the similar tasks and learning outcomes and analyzing the course with respect to constructive alignment, students' perception of the course shifted significantly. Now the workload was acceptable, their learning was increased, they realized the laboratory work's purpose and even enjoyed it. In the coming years it would be interesting to explore with letting students make some of their own worksheets to push them to a higher level of learning. This would require finding ways to make the postlab preparation less time consuming for the instructor despite the worksheets differing from group to group.

This paper shows clearly how using ideas from the literature on constructive alignment can improve student perception of workload and learning. By doing so their satisfaction is improved and they gain insight on purpose of laboratory work. This paper also demonstrates how rewarding even small improvements in teaching can be for students and teachers. It, however, also demonstrates that improvements in teaching are (and should be!) a never-ending story.

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GRADING HOMEWORK AS FORMATIVE ASSIGNMENTS – THE SOLUTION TO CHEATING?

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ABSTRACT

Homework assignments are common assessment tools used to assist learning in Engineering. Since they are meant to assist students in acquiring the material presented, they should be considered formative assessments with no grade given. Student's engagement in homework assignments is time consuming (as real learning is) so students want to be rewarded for their effort i.e., they want their homework assignments to count towards their final grade in the course. This, however, increases the stakes for students making it more tempting to cheat if the problems turn out to be too difficult or if students run out of time. If students split tasks and mindlessly copy one others' solution, copy some solution manual, or buy a solved solution form such service e.g., Chegg, the learning goal of the homework is however not met. A perfect solution that does not originate from the student contributes to much less learning than a not completely perfect solution from the student's own effort. The learning process comes from the effort and being given timely feedback to correct all misconceptions. The author of this paper therefore in 2016 stopped giving a grade for homework in two bachelor's degree courses and gave only a feedback. Just by turning in the homework students get a full score for their effort. By doing so the incentive to cheat has been eliminated and students are rewarded for their effort. To evaluate the effects of this change three sources of information are used: student teaching evaluation surveys, students' final grades and instructor's reflections. Students repeatedly state they like this approach and say it is often a breaking point in them deciding to work on the homework in those courses instead of other courses where the homework is harshly graded. Homework assignment solutions suspicious of cheating have also reduced significantly.

KEYWORDS

Homework, Formative Assessment, Reduce cheating, Standards: 1, 2, 3, 6, 7, 8, 10, 11.

INTRODUCTION

As common in undergraduate Engineering courses, in the Heat Transfer and Fluid Mechanics courses taught in Bachelor Degrees in Mechanical and Chemical Engineering at University of Iceland, there are weekly homework assignments throughout the semester. The purpose of homework is to train students in solving problems based on the course material and it is, therefore, important that they learn from their mistakes in order for them not to repeat their mistakes. To acknowledge that students put a lot of effort into those, they count 10% towards the final grade of the course. The author of this paper has always given a generous score for homework even though there were some errors or misconceptions because she believes it is important to encourage students to try even though they might not have mastered the material yet. She has always viewed the homework as formative assessment, and the grade as just compliments for their effort. But it was evident that students did not experience it in that way, only looked at the grade, missed an opportunity to learn from the feedback, and what worried her most was how many students seemed to be copying each other's solution or a solution manual. This paper discusses how making changes in grading the homework assignments can affect students learning, reduce cheating but also empower them in their learning.

LITERATURE REVIEW

Formative vs. Summative Assessment and the link to homework assignments

Feedback needs to be student and learning focused (Carless, 2015) and can be split into two categories: formative and summative (Rowntree, 1987). Summative assessment is meant to measure students' expertise in a certain field and rank them. Detailed feedback is not needed in summative assessment unless it is meant to justify the grade. Formative assessment, however, is meant to aid students in their learning (Rowntree, 1987). Therefore, in formative assessment the feedback is crucial. Giving a grade can hinder students in their learning since if they receive a grade and feedback they focus on the grade (Race & Pickford, 2007). They often neither fully understand the grade nor learn from the grade where they need to improve and how (Black & William, 2001). In addition since they do not focus on the feedback they miss an opportunity to learn from it (D. Nicol & Macfarlane, 2006). No teacher wants students to be too fixated on the score itself. Neither do teachers want students to be shy to try to work on the problems even though they might not have fully mastered the material yet. Formative feedback supports students learning most if it is fast, personal, directed to each student's needs, understandable to students, concise and in a format that fits students best (Rowntree, 1987). One cannot stress enough the importance of giving feedback while the material is fresh in students' memory. It helps students to realize themselves at what level their learning currently is, and that ability is of great importance for future learning development (D. J. Nicol & Macfarlane-Dick, 2006). Formative assessments works particularly well for learning because students realize they can improve if they put in the effort (Entwistle, 2009). It, therefore, also works especially well for those students that are less academically strong.

Not distinguishing between formative and summative assessment is very common both among faculty and students, leading both to that instructor gives detailed feedback on summative assignments and students not realizing that formative assignments are meant to learn from to improve on next similar assignment or the final exam of the course. When the author of this paper started teaching with no pedagogical training, she did not make the distinction between formative and summative assessment meaning a lot of unnecessary effort on feedback on summative assessments. So, she could have saved herself and her students a lot of effort and frustration by emphasizing the difference between formative and summative assessment both in her actions and actively talking to students about it (D. J. Nicol & Macfarlane-Dick, 2006).

Regular homework traditionally used in many Engineering, Science and Mathematics courses is meant to help students master their learning, so it is expected that they have not mastered it yet when they start working on it. Working on homework has been associated with better outcome in a course (Trautwein, 2007) and engineering practices (Widmann, Shollenberger, & Kennedy, 2007). Since its purpose is to learn the author of this paper would argue that it calls for formative assessment meaning the feedback and not the grade are of utmost importance. Despite this, the author of this paper has not seen any study on the effects of homework only receiving formative feedback and no grade. Hugo and Brennan (2016) report giving no grade for homework in some courses but also likely no feedback since there is no mentioning of feedback. The author of this paper questions if that is the correct approach especially in light of Serrano, Blanco, Calerón, Gutierrez, and Serrano (2021) report on continuous assessment. There all students report wanting "some kind of evaluation", almost 87% want weekly problem sets to be evaluated and about 74% said they would not work on weekly assignments if they were not evaluated. Admittedly only 24 students were in the course. Formative quizzes have been used previously (Pick & Cole, 2021) leading to higher level of engagement by students, increased summative score and helped students to self-assess their knowledge. Pick and Cole (2021) further showed that failure to participate in one or more formative quiz was a good indicator for poor summative score. Yalcin and Kaw (2011) also showed that giving a grade for homework had no significant effect on students' final grade in a course but collecting multiple homework did. Lauritsen (2017) report that students like to get a lot of feedback but like personalized feedback even more.

Academic Misconduct

Academic misconduct has been an issue since the beginning of academic studies. Passow, Mayhew, Finelli, Harding, and Carpenter (2006) found out by surveying 643 engineering students in 11 universities that factors influencing cheating in homework differed from cheating in exams. Predicting homework cheating proved challenging but factor as students feeling personally responsible to report cheating and that the school had dishonesty policies reduced cheating on homework but thinking it was OK to cheat to relieve stress obviously increased the likelihood of cheating on homework. First year students also cheated less than second year students on homework. Alemayehu, Logan, and Barhorst (2015) explored ways to assess homework to reduce cheating by seeking solutions from 10 colleagues and then trying those changes in a 3 yearlong study. Their colleagues' suggestions included some obvious suggestions like not using the same problems year after year, use problems form a book with no solution manual, make their own problems from scratch, make problems with multiple solutions, let the problems count less in their final grade and use quizzes. Their results show that by using this approach cheating was reduced to 46% which they say low in comparison to 90% reported elsewhere (Widmann & Shollenberger, 2006). The author of this paper finds the fact that 46% of students cheat to be completely unacceptable and is sure most instructors agree. What is striking is that there is no distinction made between formative and summative assessment in this study and not surprisingly one of their results is that even though they say homework assignments are meant to learn from their students did not view them in that way.

Ali, Sultan, and Aboelmaged (2021) did a bibliographic study on academic misconduct between 2000 and 2020. One of their foci was on contract cheating i.e., students outsourcing their assignments to others, which turns out to be a growing issue. In recent years filesharing websites have been on the rise leading to easier opportunities in contract cheating. Lancaster and Cotarlan (2021) explored the file sharing homework help site Chegg and came to the conclusions that it has exam-like questions which 85% are answered within a short while. They also show that between 2019 and 2020 the requests for answers in a five-month period (April to August) nearly doubled in five subjects within Science and Engineering. They claim Chegg solutions are used for cheating despite Chegg's (seemingly ineffective) honor code. Hill, Mason, and Dunn (2021) further confirm that conclusion showing that measures against contract cheating are far behind easy to find assignment help providers. Walsh et al. (2021) explored why students believed their peers cheated more while courses were forced to go online during COVID-19 and came to the conclusions that students' reasoning was more linked to assessment modality rather than the pandemic. Students are more likely to cheat if they believe their peers do. Walsh et al. conclude that stressing the importance of academic integrity with students and relieving pressure on students is essential. As mitigation solutions to contract cheating, stringent regulations (Bretag et al., 2019), exams rather than assignments (Harper, Bretag, & Rundle, 2021), applications of forensic techniques (Johnson & Davies, 2020) and possibly higher fines are also mentioned (Ali et al., 2021). Doerr (2021), however, claims that cheating is an inevitable resisting to testing and originates from inequal power relations. Based on Doerr's analysis it is hard to see how the mitigation solutions suggested above can be a realistic solution to contract cheating.

Student Evaluation of Teaching

Student evaluation surveys are a commonly used to improve teaching and for administrative purposes (Hammonds, Mariano, Ammons, & Chambers, 2017). Many tend to dismiss those because they do have shortcomings but countless research on those in the past several decades confirm that they can provide valuable information on teaching effectiveness (Darwin, 2012).

METHOD

Based on the suggestions in the literature the author of this paper decided that from Spring 2016 in two of the courses she teaches, Fluid Mechanics and Heat Transfer, to only give individual written feedback on homework, with the exception that in Fall 2021 the feedback was oral via Canvas Speedgrader. The feedback emphasizes what is good in that student's homework, what can be improved and how the student can improve it. The feedback is given no later than the day after the homework is due and the solutions to the homework are always available just as the deadline passes. Everyone that does an honest attempt to complete the homework receives a full score (not written on the homework). Completing 10 homework assignments in the courses (12-13 homework in total in each course), counts 10% in students' final grade in the course. The reminder of students' grade consists of in class problems (5%), midterms (10%), laboratory in Fluid Mechanics and computational project in Heat Transfer (15%) and a final exam (60%). The enrollment in each course varied from 29 to 76 students with 40 being the average number of students per course. In the first lecture of those courses, also written in the syllabus, the teacher explains this process and emphasizes that homework assignments grading is formative assessment meant for them to deepen their learning. The instructor tells them it is by no means mandatory to turn in homework but generally students that do so do better in the course. The instructor, also, emphasizes that students gain nothing from copying a solution: their grade will be the same no matter if their results are correct or not and they miss an opportunity to learn by trying to figure out the solution themselves.

To judge the effects of the changes there are three means, explained in detail in following subchapters:

1. Effects on students' exams and final grades
2. Author's own observations on students' learning and academic integrity
3. University wide students' teaching evaluation surveys
    a. Midterm – held in week 6 of a 14-week semester
    b. End of term – held in week 13 and 14 of a 14-week semester

Effects on students' exams and final grades

The effects of having homework only graded with individual feedback and not with a grade on students' final exam and final grade in the course was explored. This was done by looking at the final exam score and the final score in the course given in Fluid Mechanics 2014-2015 (homework graded) versus 2016-2021 (no grade only feedback) and in Heat Transfer 2015 (homework graded) versus 2016-2020 (no grade only feedback).

Author's own observations on students' learning and academic integrity

The author of this paper has been an academic staff member in Mechanical Engineering at University of Iceland since August 2014. During that time, she has taught multiple undergraduate and graduate courses either in teaching teams or entirely by herself. Prior to that she was a part time teacher in two graduate level courses at Reykjavik University and a Teaching Assistant in nine undergraduate courses at University of California Santa Barbara. In all those courses grading homework was one of her obligations, giving her a good overview of grading practices across three universities and over multiple years. In particular, she has been the primary grader in the courses in question, so she has had the opportunity to detect changes in homework solutions before and after the change in homework grading.

University wide students' teaching evaluation surveys

University of Iceland has two surveys for students to evaluate teaching in order to maintain quality of teaching. Information from those sources can give valuable information on the effects of homework assignment grading method. The first survey is the formative midterm teaching evaluation survey where only the course is graded from 0-10 and it has also open-ended replies. This is meant to make adjustments midterm to improve the current course. Then there is a summative end of term teaching evaluation survey with 24 5-point Likert scale questions, 15 of which are on the course, 9 are on the teacher, and also with open-ended replies. This survey is meant for improving the course next year and for administrative quality purposes.

None of the Likert scale questions address the homework directly and fluctuations in the Likert scale questions cannot be linked to changes in homework grading. However, analyzing the open-ended answers to the midterm and end of term teaching evaluation surveys of Fluid Mechanics 2014-2021 and Heat Transfer from 2015-2020 when the author of this paper taught the courses, the 24 comments were found addressing homework grading. Those were analyzed with a thematic approach (Creswell, 2014). It is worth mentioning that in Heat Transfer Spring 2016 and Fluid Mechanics Fall 2016 end of term teaching evaluation surveys the instructor specifically asked students to address this issue in the open-ended replies, resulting in particularly many replies addressing homework assignments in those surveys or in total 18 of the 24 replies addressing this issue.

RESULTS

Effects on Students' Exams and Final Grades

No obvious trend was detected in the final grades in the courses after the change in homework grading. The exam grades and final grades varied as does academic proficiency of different cohorts, but it was not statistically higher or lower before or after the change. It can, therefore, be assumed that having homework not graded but rather with only feedback does at least not hinder students in acquiring the material covered in those courses.

Author's Own Observations on Students' Learning and Academic Integrity

The author did not detect any major changes in academic proficiency of the homework solutions after the change in the grading. She did, however, observe that copying reduced after the change, but it did not vanish. There were still solutions that were suspicious of copying or students were at least working together on homework. Often it is hard to tell the difference between the two. Instructors obviously do not want them to copy since they learn nothing from that, but has shown benefits that they build learning communities (Lenning & Ebbers, 1999) and work together in the initial stages of their homework but should preferably finish their solution separately.

University Wide Students' Teaching Evaluation Surveys

23 positive comments were given in the student evaluation surveys on homework and only the following negative (translated form Icelandic by the author):

"I don't see the purpose of giving audio feedback, it would be more beneficial to have it visual inside the homework solution." (from the Fluid Mechanics midterm Fall 2021 survey)

The negative aspect of the feedback was therefore not on the feedback itself but rather on the media used to transfer the feedback.

In the positive feedback i.e., all the comments in the teaching evaluation surveys explicitly mentioning that they liked to get feedback instead of a grade for homework assignments, many just expressed that they were pleased with the setup without explaining why (5 comments). Others gave an explanation, and a few themes were detected: **usefulness – learn more** (8 comments), **speed of feedback** (2 comments), **encouraging/more likely to turn in the homework** (7 comments), **less pressure** (5 comments), **less cheating** (4 comments), **nice to get comments/not used to getting this detailed feedback** (4 comments). Several students made comments touching on multiple themes which explains why the total count of all the themes being mentioned is higher than the total number of comments on the homework assignment grading. Some examples of the comment's addressing each theme are shown in tables 1 - 6, respectively in the same order as listed above.

Table 1. Examples of comments on the theme **usefulness - learn more**

Student comment	**Survey**
I found it much better to get feedback rather than a grade on the homework. A grade is not very telling on what went wrong and much better to get an explanation.	Heat Transfer End of term Spring 2016
Very clever to get feedback instead of a grade for homework. It meant (for me at least) that I always turned in my homework to see if I was misunderstanding anything.	Heat Transfer End of term Spring 2016
Very clever to get feedback instead of a grade for homework. It meant (for me at least) that I always turned in my homework to see if I was misunderstanding anything.	Fluid Mechanics End of term, Fall 2016

Table 2. Examples of comments on the theme **speed of feedback**

Student comment	Survey
Grading of homework exemplary and usually only takes a few days.	Heat Transfer Midterm Spring 2016
Returns homework in a timely manner with written feedback which is uncommon in other courses.	Heat Transfer End of term Spring 2019

Table 3. Examples of comments on the theme **encouraging - more likely to turn in the homework**

Student comment	Survey
The course evaluation was fair and encouraged me to do well in the course, learn the material at an even paise during the semester…. I found it encouraging to get feedback on the homework.	Heat Transfer End of term Spring 2016
I was particularly happy with the grading/arrangement of the homework. I was taking [name of another course] at the same time and the arrangement of homework was completely different. There every single detail was harshly penalized even writing something correct but with an untraditional form. So, I found it very encouraging in Heat Transfer that I knew that even if I did not have time to turn in a perfect homework solution, I would get a full score and I learned more from trying than I had if I had not. In the other course I knew even though I tried my very best I would get a bad score. As a result, I turned in many more homework assignments in Heat Transfer than in the other course even although my interest on the subjects is the same.	Heat Transfer End of term Spring 2016

Table 4. Examples of comments on the theme **less pressure**

Student comment	Survey
"It relieves pressure on students to get homework back with feedback rather than a grade. So, I really liked it. Students are also more likely to turn in their homework even though it is not perfect (no one likes to get a poor score).	Heat Transfer End of term Spring 2016
The grading method for homework assignments made things much more comfortable. I didn't feel this immense pressure to complete them perfectly rather just to do my best tackling them.	Fluid Mechanics End of term Fall 2016

Table 5. Examples of comments on the theme **less cheating**

Student comment	Survey
Very good to get feedback rather than a grade for the homework assignments because then you try to understand yourself and turn your own solution in instead of copying and not understanding a thing.	Fluid Mechanics End of term Fall 2016
Great to get no grade for homework but rather full score for an attempt. This encourages everyone to try it on their own terms, make the calculations they consider correct and then receive feedback on their solution. I learn a lot from that, rather than being stressed out about the grade I receive for the homework assignment and copy a solution from somewhere as is the tradition in other courses. Good arrangement with the homework.	Heat Transfer Midterm Spring 2018

Table 6. Examples of comments on the theme **nice to get comments - not used to getting this detailed feedback**

Student comment	Survey
Good to get feedback on homework on what can be improved rather than just correct/not correct, as in other subjects. Also, good not to have to be stressed about having all the homework correct, but rather it is enough to try your best. That means I dare to try to do it myself, read about the material and try my best. If we got a grade, it would be likely that most would be copying each other's solution without understanding.	Fluid Mechanics Midterm Fall 2016
It is not often that teachers bother to give feedback on homework so to kudos to that.	Fluid Mechanics Midterm Fall 2019

DISCUSSION

In this paper the effects of giving only feedback on homework assignments and not a grade, but rather give full score for an honest attempt. In the student evaluation surveys only positive open-ended replies were given on the issue with the exception in 2021 where one student preferred a visual rather than audio feedback. Students claim getting feedback instead of a grade for their homework assignments solutions is more useful for their learning, encourages them to work on the problems, reduces cheating and reduces pressure on them. The teacher did not see worse solutions to the homework than previously but did see indication that fewer students were copying the solution from some source. No effect was seen on final exam grades or the final grades in the courses.

As presented in results only one negative comment was given to the current homework grading arrangement and the negative aspect of the feedback was not on the feedback itself but rather on the media used to transfer the feedback. This was the first time the teacher tried this audio feedback because it was now readily available in Canvas Speedgrader and because it did save time for the instructor i.e., she was able to give more detailed feedback in shorter amount of time than in the written form. When the teacher asked students during lecture about the negative comment point of view no student present agreed. She did, however, send a message to all students proposing that everyone that wanted to have visual instead of audio feedback should let her know and she would make sure to have their feedback always visual. Sadly, no student replied even though it is clear that at least one student felt this way. In the future she plans to make this statement at the beginning of each course i.e., asking students preferring visual feedback to let her know at the beginning of the course. The goal is to present the feedback in a mode that is clearest to all students.

Some may argue that with this arrangement students get too much credit for poorly done homework but the total score for returning all homework (12-13 in total) in the courses is only 10% of the final grade, most students are not trying to game the system and the author of this paper believes what is gained for them trying to solve all homework is much more valuable than the inflation that comes from those 10% in their final grade.

Some may also argue that students that copy other student's solutions or the solution manual should not get any points for completing the homework and that is probably true. But the burden that puts on the instructor to proof that a homework solution is copied (and who is copying who) is in the authors mind too high with such low stakes in their final grade. Students' major loss in copying is by far the lack of an opportunity to learn from trying to solve the homework themselves and that will be very evident in the final itself. Those students rarely pass a course and at least never with a good grade, so the author believes those worries are not necessary and the benefits of full credit only formative feedback for homework assignments by far outweighs the drawbacks. The author of this paper, therefore, only sees positive effects of using feedback instead of grades for homework.

One view is worth discussing. Is it cheating if students do not independently work on their homework solution in formative assessment? The definition of cheating is to act dishonestly and unfairly to gain an advantage and as the author of this paper has repeatedly explained to her students, they gain nothing from turning in a perfect solution not done by themselves. Their grade is the same no matter how their solution is but what they miss a learning opportunity. So maybe it is wrong to call it cheating and academic misconduct. Yet, in the coffee room discussing with colleagues the talk often focuses on how to prevent cheating on homework and they consider it academic misconduct (admittedly much less severe than on tests). Most also agree that the purpose of homework is to learn from and therefore should be considered a formative assessment (not all of her colleagues are familiar with the term formative assessment but agree on that is exactly how homework should be when explained what it means). So, cheating is what most academics (I would also argue students themselves) call the action when students do not work independently on homework despite homework being formative. The author of this paper would argue that it does not matter if we call this action cheating or something else. Our goal is to assist students in mastering their learning on a subject and they are more likely to reach that by working independently on their homework. So, finding ways to increase that students work independently on homework is immensely important, no matter what we call the action when they do the opposite.

The shortcoming of this study is that that even though it covers 7,5 years it only addresses two courses with on average 40 students each. The measurement tools used to detect the influence are not particularly made to address this issue and therefore only give a sense of a tendence rather than being a concrete measure of the effects. Final grades of a course can vary with cohorts so one would expect only drastic changes in student learning could be detected by looking at those. The intuition of the instructor is a common measurement tool in educational studies, but it is limited since it will always be tinted of her own experiences and views no matter how much she will try to be neutral. The general student teaching evaluation surveys do not address the homework directly even though the instructor did ask students to address it in the open-ended replies in one of the years in question. Students may have strong opinion on the homework but still not bother to address it in the open-ended replies or might not have participated in the survey. Students that are indifferent about the homework feedback are also probably less likely to express their opinion making the replies biased towards both extremes. Despite those shortcomings, the fact there was no open-ended reply showing anything that works against the current grading format of homework assignments the author of this paper would argue that strongly suggest giving feedback only for homework has many positive aspects but few (or even no) negative aspects in students' minds. Furthermore, those results are in agreement to what students have expressed in conversation with the author of this paper. Furthermore, despite the shortcomings listed above, the findings are supported by the literature and the author believes those findings can be a solid starting point for more rigorous research on this issue. The author of this paper strongly believes the importance of such research to be immense and that instructors have a great responsibility to find homework grading methods that serve students best.

CONCLUSIONS

This paper addresses the positive effects of using feedback instead of a grade to deal with students' homework solutions as the literature on formative assessment supports. The student teaching evaluation surveys of 7,5 years in two courses in Bachelor Degree in Mechanical and Chemical Engineering suggest that students experience learning more, feel more encouraged to try to solve the homework assignments, feel less pressure and cheat less. Instructor's experience supports those findings. It can at least be stated that students experience was improved and likely their learning too.

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DISCOVER CALCULUS THROUGH ORIGINAL 3D ANIMATED SITCOM "RATVENTURES"

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ABSTRACT

Mathematics classes are traditionally conducted using front-loading teaching strategy in a didactic manner. Our curriculum tends to emphasize the acquisition of computational skills. Many perceive mathematics as a subject that consists of a collection of formulae, rules, and skills. They do not see how mathematical ideas interconnect and much less connection with their daily lives. This project seeks to reimagine our mathematics lessons to enable sustainable learning and organic learning. Organic learning arises from the needs of a context. Through the original 3D animation sitcom "Ratventures", we aim to contextualize and make mathematics relatable to learners. Sustainable learning builds understanding. Learning activities are designed in relation to each "Ratventures" episode to facilitate the understanding of the targeted mathematical topic through guided discovery approach. Instead of the traditional didactic approach, learners are guided in their discovery of the mathematical concepts, intuitive proof of rules and formulae, and translation of contexts to mathematical applications. In the process, we seek to ease learners into the world of mathematics and make mathematics more accessible by translating learners' understanding in spoken language to the language of mathematics. A pilot run was conducted on first year engineering students in Nanyang Polytechnic, taking Calculus module. We investigated the effects on learners' mathematical achievement and engagement with the proposed strategy. The comparison between the control group receiving the traditional didactic manner of delivery and the experimental group, which was subjected to the proposed guided discovery approach, was based on data from three sources (a) survey measuring student engagement; (b) a baseline test, given as pre-test and post-test; and (c) class quiz vs final examination. The experimental group registered significantly higher engagement level than the control group. While no statistically significant difference was found for the baseline test, the experimental group achieved higher normalized gains in their final examination.

KEYWORDS

Storytelling, Mathematics, Teaching for Understanding, Concept-based, Edutainment, Standards:8

INTRODUCTION

Existing Mathematics Classroom

The engineering mathematics curriculum in the polytechnics in Singapore tends to emphasize the acquisition of computational skills in mathematics. Coupled with our largely didactic mode of delivery, many view mathematics as a subject that consists of a collection of formulae, rules and skills. Oftentimes, these facts and skills are counterintuitive to learners. This learning phenomenal is not unique to Singapore. It is well-articulated in the report by National Academy of Sciences, Washington DC (National Research Council, 2000). The report asserts that: "... students often have limited opportunities to understand or to make sense of topics because many curricula have emphasized memory rather than understanding. Textbooks are filled with facts that students are expected to memorize, and most tests assess students' ability to remember the facts."

Such lopsided emphasis on procedural fluency results in learners becoming passive recipients of isolated, memorized mathematical formulas and rules. (Martin, H., 2006). They do not see how mathematical ideas interconnect and build on one another to produce a coherent whole. Learners do not have a positive attitude towards learning mathematics. Perhaps there are occasional mention of how mathematics is connected to other disciplines or their utilitarian value in industries. Nonetheless, most see much less connection between classroom mathematics and their daily lives.

There are approaches to make explicit connections between mathematics and the core engineering modules. McCartan, C. D., Hermon, J. P., & Cunningham, G. (2010) created a model to sustain engineering mathematics learning in a CDIO environment whilst F. Seng, Y. Soo, N. Singh, N. Ling (2009) sought to integrate the learning of engineering and mathematics modules through the use of a common Engineering Formulae booklet. This paper regards mathematics as a language of science, with which engineering is based upon. It attempts to translate the abstract mathematical notations and concepts using layman’s language and from there connects the language with our daily lives that are largely surrounded by engineered environment.

Ideal Mathematics Learning

Learning mathematics is not a fragmented process. In fact, it is a holistic, integrative one that interweaves five aspects that lead to the development of proficiency in mathematics. These 5 strands of mathematics proficiency are procedural fluency, conceptual understanding, strategic competence, adaptive reasoning, and productive disposition (Kilpatrick, Swafford, & Findell, 2001). Not only do learners have to acquire the skills to carry out mathematical procedures (procedural fluency), it is also imperative for them to comprehend mathematical concepts (conceptual understanding) so that they would have to ability to formulate, represent and solve mathematical problems (strategic competence). Especially for non-routine problems, competent learners would be able to use their logical thinking to explain and justify the legitimacy of a proposed strategy or procedure (adaptive reasoning). Other than a sufficient knowledge base, learners also should see sense in mathematics and perceive it as both useful and doable (productive disposition.) Only then will he or she be willing to put in steady effort in learning mathematics to see it pay off.

Mathematical proficiency is not a one-dimensional trait. Our procedural-heavy mathematics curriculum could directly or indirectly negate learners' attitude towards learning mathematics, which might be further compounded by our largely didactic mode of delivery. To navigate and progress in today's world which is built on the integrative experiences of the STEM (science, technology, engineering, and mathematics) fields, it is imperative for us now to shift our emphasis away from building procedural fluency to nurturing thinking mathematics learners.

ORGANIC AND SUSTAINABLE LEARNING IN MATHEMATICS CLASS

The team takes a comprehensive and systemic approach ***in reimagining our mathematics lessons to enable organic and sustainable learning***. In doing so, we aim to engage learners in the learning of mathematics and improve their mathematics achievement.

Organic Learning

Organic learning is learning which develops intrinsically from within the learner when he/she is intrigued by a topic, problem or concept and seeks ways to fulfill this curiosity. Organic learning arises from the needs of a context. To engage learners in the learning of mathematics, we aim to contextualize and make mathematics relatable to learners through the original 3D animation sitcom “Ratventures”,

"Ratventures" is a series of 14-episode sitcom. The story circles around Ah Hock, a karung guni man (a Singlish term: He is our local rag-and-bone man who collects used items such as newspaper, electrical appliances, clothes etc.) and a rat named Ayden. They are co-founders of a food delivery application, "Snitch Food", that serves the rat community. Each episode features the rat's food delivery adventure. The episodes are carefully crafted to provide the contexts for learners to achieve the understanding of the targeted mathematical topics.

While we seek to spark learners' initial interest with a story, our challenge is to sustain learners' interest and engagement and ensure that it does not evaporate as the story ends. Generally, a story captivates attention with a conflict or expectation set up at the beginning. The plot becomes more complex in the middle and finishes with a resolution at the end. The 'end' or "conflict resolution" is then turned into learners’ activity. The story thus evolves into exploration and problem solving. In such a way, we attempt to engage learners not only with a story but with the mathematics in the story.

Stories present themselves as contexts which are complex, ill-structured, infused with uncertainties and assumptions, unlike textbook problems which are well-defined quantitatively to let learners practice their skills. Learners become agent of problem formulation as they begin a mathematical discourse with their peers and/or instructor. This furnishes instructors the medium to humanize the language of mathematics. A new definition and/or notation of a mathematical fact can seamlessly be introduced as learner's self-constructed understanding in spoken language is translated to the language of mathematics. This helps ease learners into the world of mathematics and makes mathematics more accessible. In the process of problem solving, non-linear cognitive thinking takes place - an iterative process of convergent-divergent reasoning. Divergent thinking occurs when learners consider myriad of possible solutions while convergent thinking happens as learners justify an optimal solution. Learners takes responsibility in both problem formulation and problem solving. Learning of mathematics arises from the needs of a context. Learning becomes organic.

Why Storytelling?

Using storytelling to teach mathematics is not new. Mathematics is rich in historical development of ideas. At times, these historical anecdotes are woven into teaching either to provide context to a mathematical topic or to incite positive attitudes towards mathematics. Nevertheless, it is mostly done informally rather than as a structured activity.

Zazkis and Liljedahl (2019) believe that telling stories in mathematics classroom creates an environment of imagination, emotion and thinking. Stories make mathematics more accessible to learners as well as more engaging. They also provide a context for making meaning of abstract mathematical concepts (Cotti, R., & Schiro, M., 2004).

Sustainable Learning

Learning is sustainable if learning is transferable beyond the time and context of its learning. Sustainable learning involves ongoing, purposeful, responsive and proactive learning; the learner effectively builds and rebuilds her or his knowledge and skills base as circumstances change (Hays, J., & Reinders, H., 2020).

Sustainable learning thus entails building understanding. According to Kivunja (2015a, p.286), understanding may be regarded as: " ... the learning process in which learners engage in critical analysis of new ideas that they encounter, link those ideas to concepts and principles that they already know, and through this process gain an understanding and long-term retention of concepts and ideas that they can then apply them in problem solving in new contexts."

Apparently, understanding calls for observable performances or demonstrations of higher-order critical thinking. Understanding is not just knowing something or being able to regurgitate it or demonstrate the skill upon demand. A learner shows understanding of a topic when he or she is able to perform a variety of thought-demanding things about a topic. For instance, find examples and non-examples, provide analogy or metaphor, explain derivation, represent the topic in a new way, apply and generalize. Such are the performances of understanding which take learners beyond what they already know. How do we teach for understanding?

Teach for Understanding Framework

We adopted Blythe & Associates (1998) four-part teaching for understanding framework. The framework fosters deep disciplinary understanding. It comprises four key ideas: generative topics, understanding goals, performances of understanding and ongoing assessment.

Generative topics are concepts, ideas, skills etc that are interesting, accessible to learners and are worth understanding. They provide enough depth, meaning and connections to support learners' development of understanding.

"Facts do not transfer, i.e. they cannot be applied directly to a new situation. When we try to apply our insights from one situation to another, we are always abstracting the conceptual level, generalizing from a specific instance to a broader rule." The key to sustainable learning is to build understanding for conceptual transfer. Erickson and Lanning (2014) concept-based model "differentiates clearly what students must know factually, understand conceptually and be able to do in processes, strategies and skills."

The content in traditional curriculum model has been largely defined by knowledge and skill objectives, using Bloom's Taxonomy. It lists what learners have to know and uses process verbs such as explain, evaluate to suggest the different levels of cognitive necessary to complete the task. While the assumption is that such approach would lead to deeper conceptual understanding, many a time, while educators could readily cite the learning outcomes of a certain topic, they struggled to articulate the conceptual understandings to be drawn from the topics and skills.

To identify generative topics, we used Erickson and Lanning concept-based curriculum design to identify the knowledge, concepts, and skills for each topic in the existing syllabus that are generative. Besides, this concept-based approach also facilitates instructors in framing the understanding goals of each generative topic to help learners focus on the most important aspects of the topics.

Curriculum design guides instructional pedagogy. The generative topics are presented in each episode in Ratventures as one of these three types of stories: story (I) that leads to the discovery of a mathematical concept; story (II) that introduces the intuitive proofs of mathematical formulae and rules; and story (III) that enables translation of contexts to mathematical applications to assess learners' transfer of understanding.

In didactic teaching, we tend to verbally define a mathematical object and its notation and expect our learners to grasp them. However, the ability to regurgitate the definition and memorize the use of the notations does not necessarily reflect learners' grasp of the concept. Stories of type (I) facilitate learners in discerning the meaning of the mathematical object through their everyday language and in visualizing it in different forms, for example, geometrical and graphical forms, in addition to its abstract algebraic expression. At polytechnic level, our curriculum does not require learners to know the mathematical proofs of the formulae and rules used in the syllabus. Learners have been using them "blindly" without understanding its derivation. Stories of type (II) give learners an intuitive idea of the derivation of the formulae and rules without going into the rigor of the mathematics. Knowledge of their derivation helps improve the understanding of related concepts and provide much ease to learners in using them. Stories of type (III) offer real-life, unstructured scenarios for learners to apply what they have learned.

Each learning experience begins with an episode of Ratventures, which engages learners not only for its plot but also its inherent mathematics content. In doing so, we seek to trigger interest and mathematical discourse amongst learners and/or between instructor and learners. Other than to provide an interesting context to introduce mathematical content, the scenario allows instructors to translate learner's understanding in spoken language to the language of mathematics. In such doing, we hope to ease learners into the world of mathematics and makes mathematics more accessible.

While we seek to engage learners with stories in Ratventures, we also craft thought provoking learning activities to sustain learners' interest, as well as to help build and demonstrate their understanding. To facilitate learners in constructing their own understanding of the mathematical object, the activities may commence with relatively simple tasks to more demanding ones (e.g. explain in your own words, give an analogy). Using open-ended and higher order inquiry, learners can be nudged to further extend their learning by generalizing concepts or by extrapolating to a similar or related topic. These inquiry-based activities are scaffolded to cater to differentiated learning abilities.

In the process, by responding to a learner's comment in a class discussion and/or an impromptu review of a learner's work, appropriate feedback is given to help learners develop and deepen their understanding. Such informal ongoing assessments, which occur throughout the entire sequence of instruction, better meets the needs of learning for understanding and make learner's growth visible. In the process, learners become aware of criteria for self-evaluation of understanding, receive feedback and are afforded opportunities for reflection. Such assessments are not only beneficial to learners, they also inform the instructor the effectiveness of his or her instruction and indicate possible improvement to any instructional strategy. Instructor can monitor the progress of learners, discern their barriers to understanding and identify ways to help learners develop understanding.

The design of each learning activity is explicit in its understanding goals so that instructors can focus on facilitating learners in making connection between mathematical topics and between mathematics and their everyday use. In the design of these learning experiences, it is important to afford the opportunities for learners to build on their prior knowledge in the construction of their own understanding of concepts. This facilitates the making of connection between mathematical concepts. By exposing the learners to a range of real-world problems afforded by the concepts within syllabus, they allow learner to apply their understanding and connect abstract mathematics to real-world applications. Wherever necessary, it may be good to harness technology by using ICT tools to investigate and explore mathematical concepts.

Why Teach for Understanding?

Comprehending mathematical concepts makes learners less susceptible to common errors and less prone to forgetting when performing procedures. Clearly, conceptual understanding supports procedural fluency. It also prevents perfunctory application and support appropriate transfer of knowledge and skills as learners encounter different temporal and contexts in problem solving. A good understanding would put learners in a better position to justify their own work without depending on a third party to check. As self-directed learners, they would be able to justify the validity of a proposed strategy or procedure.

RESEARCH

Objectives

This paper proposes guiding students in their discovery of mathematical concepts, rules and formulae for the subject of Differential Calculus through original 3D animated sitcom "Ratventures". The 3D animations of scenarios in "Ratventures", together with their associated learning activities, are created based on the principles of building understanding and to allow contextual learning.

We seek to investigate the effects on year 1 engineering students' mathematical achievement and their attitude towards the learning mathematics through the adoption of the proposed strategy. To address these 2 concerns, the following hypotheses will be tested: (1) There are no statistically significant differences in students' achievement that can be attributed to the proposed strategy at 5% significance level and (2) There are no statistically significant differences in students' positive attitude toward learning mathematics that can be attributed to the proposed strategy at 5% significance level.

Participation

Calculus is a core subject for all first-year engineering students in Nanyang Polytechnic (NYP). The NYP Institutional Review Board (IRB) approved the pilot run to be conducted in the second semester of the academic year 2020 (AY2020S2) for 6 tutorial classes of first-year engineering students in NYP. About 95% of the 122 students consented to participate in the pilot run. Participation was voluntary. The participants could withdraw any time during the pilot period. The 6 tutorial classes were spilt into 3 experimental groups with 63 consenting participants and 3 control groups with 53 consenting participants.

All students in both control and experimental groups were taught the same mathematical content and received the same assessments. The main difference lies in the delivery strategies. Those in the control group were taught using conventional front-loading teaching strategy in a didactic manner while those in the experimental group were guided in the discovery of the mathematics content using the animated learning materials crafted for the purpose of this study.

Delivery Content using Ratventures

While there are 14 episodes of Ratventures, only 4 episodes were fully animated for use during the pilot period. Table 1 shows how the generative topic of "What is derivative?" is dissected into facts, understanding and skills according to Erickson and Lanning (2014) concept-based model. Table 2 summaries the scenarios presented in the 4 episodes and their discussion points.

Table 1. Facts, Understanding and Skills for "What is Derivative?"

To Know (Facts)	To Understand (Understanding)	To Do (Skills)
Derivative: - Definition - Notation	• Derivative in different presentation forms: numerical, graphical and algebraical. • Derivative as a point / function	
	Derivation of rules of differentiations and formula based on the definition of derivative	To find the derivatives of different function types and different combinations of functions based on rules of differentiation and formulas of derivatives.

Table 2. Content of the 4 Episodes of Ratventures

Episode / Story Type / Topic	Scenario	Trigger / Discussion Question
Episode 1 Story Type: I What is Derivative?	Ayden received order for 2 glasses of soya bean milk. He used a cylindrical glass and a conical glass to collect the drink from leftovers discarded by a hawker. Happily, he added 1 spider in each glass as extra toppings for his rat customer, hoping to secure good rating for his newly launched food delivery application, Snitch Food, However, his rat customer complained that only one of the 2 glasses contained the extra topping.	Which glass did the spider escape from? Explain your answer in layman terms, in graphical form and using the language of mathematics.
Episode 2 Story Type: III Application: What is Derivative?	Ayden received an order of ice-cream. The delivery destination is right across the end of a bridge which has a speed limit of 5m/s. His “rat” customer was upset with receiving less than full serving of ice-cream and chided him for speeding. Ayden recalled being hindered by someone in wheelchair during his delivery journey but still managed to make his delivery right on time.	Did Ayden speed? Explain your answer in layman terms, in graphical form and using the language of mathematics.
Episode 3 Story Type: II Differentiation Rule: Addition	Ah Hock was getting ready for his dinner date at his own apartment. Ayden helped Ah Hock spray his greying hair black. Suddenly, they saw a spider on the wall, which he was worried might scare off his date. Ah Hock tried to catch it with his spray-stained hand but to no avail. Instead, he left a dirty mark on the wall. Ayden jumped onto Ah Hock’s hand and made another attempt, but the spider was still out of reach. Then they heard footsteps walking towards them and thought Ah Hock’s date was arriving. At this instance, they both tiptoed to reach for the spider and finally caught it. However, it was a false alarm. Ah Hock’s date was not within sight yet but 3 stains were left on the wall.	With the help of a fully labeled diagram, explain the 3 stains on the wall and how it helps us visualize addition rule of differentiation.
Episode 4 Story Type: II Differentiation Rule: Product	While waiting for his date to arrive, Ah Hock decided to lay a tablecloth to cover his rather tattered table. However, the new tablecloth he bought was too small to cover the entire	With the help of a fully labeled diagram, explain how much tablecloth the ratoon stretched to cover the

	rectangular table. Ayden recruited his "ratoon" to help Ah Hock stretch the tablecloth. Just as he tried to tape the stretched tablecloth to the table, his date arrived.	entire table within the instance and how it helps us visualize product rule of differentiation.

Research Instruments and Results

The comparison between the control and experimental groups was based on data from three sources: (a) survey measuring student engagement conducted after interventions; (b) pre-test and post-test specifically designed for the targeted conceptual topic "What is derivative?"; and (c) class quizzes as baseline assessments vs students' achievement in the final exam based on the relevant topics.

Student Engagement in Mathematics Scale (SEMS) (Leis, M., Schmidt, K. M., & Rimm-Kaufman, S. E., 2015) was used for students to self-report their learning attitude in learning mathematics. The survey consisting of 15 Likert-scaled questions, which was conducted after each intervention. Question numbers 1 – 4 are statements regarding social engagement, question numbers 5 – 8 cognitive engagement and question numbers 9 – 11 emotional engagement. Question numbers 12 – 15 test their self confidence in mathematics. A rating value of 1 represents "Strongly Disagree" while 5 means ""Strongly Agree".

Table 3 shows the survey questions, results of the Mann–Whitney U test, and the mean ratings for each question of the engagement survey for the different study groups. According to the Mann–Whitney U test, the most significant difference between the two groups is for question numbers 1, 2 and 3 ($p < 0.05$), which show more social interaction amongst learners and/ or instructors in the experimental group that are tethered to the instructional content. There are weak evidence showing differences ($p < 0.10$) between the two groups for question numbers 6, 7, 10 and 12. Questions 6 and 7 point towards the extent to which learners show their willingness to exert effort to understand content and work through difficult problems while question 10 refers to learners' connection to content, interest in learning and thinking about the content. The experimental group exhibits though weak but higher rating than the control group. There is a weak but higher level of anxiety in learning mathematics for the experimental group.

Table 3. Mann -Whitey U Test Result of Engagement Survey

No.	Survey Question	p - Value	Mean Rating	
			Control Group	Experimental Group
	SOCIAL ENGAGEMENT			
1	Today I discussed/brainstormed/talked with my classmate(s) about math in class.	**0.00001**	3.52	4.37
2	Today I helped my classmate(s) with math when he/she/they didn't know what to do.	**0.02260**	3.22	3.62
3	Today my classmate(s) helped me with math when I didn't know what to do.	**0.04036**	3.52	3.86
4	Today the discussion in my math class helped me understand the topics.	0.17384	3.89	4.13
	COGNITIVE ENGAGEMENT			
5	I paid as much attention as I could in my math class today.	0.15560	4.13	4.40
6	I put in as much effort as I could in doing the tasks in my math class today.	0.08544	4.17	4.43
7	My math class today made me do a lot of thinking.	0.08186	4.11	4.37
	EMOTIONAL ENGAGEMENT			
8	I felt bored in math class today.	0.24604	3.91	4.16
9	I enjoyed thinking about math today.	0.37346	3.89	4.11
10	Learning math was interesting to me today.	0.08544	3.72	4.11
11	I liked the feeling of solving problems in math class today.	0.80258	3.94	4.06
	SELF CONFIDENCE			
12	Studying mathematics makes me feel nervous.	0.05876	2.78	3.19
13	Mathematics makes me feel uncomfortable.	0.40090	2.70	2.89
14	I learn mathematics easily.	0.22628	3.07	2.87
15	I believe I am good at solving mathematical problems.	0.64552	3.17	3.06

Figure 1 shows that the mean ratings for all questions are higher for the experimental group except question numbers 14 and 15 which indicate learner-reported self confidence in learning mathematics. It is worth noting that higher rating for question 12 and 13 expresses higher anxiety in learning mathematics.

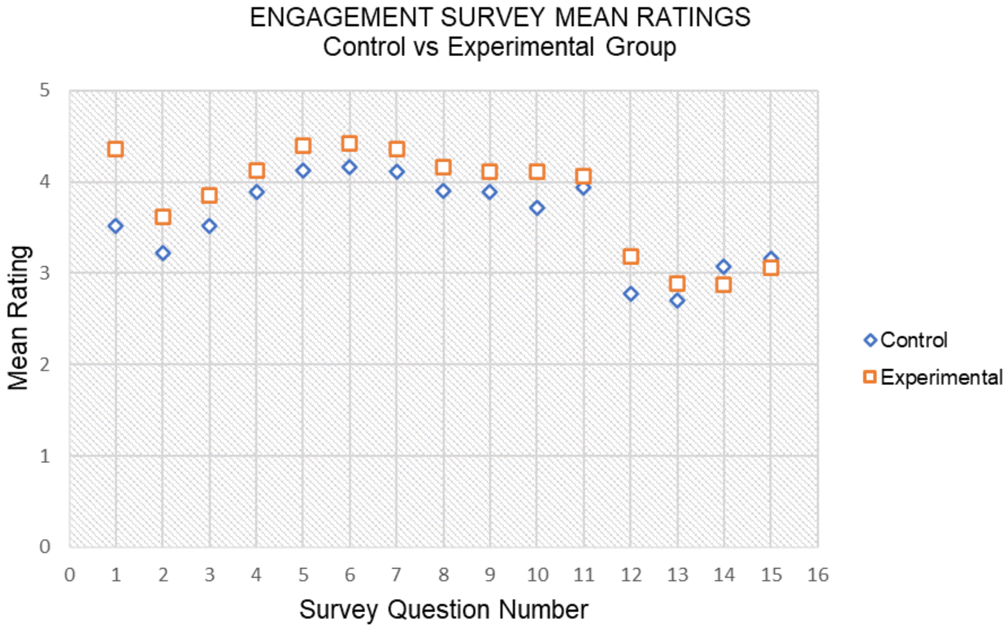

Figure 1: Graph of the Mean Ratings for each survey question between the control and the experimental group.

In the survey, participants were also asked to comment on what they liked about the class. Table 4 shows the top 3 themes that emerged from a thematic analysis (Braun, V., & Clarke, V. 2006) of the comments in the survey. In the analysis, common threads were identified in each comment and were coded. Codes of similar content were then grouped to generate the following three themes.

Generally, students find the proposed way of delivering mathematics classes to be engaging / interesting / fun / entertaining. The teaching materials used, for instance, the contexts presented in the 3D animation clips added a fun element to the classes while the mathematical discourses generated in the attempt to tackle the tasks presented in the animation clips made the class engaging. In comparison to passive learning, the discussion amongst the students and teachers that tethered to the instructional content made the class more interactive.

Table 4. Top 3 themes and their sample comments

	Themes	"What do you like about the class?"
1	Engaging / Interesting / Fun / Entertaining	Novel and unconventional method of teaching, interesting and thought provoking.
		It is engaging and makes me think like a lot
		I like how the class explains how the formulas are derived.
		It makes me think on a deeper level
2	Teaching Materials Used	It is engaging by using story telling although the end is unexpected.
		How the cartoon presents its questions
		The rat videos help explain the concept better
		The videos were very engaging and funny. There were a few learning points to take note in the video
		I like how it was a unique way of teaching through interactive videos. As such, it didn't feel as daunting to learn and understand
		I like how the concepts are simplified to help those without A-math or calculus background understand why we need calculus.
3	Interactive	It promoted teamwork and engagement with friends and teacher, which we will usually not get during math lessons
		I discussed with classmates and each of them contributed their idea so that we can learn from different perspectives

To assess if there is any improved mathematics performance, a pre-test consisting of 8 MCQ questions was given to the participants and a similar post-test was conducted right before and after the lesson for “What is derivative?” respectively. A 5% significance t-test on the difference of the mean scores of the pre and post tests for both the control and experimental groups (p-value = 0.10 > 0.05) showed no significance between the 2 groups in their mathematics performance.

On the other hand, as part of the assessment plan of the module, students have to undergo class quizzes and their final examination scores on the targeted topics. Their normalized gains, calculated as

$$g = \frac{exam\ score - quiz\ score}{100 - quiz\ score} \quad (1)$$

measured the improvement divided by the maximum possible improvement. The average gain was calculated for the both the experiment and control groups and used as an indication of how much was learnt in the respective groups during the course. A t-test on the difference in their average gains (p-value = 6.09E-11 < 0.05) showed that the experimental group performed significantly better than the control group. While the positive result may point to enhanced efforts by the students due to more positive attitude towards learning of mathematics, it may be too quick for us to conclude that the proposed strategy improved learners’ mathematics achievement. More pilot runs on different cohorts are necessary to eliminate the possibility of the experimental group in this run being an exceptionally engaged one.

DISCUSSION

The Calculus module like other mathematics modules in NYP heavily emphasizes on computation proficiency. Computation is an integral part of learning mathematic. The proposed approach aims to shift the emphasis a little by introducing more conceptual understanding in the delivery using 3D animation, "Ratventures" to engage learners and hopefully improve their mathematics achievement.

Using 3D animation may seem juvenile for the tertiary students. There was initial concern that the novelty may wear off as students are exposed to more episodes. Students' responses thus far seem to suggest that they are intrigued by discussion triggered by the stories in Ratventures.

However, the delivery of the classes may not come easy for many instructors as it involves mindful facilitation, a stark deviation from didactic teaching. It is imperative for instructors to ensure that learners possess the necessary prior knowledge before the planned lesson or include review of prior knowledge in the planned lesson. Failing which, the class may evolve into one that focuses on topics not related to targeted ones. With facilitation as key mode of delivery, the discussions in class can be very divergent. Not to be distracted, instructors have to be very mindful of the understanding goals for each lesson in order to lead students to the discovery of the intended mathematical object. The process is no doubt time-consuming.

In an education landscape that is examination oriented, students are naturally concerned if the understanding they acquired during the classes will be assessed during examination. Else, students see no purpose in understanding if questions are solely testing on mathematical computation. It is noteworthy that didactic teaching is not all bad especially since many students are used to the mode of learning and the content delivered are crucial to achieving assessment success. However, if we are committed to nurturing thinking mathematics learners, a wholistic approach to the curriculum design is necessary to ensure that our assessment plan is in line with our pedagogy and learning outcomes. It would take more than a mere change in delivery material and mode to meet our objectives of improving students' mathematical performance.

This study perhaps does more in terms of easing learners into the world of mathematics and make mathematics not as alien as it seems. It allows students to appreciate that the language used in everyday life can be seamlessly translated to the language of mathematics, for which engineering is based upon.

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Supporting engineering students learning mathematical induction with an online tutorial

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ABSTRACT

We describe an online tutorial that was developed in order to support first year engineering students' learning about mathematical induction (MI). The tutorial integrates theoretical explanations, examples and interactive reflective questions, and was designed to increase students' engagement by creating frequent interactions and using a varied collection of reflective questions. The tutorial was developed according to research-based knowledge concerning students' difficulties with MI and considering global vs. local proof comprehension. We examined the effects of the MI tutorial on the following students' achievements: (i) students' grade in the final quiz of the tutorial (FTG); (ii) students' grade in the MI question in the final exam of the course. We collected students' initial/final quiz-grades (ITG, FTG), the time students worked on the tutorial, the number of final quiz trials and students' grades in the MI question in the final exam in five semesters (before/after incorporating the tutorial). Our findings indicate that the mean FTG is significantly higher than the mean ITG (e.g., in the first semester, N=152, mean ITG=34.5; mean FTG=73.2). Apparently, the instructional part of the tutorial had a positive short-term effect on students' FTG. However, we did not find a major effect of the MI tutorial on students' grade in the MI exam question (regardless of the type of claims to be proved and other circumstantial exam settings). We also found that most students answer the MI question in the exam, which may suggest that students believe that they understand the use of MI; yet, their mean grade in this question is not very high (51.7-68.8). In addition, a change in course policy (including the FTG in the course's final grade), motivated students to achieve a high FTG but the time that students worked on the tutorial decreased, which may explain the lack of long-term effect.

KEYWORDS

Proof teaching, Mathematical induction, Online tutorial, Tertiary mathematics, Standards: 2,8,11

BACKGROUND

Mathematics is considered a fundamental subject in engineering education, since mathematical skills involve logical thinking, problem solving abilities and enable high achievements in other engineering subjects; In addition low performance in mathematical courses inhabit an academic risk and influence students' motivation (González et al., 2020).

There is an increasing interest in mathematics teaching practices at the tertiary level and in alternative approaches to mathematics teaching other than lecturing. Few of the subjects that are being studied are teaching and learning of mathematical proofs, effective ways of teaching mathematics to non-mathematics students and students' use of online resources (Biza et al., 2016).In addition, scholars are contemplating about different forms of assessment of students' knowledge and what type of performances should be confirmed in the assessment (Bennedsen, 2021). The use of online assessment is another strand of investigation that is gaining more attention, in particular in recent times (e..g., Pick and Cole, 2021).

In this paper, we describe an online tutorial developed by two of the authors, designed to help first year engineering students learning about proof by mathematical induction (MI), and discuss the effects that the MI online tutorial had on different aspects of students' achievements and learning.

Teaching and learning proof at the tertiary level

Research has identified a vast list of cognitive difficulties related to proving at all levels, including the tertiary level, for example: a lack of acquaintance with proving strategies, difficulties with mathematical language and notation, knowing how to work with mathematical definitions and understanding the logical structure of a proof (Selden & Selden, 2008, 2013). Non-mathematics students are expected to improve their proof constructing ability throughout their mathematics courses, which focus on a deep understanding of mathematical content but not necessarily on the concept of proof itself (Selden & Selden, 2008). Researchers have also been giving growing attention to affective aspects that influence the learning of mathematics, acknowledging their strong effect on students' proving process and problem solving abilities (Selden & Selden, 2013). In spite of these difficulties, there is an agreement among mathematics education researchers and mathematics lecturers that reasoning and proving are central both to knowledge construction and to the establishment of a mathematical community in the classroom. Research about teaching proof at the tertiary level did not yet accomplish a solid corpus of well-established ways for proof teaching, but a few approaches were suggested and studied in the literature. We focus here on two such approaches.

Firstly, Alcock (2009) designed a computer-based presentation of proofs called 'e-proofs', aimed to make the proof's structure and reasoning more explicit and visible to students. An e-proof comprised of a set of slides, showing a theorem and its complete proof, accompanied with audio commentary containing explanations similar to those a lecturer would give in a frontal lecture. Alcock et al. (2015) compared the effects of e-proofs with two other proof presentations (a frontal lecture, written proof) on undergraduate students' proof comprehension and found that although students liked e-proofs and perceived them as helpful, e-proofs were less desirable than textbook proofs or frontal lecture in terms of proof understanding. Alcock et al. speculated that e-proofs helped students' on-spot understanding without investing too much effort, which caused the lesser sustainability of their understanding. In fact, Alcock (2009) related to similar concerns stating that although e-proofs allow the teacher to better articulate their own understanding of a proof, students' interactivity is low and is mainly expressed by controlling pace and order of content. Alcock et al. further concluded that students' self-explanation training improves both students' mathematical reading and proof comprehension.

The second approach is the 'proof framework' instruction (Selden & Selden, 2013), designed to help students develop proof competencies. The term 'proof framework' relates to the formal-rhetorical part of the final written proof, which depends on unpacking and using the logical structure of the statement of the theorem, associated definitions, and earlier results. Selden and Selden let students prepare proof frameworks, leaving blanks in the proofs that should be filled with mathematical problem-solving content, and claim that writing such frameworks "…

not only improves their proof writing… but also… can reveal the nature of the problem(s) to be solved…" (p. 309). Selden and Selden reported that although constructing proof frameworks might be challenging for students with little experience in proof writing, after practice it can become routine and improve students' proof writing according to accepted community norms.

Stylianides and Stylianides (2017) asserted that although mathematics education research identified many difficulties in teaching and learning proof and suggested alternative pedagogical methods, less research focused on designing interventions and examining their effects on learning proof; they recommend applying research-based interventions in the mathematics classroom, or in any other formal learning setting. However, how can one assess the effect of such an intervention on students' proof comprehension? Mejia-Ramos et al. (2012) presented an assessment model for undergraduate students' proof comprehension, which may be used to design assessment instruments of students' proof understanding, as well as to evaluate the effectiveness of a specific mathematics instruction. The model addresses local and global proof comprehension. Local proof comprehension relates, for example, to understanding a specific statement and how it connects to a small number of other statements, the definition of terms and identifying the specific data supporting a claim. Global proof comprehension relates, for example, to the proof as a whole entity, and to aspects such as being able to reflect on main ideas, breaking the proof into modules and identifying the logical relation between them, applying the method of the proof in other contexts and choosing suitable illustrative examples.

Teaching and learning mathematical induction

Mathematical induction (MI) is a proving method frequently employed by mathematicians. There are different formulations of proof by MI and we use the following: Suppose one wishes to prove a conjecture that a statement $P(n)$ holds for all $n \in N$. Proof by MI has three steps:

i. The inductive base: prove that $P(1)$ holds;
ii. The inductive assumption: assume $P(k)$ holds for some $k \in N$;
iii. The inductive step: prove that $P(k) \Rightarrow P(k+1)$.

The conclusion is that $P(n)$ holds for all $n \in N$.

The pedagogical importance of teaching and learning MI in secondary school and in college was already discussed by Young (1908), who claimed that "the process of mathematical induction is exceptionally well fitted to introduce the beginner to the philosophic study of mathematical thinking" (p. 146). More than a century later, Stylianides et al. (2016) investigated the explanatory potential of proving by MI and suggested that "the explanatory power of proving by mathematical induction can help students develop their understanding of … mathematical ideas,…, ideas about proof, or both" (p. 23). Engineering students learn MI as part of their basic mathematical education, since in addition to being a fundamental and powerful proving method, it develops the logical thinking required for engineering and develops students' ability to work with sequences, particularly recursive sequences. This is true for all engineering students but bears particular importance for software engineering students, as Gunderson (2010) explains: "…because of the recent explosion of knowledge in combinatorics, computing, and discrete mathematics, mathematical induction is now, more than ever, critical in education…The theory of recursion in computing science is practically the study of mathematical induction applied to algorithms. The theory of mathematical logic and model theory rests entirely on mathematical induction, as does set theory... mathematical induction is absolutely essential in linear algebra, probability theory, modelling, and analysis…" (p. xix).

However, researchers have documented many difficulties that students encounter while learning MI, and we refer to a few main ones. Firstly, students think that MI is a circular proof in which they assume what they are trying to prove; this reflects a deep misunderstanding of the structure of proof by MI (Ernest, 1984). Secondly, many university students believe that proof by MI is a technical and superficial way of proving and do not understand the structure of the proof, in particular that the inductive base and the inductive step are independent and are both necessary for a valid proof (Movshovitz-Hadar, 1993; Ron & Dreyfus, 2004; Stylianides, Sandefur & Watson, 2016). Finally, students do not perceive MI as a natural development of their previous mathematical experience but as detached from other topics (Ernest, 1984). In order to tackle some of these difficulties, mathematics educators offered various recommendations, for example using cognitive conflict to stress the necessity and independence of the inductive base and the inductive step (Ernest, 1984; Movshovitz-Hadar, 1993) or using models such as the Domino tiles model (Ron & Dreyfus, 2004).

RATIONALE AND OBJECTIVES

We situate our work within the growing research field concerned with mathematics teaching practices at the tertiary level, in particular online tutorials that support the teaching of proof. Our research is an intervention, aimed to examine the effects of a specially designed online tutorial about MI on students' learning. MI was chosen because in spite of its centrality as a proving method in mathematics, it is usually not taught in secondary mathematics and most of our engineering students encounter it for the first time. In addition, MI has a clear structure or 'proof framework' (Selden & Selden, 2013), and there is vast established knowledge about students' difficulties with MI.

The online MI tutorial started with a quiz and proceeded with an instructional part containing theoretical explanations, examples and interactive reflective questions designed to support global and local proof comprehension (Mejia-Ramos et al., 2017) and to increase students' involvement. The tutorial ended with a quiz and the students received a final tutorial grade (FTG).

The objectives of the study presented here are to examine the effects of the instructional part of the MI tutorial on students' FTG and on students' grade in the MI question in the final exam of the course.

METHOD

The study was conducted in a discrete mathematics course, taken by Software engineering students and Industrial engineering students in an Engineering college in Israel. The course is taken by students in their first year of studies. As stated above, most students did not learn proof by MI in high-school; all students use MI in other courses (e.g., Calculus). In the course, MI is taught in a frontal lesson (3 hours). The lesson was supported by an online tutorial designed and programmed (using Articulate Storyline - an application used to build interactive online courses) by two lecturers of the course. The tutorial starts with a quiz that is graded (ITG), but the students do not get the grade or any feedback. It proceeds with an elaborated instructional part, and ends with a final quiz, identical to the initial one, which the students can repeat, receive feedback and a final tutorial grade (FTG). The initial/final quiz contains 10 questions that relate to global and local comprehension of proof by MI.

The instructional part of the tutorial is divided into sections, some contain theoretical explanations about MI together with examples and some MI proofs of different types of claims (algebraic, geometric). Figure 1 presents a scheme of the MI tutorial. The tutorial is interactive; students answer different types of reflective questions (e.g., typing algebraic expressions, multiple-choice, dragging expressions), that require global or local proof comprehension; the tutorial continues when students answer correctly. Students can also return to a previous section using a side content.

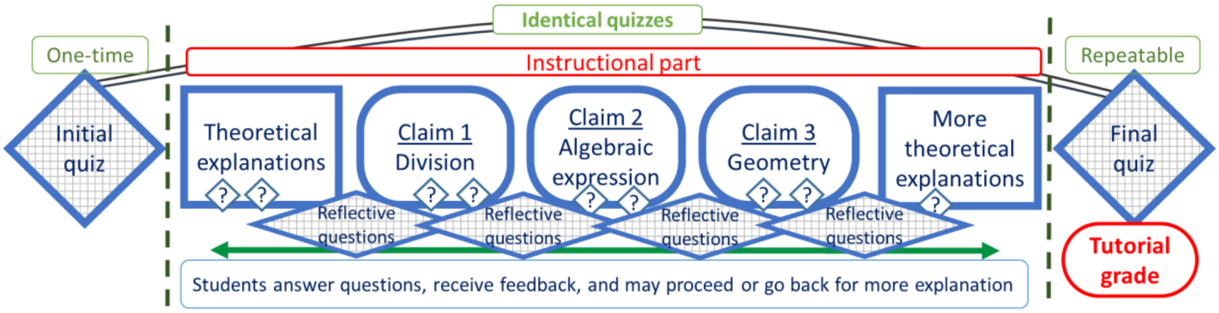

Figure 1: A schematic representation of the MI tutorial

Figure 2 presents an example of two tutorial screens containing global/local questions. The students have to complete the tutorial at home in their own pace, as long as they complete it before the end of the semester.

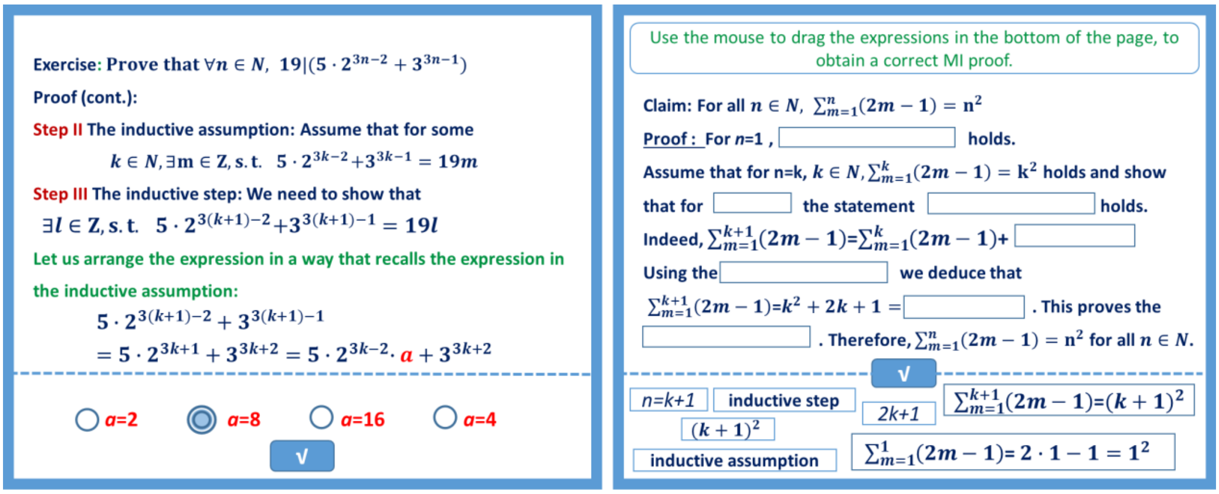

Figure 2: Examples for reflective questions (left/right – local/global comprehension)

Every final exam in discrete mathematics course includes a question (or part of a question) about proof by MI and the students have a choice of overall 5 of 6 questions. We collected data from two semesters before the incorporation of the MI tutorial in the course (Sem-BT1, Sem-BT2) and three semesters after the MI tutorial was incorporated as a mandatory activity in the course (Sem-T, Sem-TG1, Sem-TG2). In Sem-T the students were simply required to finish the tutorial before the final exam. In Sem-TG1/Sem-TG2 the FTG was incorporated in the final grade of the course (range 0-100): the students received 2.5 points in the final grade of the course, only if FTG ≥60.

We collected students' grades in the MI question in all five semesters. In the semesters that the MI tutorial was incorporated, we collected students' grades in initial and final tutorial quizzes (ITG/FTG), the time that students worked on the tutorial and the number of final quiz trials. Table 1 presents the MI final exam questions in each semester.

Table 1: Final exam MI questions

Semester	MI question in the final exam
Sem-BT1	Prove by MI that for any $n \in N$, $4^n + 15n - 1$ is divisible by 9
Sem-BT2	Prove by MI that for any $n \in N$, $\sum_{k=1}^{n} k^2 < \frac{(n+1)^3}{3}$
Sem-T	We will prove by MI that $\forall n \in N,\ 1 + \frac{1}{4} + \frac{1}{9} + \ldots + \frac{1}{n^2} \le 2 - \frac{1}{n}$ (a) Check the inductive base; (b) Write explicitly the inductive assumption and what is needed to prove in order to show that the inductive step holds; (c) Prove the inductive step; (d) Write explicitly the conclusion; (e) prove that $\forall n \in N,\ 1 + \frac{1}{4} + \frac{1}{9} + \ldots + \frac{1}{n^2} < 2$; (f) Can the claim in (e) be proven by MI? Please explain.
Sem-TG1	Prove by MI that $\forall n \in N,\ \sum_{j=1}^{n} (2j-1)^2 = \frac{n(4n^2-1)}{3}$
Sem-TG2	Prove by MI that $\forall n \in N,\ 4^{n+1} + 5^{2n-1}$ is divisible by 21

FINDINGS

Students' achievements in MI tutorial

Table 2 (below) presents the mean of students' grades in the initial/final quiz (ITG/FTG) in three semesters. The two columns on the right present the percentage of students who repeated the tutorial, where the term 'successful repeating students' (the last column on the right) relates to students that their first FTG was ≥ 60 but repeated the tutorial nevertheless.

We considered data of students with FTG; we omitted data of students with FTG=0 where the time they worked on the tutorial was less than 2 minutes or more than two hours. Mean time was calculated for students that worked on the tutorial and completed the first trial of the quiz in less than 2 hours.

Table 2: Tutorial grades and other tutorial parameters (SD = Standard deviation)

	ITG Mean (SD)	FTG Mean (SD) First trial	FTG Mean (SD) Highest trial	Mean time of first trial [min.]	Mean number of trials	% of repeating students	% of successful repeating students
Sem-T (N=152)	34.54 (20.3)	73.2 (18.3)	74.47 (18.8)	42.41	1.05	4	4
Sem-TG1 (N=186)	38.06 (20.2)	65.54 (23.6)	82.26 (16.5)	30:28	1.51	41	13
Sem-TG2 (N=169)	36.09 (21.9)	53.31 (34.3)	85.56 (15.9)	26:03	1.89	56	9

Students' achievements in final exam

Table 3 presents the MI question grade statistics and the percentage of students that answered the MI exam question in each semester. In Sem-T* we calculated mean grade for items a-d of the MI question (omitting the grades of items e-f), so that the question is more similar to MI exam questions in other semesters (Table 1) and the grades will be more comparable. The separate grades of items a-f are presented in Table 5.

Table 3: Students' grade (0-100) in MI question in final exam (SD = Standard deviation)

	Sem-BT1 (N=113, 72%)	Sem-BT2 (N=137, 94%)	Sem-T* (N=159, 92%)	Sem-TG1 (N=171, 96%)	Sem-TG2 (N=145, 95%)
Mean (SD)	51.7 (34.1)	68.8 (29.2)	60 (27.2)	63.3 (23.5)	67.6 (36.8)
Median	40	80	55	66.7	100

In order to investigate further the relation between students' first/highest FTG and students' grade in the MI final exam question we calculated the correlations between these grades, as presented in Table 4. We regarded only to grades of students who have a FTG and answered the MI exam question.

Table 4: Correlation between first/highest tutorial grade and grade in MI exam question

	Sem-T (N=124)	Sem-TG2 (N=153)	Sem-TG1(N=138)
Correlation	-0.01 / 0.04	0.19/ -0.1	-0.07 / -0.01

Finally, Table 5 presents students' grades in items a-f in the MI exam question in Sem-T (see items a-f in Table 1).

Table 5: Students' mean grade breakdown (0-100) in MI question in final exam in Sem-T

N=159	a (base)	b (assumption)	c (step)	d (conclusion)	e (consequence)	f (proof comprehension)
Mean grade	90.57	63.52	51.70	64.15	44.65	24.21

DISCUSSION

Our first objective was to study the effects of the instructional part of the MI tutorial on students' final tutorial grade (FTG). Table 2 demonstrates that the mean FTG after the first trial of the final quiz is significantly higher than the mean ITG. It seems that the instructional part of the MI tutorial had a very positive effect on students' FTG. The other tutorial parameters that we examined (Table 2) demonstrate that the mean time for completing the tutorial and the mean FTG after first trial decreased; the mean highest FTG as well as the mean of number of trials increased. There is also a big gap between the percentage of students who repeated the tutorial in Sem-T and Sem-TG1/Sem-TG2. In other words, in Sem-TG1 and Sem-TG2 students spent less time on their first trial of the tutorial, their first FTG decreased, but they repeated the final quiz until they achieved a higher FTG. We suspect that this is a result of the change in course grading policy, for as explained above in Sem-TG1 and Sem-TG2 the course grading policy changed and the FTG became an ingredient in the final grade, probably motivating students to achieve higher FTG. However, Table 2 also demonstrates that in all the semesters there were students that repeated the tutorial even though they already gained a passing grade, i.e their first FTG was ≥ 60. This happened regardless of the fact that the FTG itself was not part of the course's grade (as explained above students received 2.5 points in the final grade of the course if FTG ≥60). This may point to high motivation of these students and a high level of engagement with the tutorial. Pick and Cole (2021) report similar phenomenon in their study, concerning students that attempted to increase their score even after a pass mark had been achieved. If this is a feature of using online tutorials and quizzes – it is a very positive one, and should be further investigated.

Our second objective was to study the effect of the MI tutorial on students' grade in the MI exam questions. Table 3 does not demonstrate a clear effect of the MI tutorial neither on the mean nor on the median in the MI question. In fact, we did not detect any clear trend in the grades of the MI question along the five semesters. Of course, one should consider the difference in the type of claims to be proved (sum, division, etc.), the questions' type (with/without division into items) and even who the grader of the question was (the exams are checked each semester by a different lecturer). In addition, some of the semesters in which the data was collected were during the Covid-19 pandemic so the external circumstances varied from semester to semester (class exams, home exams). If we examine students' grades in Sem-BT1 and Sem-TG2, in which the exam questions were very similar (proving claims about division properties), the data shows that the mean and median grade are higher in Sem-TG2 but it is difficult to deduce that the increase was a result of the incorporation of the MI tutorial. The data in Table 4 supports the lack of a major effect of the MI tutorial on students' grade in the MI exam question. Nevertheless, Table 3 reflects that the percentage of students that choose to answer the MI question is high in all semesters (in 4 of 5 semesters it exceeds 90%). This suggests that students possess high beliefs concerning their ability to prove claims using MI, in spite of the fact that their mean grade is not very high (51.7-68.8). This supports research that asserted that students (at various levels) perceive proof by MI as a series of technical manipulations and do not possess a deep understanding of the structure and logic of MI (e.g., Ron & Dreyfus, 1994).

In order to consider other effects of the MI tutorial we relate to the MI exam question in Sem-T. Items a-d of the question resembled MI questions in other final exams; items e-f required less procedural understanding and involved meta-mathematical thinking. Table 4 demonstrates that students encountered difficulties especially in item c and in items e-f. Based on our experience, the difficulties in item c had mainly a technical nature and concern performing algebraic manipulations. Yet, the grades in items e-f indicate that students were unable to deduce a direct conclusion from the claim they have just proved; they were also unable to explain why they cannot use MI to prove a slightly different claim, where such an explanation requires local proof comprehension of the MI proof they have just performed in items a-d. In that sense, it seems that the MI tutorial did not support profound long-term proof comprehension. Granted, the MI tutorial did not focus on enhancing students' understanding of such subtleties. We consider this a matter for future research, in particular how to improve the tutorial to support deeper students' understanding.

CONCLUSIONS

To conclude, one aim of the MI tutorial was to teach students how to construct and write a correct MI proof, in the sense that they will be able to construct a correct 'proof framework' (Selden & Selden, 2013). It seems that the use of the MI tutorial had a positive effect on short-term students' grades (FTG) but no clear effect on their MI exam question grade. This finding is similar to what Alcock et al. (2015) called the 'on-spot' effect of e-proofs, which Alcock (2009) regarded a consequence of students' relatively passive learning. The design of the MI tutorial presented in this paper took this into account and encouraged students' activity by creating frequent interactions and using a varied collection of reflective questions, yet we did not notice a clear positive effect of the MI tutorial on students' achievements in the MI exam question. Thus, our main pedagogical conclusion is that relying solely on an online tutorial to address students' difficulties with MI is an unrealistic expectation and that the online tutorial cannot replace a discussion in a frontal lecture.

However, we still did not address possible effects of the MI tutorial on affective aspects of learning, such as learning experience or motivation and on their learning habits. In our study, we have overall positive feedback from students regarding these aspects, in concurrence with other studies that examine the use of online learning materials and quizzes, e.g., Pick and Cole (2021), who report students' high satisfaction with online quizzes. González et al. (2020) found that developing metacognition skills, time management and study habits help students to overcome challenges in their engineering studies and concluded that engaging engineering students in new learning spaces supports the development of these skills. Mathematical online tutorials, as the MI tutorial we discuss, are an example of such new learning spaces. Yet, reaching established conclusions on this matter requires further research.

Other future research directions concern the effects of flipping the MI lesson: replacing the frontal lecture by using the MI tutorial as a self-study unit, discussing MI in class and repeating the study while maintaining higher standardization (e.g., regarding exam questions and grading policy). We believe that as Stylianides and Stylianides (2017) recommended, intervention studies are an important source for gaining information of effective teaching methods, especially in times when online teaching is becoming more common.

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DUAL USE OF TIME: FRAMEWORK FOR UNDERSTANDING POSSIBILITIES AND PITFALLS

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ABSTRACT

A typical concern among faculty faced with requests for adding new and broader learning outcomes to existing degree programs, is that they might be forced to reduce their core disciplinary curriculum to make place for these new outcomes. The CDIO response to this is *dual use of time* – by means of integrated learning experiences, the same course slot can be used both to convey core disciplinary knowledge, professional skills, and societal relevance. However, empirical evidence for the effects of dual use of time seem to be limited. In this paper, we review empirical literature on various types of integrated learning, namely project-based learning, work-integrated learning, and content-language integrated learning. In addition, we discuss cognitive load theory and whether its findings have implications for such dual-purpose educational designs. Towards the end, we briefly discuss some frameworks, possibilities, and pitfalls for such integrated teaching.

KEYWORDS

Integrated learning, Dual use of time, Project-based learning, Conceptual load, Learning outcomes, Standards: 2, 3, 7, 11

INTRODUCTION

The employability of STEM candidates depends not only on strength in their core engineering discipline, but also on broader professional competencies such as communication skills, teamwork, and entrepreneurship (Forcael et al., 2021; Winberg et al., 2020), and the CDIO standards have recently been updated with sustainability and digitalization as key competencies for the future (Malmqvist et al., 2020). A typical concern among faculty faced with requests for adding new and broader learning outcomes to existing degree programs, is that they might be forced to reduce their core disciplinary curriculum to make place for these new outcomes. The tempting response to this from a CDIO perspective is to offer integrated learning experiences, so that the same course slot can be used to pursue several competencies in parallel, for instance core disciplinary knowledge, professional skills, and societal relevance. In CDIO literature, this approach is often called "dual use of time", though it could be discussed whether this is the best term. Generally, the term "dual use of time" applies to performing several things in parallel – for instance that drivers should be able to perform other useful activities while waiting for their electric cars to charge (Philipsen et al., 2016). Early usage of the term in pedagogy also entails several activities in parallel, such as repeating key concepts while in the restroom (e.g., from notes posted on the wall), or listening to instructional cassette tapes while travelling (McCormick, 1988), thus learning something when you would otherwise be intellectually idle. The "dual use of time" proposed in the CDIO context is much more ambitious – rather than learning when otherwise idle, the goal is to learn multiple competencies in parallel, e.g., learning both fundamentals and professional skills (Bankel et al., 2003), thus reducing the need for dedicated courses (Armstrong et al., 2006). As stated in Edström et al. (2007), due to the cramped curricula of engineering study programs, "a curriculum has to make dual use of time and resources within disciplinary courses already available, capitalizing on the synergy of the simultaneous learning of skills and disciplinary outcomes." (p.79). However, unlike listening to instructional tapes while driving, which is clearly two different activities with no particular synergy, the CDIO approach is more often one integrated activity (e.g., students working in a team project about some engineering design task), hence it could be argued that the duality lies not in the use of time, but rather that the activity has *dual purpose,* e.g., to reach learning outcomes both in engineering design and in collaboration skills.

A key assumption for dual use of time from the CDIO viewpoint is that new learning outcomes that we want to add can be pursued in synergy with disciplinary learning outcomes – by use of appropriate learning methods such as project-based learning (Edström et al., 2007), so that students will reach the new outcomes (say, teamwork and collaboration skills) while still learning as much of the disciplinary topic (say, software design) as they did before. There have been many positive research results showing good learning effect from using such approaches, e.g., (Andrews & Clark, 2011; Kans & Gustafsson, 2012; Malmqvist et al., 2015), and Levine et al. (2008) show significant gains in 4 of 6 kinds of learning following the joint redesign of 6 courses in the same study program. Yet, the empirical evidence directly addressing the learning effects of dual use of time seems to be rather limited – at least a literature search for "dual use of time" + "empirical evidence" will give few relevant hits. This does not necessarily mean that evidence is absent, rather research could have been published using other terms than dual use of time, such as for instance integrated learning.

Our research questions for this paper are: (1) Along which different dimensions of competency can dual use of time be pursued? (2) What are the typical learning gains from dual use of time? (3) What – if any – are the most dangerous pitfalls of dual use of time?

This rest of this paper is structured as follows: In the next three sections, we look at three different types of learning that could be classified as "dual use of time" – or maybe better: dual purpose – namely Project-Based Learning (PjBL), Work-Integrated Learning (WIL) and Content and Language Integrated Learning (CLIL) – looking at empirical evidence for learning gains of these approaches. Next, we look at Cognitive Load Theory, which might in some situations pose an argument against dual use of time. In the final section, we outline a more general framework for considering potential gains and pitfalls of dual use of time.

PROJECT BASED LEARNING (PjBL)

Project-based learning (PjBL) is a natural starting point in this paper, as it has been identified as the dominant approach for integrative STEM learning (Mustafa et al., 2016), and CDIO-inspired redesign of study programs will likely have PjBL as a central component (Bolstad, 2021). A typical transformation might be from disciplinary courses previously taught through a series of lectures and small weekly exercises, to instead having students work with larger projects, individually or in teams (Leslie et al., 2021). From a perspective of outcomes, teachers used to a lecture-based approach and favoring content knowledge may fear that a change to projects will imply that some of the students' study time gets consumed by overhead related to the project collaboration, hence reducing their learning outcomes in terms of content knowledge. However, a review of empirical evaluations of PjBL courses by Ralph (2016) indicated that PjBL instead caused an increase in content knowledge – though it must be acknowledged that the number of reviewed studies was rather limited (14). Chen & Yang (2019), in a more comprehensive meta-analysis of studies directly comparing student achievement from PjBL vs. traditional lecture-based pedagogy found an average effect size of 0.71 in favor of PjBL, which can be described as a medium to large effect. The size of the effect differed somewhat between disciplines (larger in social sciences, smaller in STEM) and cultures (larger in Western countries, smaller in Asia), but is anyway a positive result for PjBL vs. a lecture-based approach. Looking at progression from junior to senior projects in study programs, (Lowe & Goldfinch, 2021) found a clear increase in breadth of knowledge drawn upon in the projects. However, there was no evidence of similar progression in the expected integrative capability of the students, suggesting a critical need for more work in that area.

Guo et al. (2020) reviewed publications assessing the outcomes of PjBL and found four main groups of outcomes being assessed: cognitive outcomes (knowledge, strategies), affective outcomes (perceptions of benefits and effectiveness of PjBL), behavioral outcomes (skills, engagement), and artefact outcomes (quality of the artefacts developed by the students).
An observed weakness, however, was that most of the reviewed studies evaluated outcomes largely by means of students' self-reported perceptions of learning outcomes, rather than more objective measures, such as pre- and post-tests measuring progress in content knowledge and skills from the PjBL course, or controlled comparisons of students who learnt a topic through PjBL versus students following a no-project approach

Paradoxically, there is more research documenting gains in content knowledge from team projects than there is evidence of gains in, e.g., collaboration skills. One reason could be that collaboration skill is a complex concept which is hard to measure (Scoular, 2021) and most teachers in project-based engineering courses are experts in their engineering discipline, not in collaboration, so teaching and assessment tends to focus on the engineering more than the collaboration as such, the latter assumed to be learnt by immersion. As indicated by Pazos et al. (2016) more scaffolding of the collaboration aspect could be needed to ensure students have substantial progress in this respect.

Hence, although PjBL can be an excellent way to achieve balanced learning of an engineering discipline together with employability skills such as communication and collaboration (Winberg et al., 2020), there is a potential tension between the teaching of content and skills, for instance concerning how much teacher and student effort goes into the scaffolding of each, and how much effort goes into the assessment of each.

WORK-INTEGRATED LEARNING (WIL)

Work-Integrated Learning (WIL) is a learning approach which includes placement of the student in an authentic work context. This does not mean that any placement or internship would qualify as WIL, rather the term WIL requires that there is a combination of formal education and the practical application of knowledge and skills in an authentic work-life context (Jackson, 2018). Hence, in a WIL unit within a university program, students typically have to deliver some kind of report to document their learning from the placement period. As described by Wood et al. (2020), in addition to WIL where the student is in the workplace, there may also be remote WIL where the student may interact with the authentic work task through the internet, and simulated WIL – which may be slightly less authentic, e.g., the university setting up work tasks which resemble as closely as possible authentic industry tasks. Remote and simulated WIL have received increased attention recently, as pandemic restrictions may have prevented students from physical presence in the workplace. Work-placement which does not have any formal framework may have great learning value for some students, but this will vary a lot from placement to placement. According to (Nagle et al., 2018), there is also a risk that such extra-curricular placements mainly lead to tacit knowledge which is hard to assess and hard to integrate with disciplinary knowledge. Hence, they suggest that WIL needs to be semi-formal, balancing explicit learning outcomes and assessment procedures with room for improvisation based on the nature of the placement and viable work-tasks.

Assessment in WIL is challenging as some outcomes may be unpredictable and differ from student to student. To address this challenge, Ferns & Zegwaard (2014) point to e-portfolios as a good way to enable students to document and reflect upon their learning in such. As argued by Leal-Rodriguez & Albort-Morant (2019), while there is plenty evidence for advantages of student-active learning methods, the evidence for gains in conceptual understanding resulting from experiential learning is scarce. However, in their study they found that company placement in a course in Management Skills affected positively the grade in a later exam focusing on mastery of theoretical concepts of management skills.

Dean & Sykes (2021) made an ethnographic study observing three students on placement. They found many positive learning experiences from WIL, but also found that it may have a lot of what they called “dead time” – where the students were unable to do much (or even learn much) because they were waiting for a workplace leader or mentor to allocate tasks to them or give feedback on performed tasks. There are several risks to WIL (Effeney, 2020), for all stakeholders involved. For the company it could be student misconduct in the workplace, for the university, it could be loss of reputations if placements fail. From a dual use of time perspective, poor learning outcomes for the student might be the most relevant risk to note. One specific cause might be if companies are using placement students mainly as cheap labor, caring less about learning outcomes (Mutereko & Wedekind, 2016). Also, there could be other causes, such as the abovementioned “dead time” or mismatch between job tasks and intended learning outcomes. However, based on studies of WIL in Australia, Jackson (2015) claims that cases when WIL was seen as less successful in learning outcomes could mostly be attributed to poor design of the WIL course unit, or of the study program at large, rather than an inherent problem with WIL as such. A typical challenge was students insufficiently prepared through previous courses regarding knowledge and skills they would need for their placement.

An interesting discussion by Björck & Johansson (2019) addresses the duality of theory vs. practice in WIL, criticizing the typical assumption that the learning of theory is what takes place in university, while practice in industry, industry thus representing “the real world” which academia is somehow not part of. They argue that rather than positing WIL as a way of bridging the divide between theory of practice, one should abandon this idea of duality altogether, instead viewing theory and practice as inseparable aspects of competency, as any theory is necessarily learnt in some social environment where it is practiced. Another interesting reflection by Fleming & Haigh (2017) is the danger that WIL is often designed with too much focus on preparing the students for the “now”, while they also need to be prepared for future jobs that do not yet exist.

CONTENT AND LANGUAGE INTEGRATED LEARNING (CLIL)

Content and language integrated learning (CLIL) is a pedagogical approach where a subject is taught in another language than the native language of the students (Dalton-Puffer, 2011), with the dual purpose of learning subject content (e.g., History) and a language other than the students' native one (e.g., English as a Foreign Language). Obviously, master level courses are taught in English in many countries although most of the students have a native language other than English. However, this as such would *not* qualify as CLIL – there needs to be the dual purpose of teaching subject content *and* the language through the same course. CLIL has received a lot of enthusiasm, and several studies have indicated gains compared to non-CLIL approaches with content instruction and language instruction separated in different courses – though evaluations have mainly focused on the language learning part (Dalton-Puffer, 2011), with much fewer studies identifying clear gains in content learning. Also, there may be cultural differences impacting the success, as CLIL has been more successful in southern Europe, e.g., Spain, less so in Sweden (Sylvén, 2013). CLIL has been used and researched mostly in secondary education, but there are also studies in tertiary education, for instance by Aguilar (2017) who found that engineering teachers tended to prefer English Medium Instruction (teaching a topic in English but focusing on the content without any dual purpose of teaching the language, too) rather than CLIL, because they identified as experts in the engineering topic, not in technical English.

In addition to the challenge that teachers do not identify as language teachers, they may also fear that content learning will be watered down if language learning takes some of the class time. Empirical results are conflicting on this issue. A review by Cañado (2018) found that CLIL did not water down content learning, and Surmont et al. (2016) even found gains in mathematics learning for CLIL vs. non-CLIL students. On the other hand, Fernández-Sanjurjo, et al. (2019) found CLIL students having a slightly weaker performance than non-CLIL students on subsequent content tests. A recent review by Cimermanova (2021) found no significant difference between CLIL and non-CLIL content learning outcomes, though there was a weak (but non-significant) advantage for non-CLIL.

Bruton (2013) criticized CLIL and its research, arguing that many studies have methodological weaknesses, such as selection bias (e.g., more ambitious students selected CLIL variants in the first place). Also, he considered the assumption of «two for the price of one» held by the most enthusiastic CLIL supporters to be unrealistic. Moreover, the learning of the second language will have a somewhat narrow focus towards discourse of the content domain, rather than more widely applicable mastery of the language.

Harrop (2012) makes an interesting analysis of the possibilities of CLIL, as well as its limitations. While the claim of increased language learning has been evidenced by many studies (though not all), she observes that a tension between content and language still exists, and for language learning, the lack of focus on form can lead to early fossilization of student errors. While CLIL may increase motivation for foreign language learning because there is an immediately added purpose (grasping the content of the course), this increased motivation does not seem to apply to all student groups. For some, CLIL increases the complexity. Students with low language proficiency may experience this as an extra hurdle towards learning the content. Another finding from some studies is that while middle and somewhat below middle students tend to benefit from CLIL, there are fewer students over-achieving with respect to the learning outcomes, indicating that over-achievement is likely capped by the extra complexity added by the foreign language.

COGNITIVE LOAD THEORY

Although PjBL, WIL, and CLIL have many differences, they have some clear similarities. All three posit that learning activities with a dual purpose (content and skills; theory and practice; content and language) can do better than the alternative of having two single purpose learning activities. To the extent that dual use of time implies trying to learn two things simultaneously, cognitive load theory might indicate that this is not always a good idea, as it would often recommend focusing at one thing to be learnt at a time (Paas et al., 2003). For instance, Edwards et al. (2020) found that learning syntax before problem-solving gave better results in CS1 (introductory programming) than a more integrated approach of learning syntax and problem-solving together. This would not make a PjBL approach to programming impossible, but at least indicate that some drill-oriented learning activities should precede the project, to ensure students have sufficient initial competence. Hence, such a course unit would have to be single purpose at least some of the time.

Leppink & Duvivier (2016) propose twelve tips for curriculum design from a cognitive load theory perspective, based on a three-dimensional taxonomy where student learning will gradually move from high support or scaffolding towards increased autonomy, from low to high task fidelity, and low to high complexity. While specifically targeting medical education, their general taxonomy of gradually increasing autonomy, fidelity and complexity could apply to most fields of education. Their tips are not in conflict with project-based or problem-based learning, and especially the latter has been used a lot in medicine. However, they do imply that early projects must in some cases be simpler, and less realistic, than an industry-style project. A case analyzed by (Peters, 2015) indicates how an open-ended, ill-formed project resulted in cognitive overload for first year students, concluding that they likely could have learnt more from a less complex project with a more scaffolded design.

There is limited literature in the intersection of cognitive load and WIL. However, on the duality of content and language, Roussel et al. (2017) claim that CLIL – with a dual purpose of teaching both content and language – is actually better than English Medium Instruction (e.g., teaching an engineering subject in English, although the students are not native English speakers). This because EMI will not take any measures to address the extra cognitive load resulting from the teaching of content in a non-native language, whereas CLIL – with its explicit purpose of teaching the language, can provide the measures for the students to overcome this load.

As cognitive load theory has mostly been researched in relation to the individual, there are few studies of cognitive load for students working in teams, as will typically happen in PjBL. However, Kirschner et al. (2018) discuss what they call collaborative cognitive load theory, which could apply to such situations. They find that collaboration can sometimes mitigate cognitive load, as the group develops a collective working memory which can contain more information than the working memory of any single individual, thus reducing the cognitive load on any single individual in the group. On the other hand, collaboration can in other cases aggravate cognitive load, specifically if there is cognitive load associated with conflicts and misunderstandings in the collaboration itself.

FRAMEWORKS FOR POSSIBILITIES AND PITFALLS

There are already some frameworks that can be used to understand possibilities for integrated learning, aiming for a dual purpose, rather than a singular content focus. One example is the

Taxonomy of Significant Learning proposed by Fink (2013). Unlike Bloom's taxonomy, which presents knowledge outcomes in a hierarchy of increasing levels of ambition, Fink's taxonomy identifies six kinds of learning: foundational knowledge, application, integration (seeing relationships between different parts of knowledge), human dimension (e.g., communication, collaboration, self-directedness), caring (having a genuine interest in the subject), and learning how to learn. Fink claims that these different kinds of learning are synergistic, thus a teacher does not have to give up on one kind of learning for the students to also achieve another. Hence, the "zero sum game assumption" often encountered in education redesign need not hold true. Dosmar & Nguyen (2021) describe experiences from designing a capstone project in biomedical engineering based on Fink's taxonomy, with strong learning outcomes and positive course evaluations from the students. Based on Fink's taxonomy, a dual (or even multiple) purpose for a course would be easier to achieve if combining different kinds of learning (e.g., foundational knowledge + application + caring), but harder if combining more of the same kind, say, foundational knowledge with some other foundational knowledge.

Cheng & So (2020) propose a typology and four models of ways for achieving integration in STEM learning. Three different types of integration are suggested: content integration, pedagogical integration and learner integration, and based on this they propose advice on how to achieve viable integrated courses. CLIL would likely be classified as content integration in their taxonomy (i.e., integrating two types of content, like an engineering subject and a foreign language), although from a CLIL researcher's point of view, the language would not be considered as content. WIL might to a larger extent be classified as pedagogical integration, of classroom pedagogy with learning through the work placement. PjBL might include several types of integration, e.g. integrating two subjects (say electrical engineering and mathematics) or a subject and an application domain (e.g., software engineering for a customer in finance). It could also imply pedagogical integration (various learning approaches used within the project, for instance as part of scaffolding for the content, or for effective collaboration) – and of course learner integration with students working in teams.

Our brief reviews of PjBL, WIL, and CLIL earlier in this paper indicate promising results for all of these – with many (though not all) empirical studies indicating that a dual-purpose course design need not reduce learning outcomes compared to having a singular purpose. On the other hand, some pitfalls have also been identified. Just like there may be a tension between content and language in CLIL, with teachers tending to identify as content experts, not language experts, so could there be a tension between content and skills in PjBL, teachers often experts in the engineering discipline, rarely experts in generic competencies like collaboration. Such tensions could have negative impact on the teaching and assessment of at least one of the outcomes. Finally, as indicated by cognitive load theory, a dual purpose need not cause cognitive overload for the students – a PjBL team project might sometimes instead reduce cognitive load due to establishment of a collective working memory. However, in other cases collaboration might increase cognitive load, and to avoid this, it is important that challenges related to collaboration are appropriately scaffolded relative to the level of the students and their prior experience with collaborative projects.

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GENDER DIFFERENCES IN ATTITUTES TOWARDS ENGINEERING STUDIES AND IN GRADUATES

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ABSTRACT

Gender difference in Science, Technology, Engineering and Mathematics (STEM) education is well reported and analysed, and models and recommendations have been put forward. Research has revealed that different engineering programs are more attractive to one gender than the other and understanding university students' attitudes towards STEM is essential for changing this situation. Choice of studies can be difficult because so many factors are involved, e.g. peer pressure, stereotypes, access and availability and local cultural expectations. This paper seeks to ascertain if there is a gender difference in engineering students' attitudes toward engineering, and if the development of gender balance has been changing during the last decade in the different engineering fields. Survey data was collected from students enrolled in a university engineering program at Reykjavik University, Iceland, and available data on the number of graduates between 2008 and 2021 were analysed. The results show that the genders may have divergent interest in different disciplines of engineering which is reflected in quite different gender ratios at graduation, but at the same time there is a systematic change during the last decade in some engineering disciplines. Furthermore, females are getting interested in engineering education significantly later than males, but the genders report similar reasons for choosing engineering education. This topic touches on CDIO Standard 1 (program philosophy), 7 and 8 (new methods of teaching and learning).

KEYWORDS

STEM, gender difference, engineering, CDIO standards 1, 7, 8.

INTRODUCTION

Gender difference in Science, Technology, Engineering and Mathematics (STEM) has slowly decreased over the years, but is still of considerable concern. In engineering the situation is different in different countries and even universities and different engineering programs appeal differently to the genders. Female students and professionals are often around 10 – 25% in the engineering field in many parts of the world. As an example, in the UK, women were 14.5% of all engineers in 2021, an increase by 25.7% since 2016 (SWE, 2021). In the USA, women where 22.5% of bachelor's graduates in 2019 and the enrolment was 23.8% (American Society for Engineering Education, 2020). In Japan, women have been 9-10% of graduated engineering students, but only around 1% of working engineers (Balakrishnan, 2014). Lichtenstein et al. (2014) phrase it well when they say, "… in spite of a policy agenda targeted at boosting participation of women and underrepresented minorities in the engineering workforce, progress has been slow" (p. 325–326).

According to González-González et al. (2018) the five most common barriers that women encounter in engineering education are: lack of mentors, lack of female role models in the field, gender bias in the workplace, unequal growth opportunities compared to men, and unequal pay for the same skills. To understand the situation today and the driving forces for this development it can be helpful to analyse engineering students' attitudes to the discipline of engineering. This could lead us in the effort to recruit not only more females in STEM, and especially engineering and applied engineering, but more students overall.

The objective of this study was to ascertain with a survey if BSc students reported different attitudes toward engineering depending on gender and line of study. These results are then compared to how gender ratios have evolved for graduates in the last 14 years at Reykjavik University (RU). More specifically, the two research questions are: Is there a gender difference in students' attitudes toward engineering? and Has the development of gender balance been changing for the last decade in different engineering fields?

RELATED WORK

STEM is recognized as a driving force for innovation and the economy; thus, it is important to attract more students and promote equality, diversity, and inclusion (EDI) in the field. Although more women are attending STEM, their interest seems to be mainly in health-related disciplines and life sciences and they have been underrepresented in math, physical science, engineering, and computer science (Matthiasdottir & Palsdottir, 2016; Funke, Berges, & Hubwieser, 2016; Lin, Ghaddar, & Hurst, 2021).

STEM fields have very diverse cultures (Cheryan et al., 2017). The masculine culture of engineering and a lack of role models and community for women has characterised the field for a long time (Robinson, & McIlwee, 1991). Anyhow, more women are attending engineering education today than before, but the development has been rather slow. In 2018, 85% of bachelor's degrees in health-related fields were to women, but only 22% in engineering (Fry, Kennedy, & Funk, 2021). According to American Society for Engineering Education (ASEE, 2021) report, Profiles of Engineering and Engineering Technology, females where 17.8% of bachelor's graduates in 2010 and 23.1% in 2020 in the USA. In Spain, 29% of students in engineering and architecture were women (Previo, 2017). One can even find an example of a university in Sweden were 39% of the students in engineering were females (Peixoto et al., 2018).

Universities offering engineering education have a variety of study lines for students to choose from and the gender balance in the programs are different. In a new SWE (Society of Women Engineering) report, the top five engineering degrees awarded to women in the USA in 2019 were 1) Mechanical engineering, 2) Chemical engineering, 3) Computer science, 4) Biomedical engineering, and 5) Civil engineering (SWE, 2021). The situation is a little bit different in a report from the American Society for Engineering Education (ASEE, 2021), where the top five bachelor's degrees in 2020 awarded to women in the USA by discipline were 1) Environmental engineering, 2) Biomedical engineering, 3) Biological and agricultural engineering, 4) Chemical engineering, and 5) Industrial/Manufacturing/Systems (ASEE, 2021). At Chalmers University in Sweden, 61% of female students attended Industrial Engineering Design, but only 8% Marine Engineering. In Canada in 2004, the highest proportions of women in engineering sub-disciplines were in biosystems, environmental, chemical, and geological engineering, and all these four were still in the top quartile in 2017. On the other hand, he lowest proportions of women in Canada 2004 and 2017 were in electrical, computer, software, and mechanical engineering (Sweeney, 2020). This shows that the trend is different between countries but one must keep in mind that the classification and names of similar sub-disciplines can be somewhat different.

Deciding on an academic study or a career is easy and straight forward for some individuals, especially when they have an interest and knowledge of the profession of choice earlier on. For others, this can be a provocative and strenuous project because of the many influencing factors. In an Icelandic study from 2018, 70% of the students said they got interested in engineering between 15 and 22 years of age (Matthiasdottir, 2018). Cruz and Kellam (2018) found out that students seemed to have limited understanding of what is involved in an engineering program in the USA before they started their study and Salas-Morera et al. (2021) concluded that high school students are not well informed about engineers' work and girls less than boys. To know when students develop interest in their field of study is relevant for those who want to reach out and introduce engineering to potential students.

Research has revealed different factors that influence the gender differences in choices of academic studies. In particular, the study by Cheryan et al. (2017) revealed forces, both within STEM (e.g., role models) and outside STEM (e.g., cultural stereotypes about these fields), that direct both women and men into some of the STEM fields. In a study from 2018, it appeared that males had more interest in the engineering profession, but females were more influenced by their success in science at earlier educational levels (Matthiasdottir, 2018). The model by Cheryan, Ziegler, Montoya and Jiang's (2017) to explain gender gaps in computer science, engineering, and physics is based on three factors: "(a) masculine cultures that signal a lower sense of belonging to women than men, (b) a lack of sufficient early experience with computer science, engineering, and physics, and (c) gender gaps in self-efficacy". They do emphasise that these factors may also be helpful to analyse gender differences in fields where men are underrepresented.

METHOD

The data used in this study originates from two sources. First, a survey was conducted among engineering students in the BSc program in engineering at Reykjavik University (RU), and second, data was obtained from the university registry on the number of students graduating with particular engineering sub-discipline. The BSc engineering program at RU is a 3-year program, and it follows the Bologna three-cycle degree structure

Survey

Participants

An online survey was e-mailed to 478 students that were registered in the bachelor program in engineering at RU. In total 124 (26%) replied, 64 (51.2%) males and 57 (45.6%) females. Four did not indicate their gender. The males' average age was 22.4 (sd=4.0; range=19-45) years and the females' 21.3 (sd=1.9; range=18-28) years. Thirty-two 32 (26.9%) were first year students, 55 (37.8%) second year, 38 (31.9%) third year and 4 (3.4%) fourth year, and the response rate between genders appeared not significant (Chi-square=1.16, p=0.76).

Measures

The online survey consisted of nine questions partly designed for this study and partly based on one of the author's study from 2018 (Matthiasdottir, 2018), with similar objectives as the current survey. The survey included students in both engineering (as in the current survey) and in applied engineering, but the latter group is more male dominated and includes a bit older students. The four background questions were on gender, age, line of study and year of study, and the five following questions concerning the participant's experience and attitudes:

- *Why did you choose to study engineering?* Thirteen answering options were given and the participant was instructed to select the three most relevant for him/her without ranking them.
- *Was something else than engineering an option?* The answering options were: yes, no, If yes, then what?
- *When did you first get interested in engineering?* Four age categories were provided: younger than 14, 15-18, 19-22 and older than 22.
- *What image did you have of engineers before you started your studies*? Eleven answering options were given and the participant was instructed to select the three most relevant for him/her without ranking them.
- *How much computer skills do you consider you had before you started to study engineering?"* This question was rated on a five point Likert scale, ranging between "Great skills" and "Very little skills". The term "computer skills" was not defined in the questionnaire and the participant could select one answer.

Of these five questions, all except the one on the image of engineers were in the survey by Matthiasdottir (2018).

Procedure

The system Free Online Surveys (https://freeonlinesurveys.com) was used to put the survey online and a link was sent to the participants by e-mail on the 2th December 2021 and a reminder on the 20th December. Teachers were also asked to encourage students to answer the survey. The survey was closed on the 30th of January 2022. Data analysis was carried out in Excel and the Statistical Package for the Social Sciences (SPSS).

Graduating students

The engineering department registry office provided information on students that graduated from the bachelor program in engineering. The data was for the years 2008-2021 and classified by gender and different sub-disciplines.

RESULTS

Survey

Table 1 shows the distribution of the genders between sub-disciplines in engineering as reported in the survey. Biomedical engineering is the most popular among the females (39.3%), but mechatronics engineering (28.1%) among the males. Second most popular discipline for the males is financial engineering (25.0%), but engineering management (26.6%) for females.

Table 1. Participants reported sub-disciplines according to gender.

	Male N (%)	Female N (%)	Total N (%)
Financial engineering	16 (25.0)	5 (8.9)	21 (17.5)
Mechatronics Engineering	18 (28.1)	4 (7.1)	22 (18.3)
Biomedical Engineering	10 (15.6)	22 (39.3)	32 (26.7)
Energy engineering	1 (1.6)	1 (1.8)	2. (1.7)
Electrical engineering	1 (1.6)	0 (0)	1 (0.8)
Engineering Management	7 (10.9)	16 (26.6)	23 (19.2)
Mechanical engineering	8 (12.5)	4 (7.1)	12 (10)
Software engineering	3 (4.7)	4 (7.1)	7 (5.8)

Both males and females selected the same top four reasons for choosing engineering education, i.e. "interesting profession" (56.3/38.6%), "interested in science" (53.1/40.4%), "good salaries" (50.0/43.0%), and "good employment outlook" (48.4/43.9%) as shown in Table 2. The gender difference was only significant for "interest in math", which was chosen by 38.6% of females and 20.3% by males (*p<0.05).

Table 2. The participants' reason for selecting engineering education.

	Male	Female	
	Yes N (%)	Yes N (%)	Chi-Square
Interesting profession	36 (56.3)	22 (38.6)	3.76
Good employment outlook	31 (48.4)	25 (43.9)	0.25
Good salaries	32 (50.0)	25 (43.0)	0.46
Interested in math	13 (20.3)	22 (38.6)	4.90*
Interested in computers	10 (15.6)	5 (8.8)	1.30
Interested in science	34 (53.1)	23 (40.4)	1.97
Did well in math in upper secondary school	13 (20.3)	19 (33.3)	2.63
I just wanted to try	6 (9.4)	11 (19.3)	2.46
Diversified profession	17 (26.6)	14 (26.6)	0.06
There has never been anything else	6 (9.4)	5 (8.8)	0.01
I was encouraged by others	2 (3.1)	5 (8.8)	1.76
Familiar with the subject through my family	5 (7.8)	3 (5.3)	0.32

Participants were asked if they had considered to study another subject at university and the most frequent subject mentioned was medicine (mentioned by 13 participants of which 8 were students in biomedical engineering).

Table 3 shows when participants felt they got interested in engineering education. There was a significant different between the genders (Chi-Square= 11.59 p<0.01), the females reporting higher age than the males.

Table 3. Gender and age when participants claimed they got interested in engineering education.

	Male N (%)	Female N (%)	Total N (%)
Younger than 14 years	13 (20.3)	1 (1.8)	14 (11.6)
15-18 years old	29 (45.3)	27 (47.4)	56 (46.3)
19-22 years old	18 (28.1)	26 (45.6)	44 (36.4)
Older than 22 years	4 (6.3)	3 (5.3)	7 (5.8)

Table 4 describes the participants reported image of engineers before they started their study. Both groups, males and females, reported solution-oriented (87.5/77.2%) and good at math (76.6/80.7%). Only the "masculine" image revealed significant difference (*p < 0.05). One participant added an item to the image list and said that his image of engineers was "nerds".

Table 4. The participants reported image of engineers before starting their study in engineering.

	Male N (%)	Female N (%)	Chi-Square
Masculine	10 (15.6)	19 (33.3)	5.19*
Feminine	0 (0)	1 (1.8)	-
Neither masculine nor feminine	6 (9.4)	11 (19.3)	2.46
Good at math	49 (76.6)	46 (80.7)	0.31
Tidy	4 (6.3)	3 (5.3)	0.05
Solution-oriented	56 (87.5)	44 (77.2)	2.23
Foresighted	22 (34.4)	12 (21.1)	2.65
Promote innovation	33 (51.6)	22 (38.6)	2.04
Promote sustainability	5 (7.8)	7 (12.3)	0.67
Formative	14 (21.9)	16 (28.1)	0.62

Table 5 describes how skilled the participants said they were before they started their study. As the table shows, 14.3% of the males considered them to have great computer skills before they started, but only 3.5% of the females. The difference appeared significant (Chi-Square = 10.42, p < 0.05).

Table 5. The participants' computer skills before they started studying engineering at university.

	Male N (%)	Female N (%)	Total N (%)
Great skills	9 (14.3)	2 (3.5)	11 (9.2)
Many skills	20 (31.7)	9 (15.8)	29 (24.2)
Average skills	18 (28.6)	27 (47.4)	45 (25.4)
Little skills	12 (19.0)	14 (24.6)	26 (21.7)
Very little skills	4 (6.3)	5 (8.8)	9 (7.5)

Graduating students

Table 6 shows how many female students graduated between 2008 and 2021 from the engineering department and the trend over the last 14 years (since the program started at RU).

Table 6. Female BSc engineering graduation between 2008 and 2021.

	Financial engineering	Mechatronics Engineering	Biomedical Engineering	Mechanical engineering	Engineering Management
Female	81 (33%)	48 (21%)	197 (77%)	11 (17%)	210 (55%)
Linear trend (%/year)	-0.8	2.1	0.1	4.4	0.9

Figure 1 shows the proportion of female students graduating from sub-disciplines from 2008 to 2021. Due to the low number of students, there are fluctuations in the number of graduates, but nevertheless when viewed with time like in Figure 1 there are clear trends for several of the programs.

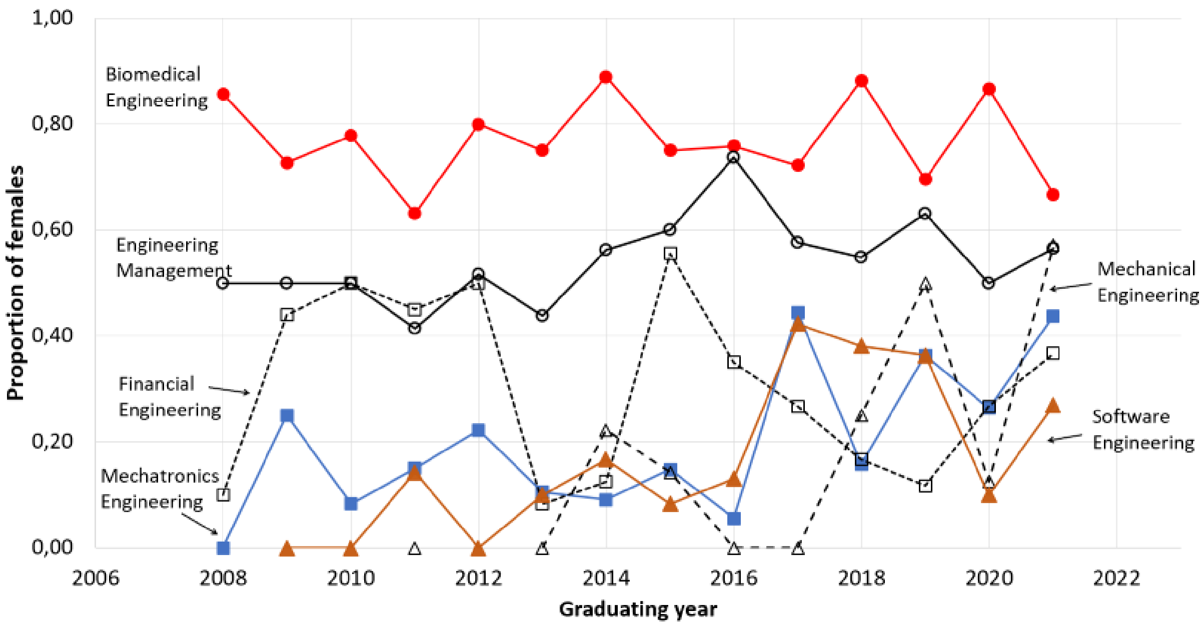

Figure 1 Proportion of females graduating from six engineering sub-disciplines during the years between 2008 and 2021.

DISCUSSION

The two main research question of the study where: Is there a gender difference in students' attitudes toward engineering? and Has the development of gender balance been changing for the last decade in different engineering fields?

The survey shows clearly a difference in what sub-discipline the genders select, biomedical engineering being the most popular among the females and mechatronics engineering among the males, who put biomedical engineering in the third place (Table 1). These results are consistent with the number of graduating students (Figure 1). The results are in line with the ASEE report, Profiles of Engineering and Engineering Technology from 2021 (ASEE, 2021). Research has shown that women are more interested in health-related subjects than males (Funke, Berges, & Hubwieser, 2016; Lin, Ghaddar & Hurst, 2021). The proportion of females in each graduating class in biomedical engineering has been amazingly high (77% females) and stable since the program started in 2005. It is worth mentioning that at RU the term for the discipline “biomedical engineering” when literally translated is “health engineering” (in Icelandic “heilbrigðisverkfræði”), and the program is based on similar foundation as for example mechatronics engineering, but has courses on physiology and biomedical engineering. Names of programs can influence students’ interest and especially women (Farrell, 2002; Brown, 2014) so this can partly explain why biomedical engineering is so popular among female students in Iceland. Moreover, there are nil or few role models in biomedical engineering in Iceland and for a long time all the faculty in biomedical engineering at RU were males (one female faculty joined the team two years ago).

The genders agreed on the main reasons for choosing engineering education, namely that it is an interesting profession with good job opportunities and good salaries, but one significant difference appeared. The females reported more frequently that interest in math was one of their reasons for choosing engineering at university which is in line with previous studies in Iceland (Matthiasdottir, 2018). It may be of interest that studies show that negative attitudes towards math among females seem to have declined over the years (Jacobs, 2005; Huang, Zhang & Hudson, 2019). Research has suggested that computer use in education can impact educational performance and could encourage more technology self-efficacy among students (Paino & Renzulli, 2013; Matthiasdottir, 2018). And once again, males reported better computer skills than females which has appeared in many studies before.

This study shows that females and males both view engineers before entering engineering as “solution-oriented and “good at math”. On the other hand, females in this study reported more masculine image of engineers before starting university and that they became interested in engineering education significantly later than males. This may give an indication when and how we should introduce engineering to students. In view of current popular discussion, it is worth noting that “promote sustainability” was ranked low for both groups, which is something worthwhile to look into regarding interest in STEM education, but is outside the scope of this paper. Overall, the results from the current survey are consistent with the survey by Matthiasdottir (2018) for the questions that are the same, bearing also in mind that the surveyed population is somewhat different. This further supports the results and conclusions in this study despite a low participation rate.

Pros and cons of online data gathering has been discussed for decades and as Lefever, Dal and Matthíasdóttir (2006) pointed out there are factors as for instance participants age, gender, interest and maturity that can influence the response rate. Despite some limitations of the survey, especially the limited participation, the main trends appeared clear and distinct, and in addition are consistent with previous survey (Matthiasdottir, 2018). Therefore, we believe that the results in the survey gives us a good idea of the situation and can guide us in working toward more equality in STEM education.

The trends in graduates as shown in Figure 1 show that although the ratio of graduating females is low in mechatronics, mechanical engineering and software engineering, the proportion of females appears to be increasing for the last decade. At RU at least, in some fields of engineering females dominate and in others males dominate, but the trend is in the right direction towards improved equality.

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CLOSING THE GAP BETWEEN CLASSROOM AND REALITY THROUGH VIRTUAL BRIDGES

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ABSTRACT

Online guest lectures serve as an important learning activity for students to bridge the gap between the classroom and the reality of business and has become common during the Covid-19 pandemic. Such lectures enable students to better link theories and concepts to practice and can provide valuable network opportunities for students by facilitating contact with professionals in their field of studies. Online guest lecturing has also proven to have benefits for the course administration such as an easier allocation of guest lecturers and a more effective use of resources.

This paper is part of a pre-study for determining the opportunities and challenges that online guest lecturing can have for students of engineering and management programs at a master level. Specifically, the purpose of the pre-study is to explore how online guest lectures are perceived among students and course directors, and how they can be improved. The method used involves a narrative literature review and an empirical pre-study.

The results suggest that online guest lectures allow students to enhance their knowledge on the course contents and allow them to make more informed career choices. They also suggest that course directors use guest lectures as a means for inspiring and supporting the learning of the students. However, the results also suggest that students can adopt a more passive role in online guest lectures compared to face-to-face guest lectures. Learning in online guest lectures could be enhanced when connected to learning activities that support them, e.g., follow-up seminars, assignments, and reflection documents.

In terms of implications, this study presents course directors and students' perceptions of online guest lectures, as well as presents improvement suggestions for course directors and guest lecturers when planning and performing guest lectures in university courses to enhance learning among students.

KEYWORDS

Guest lecture, STEM, online education, e-guests, postgraduate, CDIO standard 7, CDIO standard 11

INTRODUCTION

Integrated learning experiences is focused in CDIO standard 7 focusing on the acquisition of disciplinary knowledge with personal and interpersonal skills, and product, process, system, and service building skills. Using pedagogical approaches that integrated professional engineering issues contexts with other disciplines, help students to understand and prepare for the future career in the engineering role (CDIO, 2021). Guest lecturing in collaboration with industrial partners, alumni, and other key stakeholders are often helpful in achieving this integrated learning experiences. Different studies confirm benefits of using guest lecturing to connect students to the real-world working environment in industry, promoting integrated learning experiences (e.g. Jackson, 2017; van Hoek et al, 2015).

Nevertheless, the Covid-19 pandemic had a huge impact on university education. Teachers had to change their offices for their homes and students had to be educated through a screen. This represented challenges for the pedagogical methods used in university as almost all learning activities had to be adapted to fit a new way of teaching, with an online approach. Guest lecturing was not an exception.

Online guest lectures have become a common learning activity during the Covid-19 pandemic, which has forced the use of online applications for previous on-campus learning activities. Guest lectures have been performed online before the pandemic (Alebaikan, 2016; Costello, 2012) and it is anticipated to continue to be a requiring activity in higher education.

Previous research has recognized different strengths and weaknesses from using online guest lectures instead of face-to-face guest lectures (e.g. Hemphill and Hemphill, 2007; Li and Guo, 2015; Alebaikan, 2016; Fulton, 2020). On the one hand, online guest lectures provide increased flexibility and accessibility as students and guest lecturers can participate from different locations. On the other hand, such lectures tend to reduce social interaction between students and the guest lecturers in comparison to face-to-face settings, which can negatively impact learning among students (Fulton, 2020). Literature have presented different important aspects of online guest lectures (e.g. strengths, weaknesses, strategy and planning of such an activity). However, there is still a lack of understanding how this teaching activity is perceived by both students and course directors in different programs and contexts, as well as how this activity can be improved to enhance learning among students at a university level. Scholars have recommended further investigation on both the impact on learning and the perception of using online guest lectures in higher education (Alebaikan, 2016). This to further understand and improve online guest lectures to close the gap between the online classroom and reality. The purpose of this study is to explore how online guest lectures are perceived among students and course directors, and how they can be improved.

The outline of this paper includes a frame of reference, followed by the method used. Thereafter, the findings from the empirical data are presented, followed by a discussion. The paper ends with a presentation of the conclusions and implications.

FRAME OF REFERENCE

Previous literature on face-to-face and online guest lecturing centres in the suggestion that guest lecturing narrows the gap between the theory that students learn in a course and the reality when it is applied in a company (Costello, 2012; Deweck et al, 2005; Eveleth & Baker-Eveleth, 2009; Fulton, 2020; Hemphill & Hemphill, 2007; Rich et al., 2018; Rowland & Algie, 2007). Rowland and Algie (2007) mentioned that guest lecturing has the potential for improving the student's first-hand knowledge from real-life business practices. Ji et al. (2021) stated that guest lecturing can be seen as a way of experiential learning that provides a more accurate picture of the contents of the course. Experiential learning is explained by Biggs and Tang (2011) as a way of learning that involves the transfer of knowledge from real experiences to the students and constitutes a way to deepen and strengthen learning in students. Moreover, guest lecturing can be used to highlight the current state of the art implementations in industry and keep students up-to-date and ready for the business world (Quist et al, 2017). Then, Hemphill and Hemphill (2007) added to the deepening of knowledge by stating that online guest lectures can enhance the students' critical thinking.

Several researchers highlight benefits from using online guest lecturing. According to Rich et al. (2018), guest lectures have the potential to awaken interest in a subject and to evidence the relevance of the methods studied in previous lectures and literature. Similarly, Eveleth and Baker-Eveleth (2009) stated that the credibility that the guest lecturer possesses by presenting real-life events may be able to reinforce learning of the contents of the course. Ji et al. (2021) suggested that it is important for the students to be able to relate to the guest lecturer. Therefore, it is often preferred to have alumni and recent graduates as guest lecturers. In addition, Ji et al. (2021) found that students see guest lectures as a possibility to obtain professional connections. In particular, guest speakers can provide the students with the possibility to have an introduction to career choices and to understand in a better way their field of studies (Belsera et al., 2018; Costello, 2012).

Challenges with online guest lecturing were also found in previous literature. Fulton (2020) suggested that the guest lectures should be used in combination with other teaching activities besides traditional lecturing for increasing the learning opportunities. The author explained that online guest lectures can have a difficulty for enabling interaction among participants. Some researchers suggested that the use of more interactive teaching forms than traditional lecturing could have a better result in the learning (Craig et al., 2021; Merle & Craig, 2017; Riebe et al., 2013). Interactive teaching forms include teaching activities with questions and answers or discussions where the students are included to increase their engagement. Hemphill and Hemphill (2007) also highlighted the importance of student engagement and consider that online guest lecturing can enhance engagement among students. In contrast, Merle and Craig (2017) stated that traditional lectures are a more recommended approach than the online alternatives for enabling the interaction and engagement.

Furthermore, Riebe et al. (2013) mentioned a challenge related to the participation of the students. These authors stated that for the learning to be deepened by the guest lecture, the students need to have an active participation. This active participation can be included by linking the guest lecture to an additional evaluation or learning activity. Some examples to these activities are case solving, discussions, and simulations.

There are certain considerations referring to the way a guest lecture is performed. Riebe et al. (2013) highlighted the importance of having an appropriate guest lecture. The authors suggested that a guest lecture should be well-organised, focused, interactive, and have a clear and well-stated purpose. A guest lecture should also enable students to have critical thinking, analytical and allow them to apply the learnings from the course to the contents of the guest lecture.

Eveleth and Baker-Eveleth (2009) refer to the importance of choosing an appropriate speaker for the lecture. The guest lecturer should have expertise, be credible and have good communication skills for having a greater impact on the students' learning (Eveleth & Baker-Eveleth, 2009; Farruggio, 2011). Fulton (2020) stated that the guest lecturer should have appropriate expectation on the lecture and communicate those expectations clearly to the students. Additionally, and particularly for online guest lecturing, is it advisable that the guest lecturer explains the technologies associated to the development of the guest lecture. Items such as the opportunities to ask questions in a chat and calling for the attention of the speaker enables a better communication with the audience. It is also recommended that the students are familiar with those technologies prior to the guest lecture.

METHOD

This paper constitutes a pre-study, in a work in progress status. It is a qualitative investigation on the perceptions of online guest lecturing from the students and the course directors' perspectives. As a first step, a narrative literature review was performed, followed by an empirical pre-study. The pre-study involved students' and course directors' perceptions from three different courses given at the division of Logistics and Quality Management at Linköping University for the first semester 2021. The data collection in the pre-study involved interviews with both students and course directors from these courses. The literature review and the empirical pre-study are further explained in the upcoming section.

The literature review

A narrative literature review with a snowball approach was used for this paper. Initially, relevant papers regarding guest lecturing were searched and read by the authors. For this initial review, search terms such as "STEM", "Guest lect*", "distance", "online", "digital" and "university" were used, where "*" was a wild-card.

The results from this initial review constituted the base articles for the snowball approach. In the review with the snowball approach, new sources were discovered from the base articles leading to other relevant literature for the purpose of this paper. The literature review resulted in the frame of reference of the paper and worked as a base for designing the questionaries used in the upcoming data collection.

The empirical pre-study

The empirical pre-study involved three courses at a master level. The settings of the courses are summarized in Table I.

Table 1. Courses information

Course	Content	Pre-requisite	Teaching language
A	Introductory course on quality management	None	English
B	Introductory course on Lean production	Basic knowledge in quality management	English
C	Introductory course on buying strategies	Basic knowledge in logistics	Swedish

All guest lectures in all three courses were conducted online. The guest lecture for Course A involved a single guest lecturer from a consultancy company who presented their ways of working with quality management for enhancing sustainability, in different companies. The guest lecture in Course B constituted a two-and-a-half-hour conference where five representatives from different organizations presented Lean initiatives in their companies. The companies included in the conference were a vehicles and tools production company, a pharmaceutical company, a regional governmental entity, an insurance company, and a company dedicated to aerostructures. As an introduction to the conference, the representative from one of the companies did a 45-minute presentation about how his organisation has been working with Lean. Then, there was a discussion panel in which all five representatives joined in answering questions from students and discussing. Finally, course C involved two guest lecturing sessions, which involved a presentation by the lecturer and ended with a question session where the students could ask questions. The first lecture involved two guest lecturers from a consulting company, which presented how they adapted a traditional purchasing process (known from the course) in their own work. The second lecture involved one guest lecturer, who held a presentation about strategic purchasing and her experiences from working at different purchasing companies as well as in different business sectors.

Data collection

The data collection included interviews with students and course directors, conducted in two sets. Based on literature from the initial review, two questionnaires about guest lectures were designed and reviewed by the researchers. The first set involved the interviews with the course directors, which involved questions related to guest lectures from a course director´s perspective. Due to time constraints, the questionnaires were sent by e-mail and answered by the course directors. Follow-up questions were done when needed.

The second set involved the student Interviews, which involved questions related to guest lectures from a student´s perspective. Emails were sent to some of the students of the courses explaining the purpose of the pre-study and the anonymity of participating in it. The students that replied were interviewed by one of the researchers. All interviews were recorded. The interviews were conducted in a semi-structured way, following a guide questionnaire. The language of the interview was determined by the course language. The selection of the students for the interviews of courses A and B was restricted to students that had attended both courses.

Analysis

For this pre-study, an analysis based on pattern matching was performed. The researchers scanned for similarities between what the students and the course directors expressed during the interviews and what was found in the literature review. Moreover, a cross-case pattern matching was performed by comparing the experiences of the students and course directors from Course A, B and C.

FINDINGS

The key findings from the analysis of the empirical data are presented in the upcoming section. To start, according to the course directors, the aim of the guest lectures was typically to create a better connection to reality and to deepen the knowledge related to the course. Several benefits from guest lecturing were mentioned by the interviewees. The courses directors mentioned that the use of online guest lectures facilitates the allocation of resources. It is easier to allocate potential guest lecturers without constraints such as distance, location, and time. It is a way of having simpler and more economic guest lectures in a course.

The course directors also reflected on having higher rates of attendance compared to onsite guest lectures in previous years of the same courses. However, they identify certain issues when dealing with online guest lectures, in particular interaction with the students. The directors experienced a lower number of questions and overall participation when the lectures were online despite the higher attendance. Similarly, the students mentioned that onsite guest lecturing could facilitate for the students to ask questions and be more inviting for a discussion.

Moreover, the course directors mention that it is difficult to engage the students in the lecture, this was confirmed by the students. The students mentioned problems to stay focus due to other distractions and possibilities like surfing in social media or developing other assignments while listening to the guest lecture. The students feel more confident to ask questions when it is possible to see the reactions of their peers. In online options of teaching, it is common that the students have the camera off during the lectures if they don't get another indication from the lecturer or course coordinator. Overall, the findings suggested that achieving the students' engagement requires more effort from the lecturer when using an online modality.

From a students' perspective, they feel compelled to listen during an onsite guest lecture, whereas in an online lecture the student felt less compelled and was more inclined to do something else or leave. The reason for the higher sense of responsibility was attained to the sense that the guest lecturer seems to make a bigger effort by traveling to the university to give the lecture. One of the guest lectures in course C involved a presentation followed by a discussion, the attendance decreased before the discussion began. The following quote describes what happened:

"[a challenge with online guest lectures is...] group discussions, getting feedback or reconnection. It is hard to force students to discuss and many disappeared when it was time for the discussion."

-Course director for Course C

Moreover, the respondents mentioned that the online guest lectures were sometimes more difficult to listen to. For instance, it was difficult for the students to follow the discussion during the conference in course B, when several lecturers were speaking at the same time in a discussion panel. The respondents also mentioned technical issues related to the online guest lectures, such as internet connection and audio issues. These issues made it hard to stay focused, and to interact with the guest lecturer. Language skills was also mentioned as a relevant factor that could be a hinder for students attending online lectures. The risk for this hinder is reduced for onsite lectures by adding the body language of the people involved.

The findings also include key components of a good guest lecture. Most of the respondents mentioned that a guest lecture needs to be inspiring, relatable, and serve as a complement to the other learning activities in a course. The interviewees mentioned the importance of "real-life" examples, where theory presented in the courses were applied on real problems.

"[in guest lectures...] students get pictures and experiences from practitioners. Theories taught in the course got reflected, emphasize or brought to life by the guest lecturers"

-Course director for Course B

Students express that there is a lack of "real-life" examples that they can relate to, and that larger parts of the lectures often constitute the guest lecturer presenting the company´s achievements without relating it to the course. Instead, the students request an honest approach from the guest lecturers, where they present important skills sets as well as common pitfalls that they have encountered in their work. This enables the students to better understand the practical use of the content taught in the course. The students considered that the online guest lectures allowed a limited interaction, which limited the opportunities for networking and for identifying employment opportunities. Nonetheless, some of the students considered that the nlyne guest lectures provided them with a better insight of different working opportunities and industry branches. This insight can support them on making future career decisions, for example the type of desired employers or the choice of branch. This was an expectation from one of the course directors, who stated that guest lectures could give the students a better picture about the future career and a vision to the future of the field of the course.

Students considered the guest lectures as an “eye opener” and mentioned that it was during this kind of lectures that they realized that the theory studied in the course usually needs modifications, simplifications, and adaptations to the different contexts. Also, that tools and methodologies might seem simple, standardised, and applied stepwise whereas; their application, can be more abstract and context dependent. Therefore, students see in the connection between the guest lecture and the course contents a requirement.

Students mentioned that a relevant aspect of guest lectures is the timeframe in which they are placed in the schedule. Some students reflected on the timing of the guest lectures and wish they came earlier in the course. Perhaps as a lecture with an introduction purpose to the subjects of the course. In addition, the students mentioned that it was more likely that they would prioritize other things when the guest lectures were in the end of the course and not connected to any evaluation activity.

Similarly, in terms of preparations and examinations connected to the guest lectures, only two of the courses had other learning activities connected to the guest lectures. Before the conference in course B, the students had to submit three questions per student group. The students express that it was interesting to design questions that they could ask before the conference. However, it was difficult to design relevant questions since they did not have any knowledge about the specific contents of the conference beforehand. Moreover, the students expressed their disappointment because not all questions were asked to the lecturers. Also, it was the course coordinator who asked all the questions which limited the opportunity for the questions to lead to a discussion or for follow-up questions to emerge. In Course C, it was recommended to read course literature before the guest lecture, however, the literature was not directly connected to the specific lecture. The student from this course did the recommended reading but expressed a wish to have a more active role, for example by being able to ask questions to the lecturers.

In terms of examination, the students in Course B had to submit a reflective document after the guest lecture, and in Course C the content of one of the guest lectures were used in the final exam. The course coordinator for course A explained that the reason for not having an examination connected to the guest lecture is that, while having a grading assignment might increase attendance to the lecture it might also result in the student focusing more on studying the lecture instead of thinking freely and have a more reflective posture to the contents of the lecture. Moreover, the course coordinator considers that the guest lecture in that specific course is intended as a moment for developing and stimulating new ideas for students. This distraction situation was mentioned by a student from Course B. The reflection document required after the guest lecture made him prioritise identifying connections between the lecture and the contents of the course for writing the assignment. The student reflects on an issue in which it was possible that he missed other aspects for writing the assignment while the lecture was held.

According to the expectations for the guest lecturing, the course directors wanted the students to get a clearer and deeper understanding of the contents of the course. They also expected the students to get a better understanding of the practical applications of those concepts. Most of the students had none to low expectations on the guest lectures, as their previous experiences from guest lectures had lacked relevance and were not prioritized as they typically were not a part of the examination.

Furthermore, the analysis presented the importance of skilled guest lecturers to motivate and stimulate learning among students. The empirical data presented several key features of a guest lecturer. To start with, most respondents argued that a guest lecturer should be knowledgeable, inspiring, energetic, and have excellent communication skills to captivate the audience. In addition, alumnus was often preferable as guest lecturers among the students as they tend to be more relatable to the students and have previous experience of the structure and the content of specific course that enable the guest lecturer to create more informative and relatable content.

Finally, the respondents preferred onsite guest lectures over online lectures. The main reason for this was that the respondents found it easier to listen, to focus and to interact with the lecturer onsite. Also, the students consider that the results of the guest lecture are not that sensitive to the speaker skills when performed onsite.

DISCUSSION

From the student and course coordinator perspectives, online guest lectures' main contribution is to increase the proximity between "real-life" and the course contents. The empirical data confirms what is stated in literature in terms of the purposes for using guest lecturing. Then, it also confirms the suggestion that having online modalities to guest lecturing has certain benefits from a course coordination perspective. For example, easier to find guest lecturers, less constrains in terms of time, costs, and distance, and increasing the possibility to have more guest lecturers due to the resource effectiveness aspects related to online teaching.

Online guest lecturing also allows the students to have more freedom, if the student is really interested in the subject, they can listen to the entire lecture but if the subject is not interesting then they have the possibility to leave the lecture or to focus on other tasks. Undoubtably, this can also be seen as a drawback since the students can have difficulties to stay focused on the lecture. They have more accessibility to distractions without the lecturer noticing their lack of attention. This challenge for the lecturer to "read" the audience becomes then a hinder for taking actions to catch the attention of the students and make pauses when the students need it. This also becomes a challenge for the students to read their peers reactions during the lecture, especially when no video of the students is included. This represents a hinder for the students to dare ask questions and starts discussions with the guest lecturer.

In literature, one of the benefits mentioned for guest lecturing was the professional opportunities to which having guest lecturers can lead to. The empirical data confirms that online guest lectures can give the students insight on their field of studies, as well as inspire them and aiding them in the selection of their future career paths. In contrast, the students do not see in online guest lecturing an opportunity that could lead to employment opportunities or professional networking. This is attained to the limited-to-no interaction between the guest lecturer and the students.

The student-guest lecturer interaction is mentioned as a relevant requirement from both a student and a course coordinator perspective. In literature, it is also mentioned as one of the biggest challenges, especially for online guest lectures. Both students and course directors mentioned the benefits from supporting the guest lectures with another type of learning activity.

However, as expressed by one of the course directors, examination activities might lead to a distraction for students. This was the case for one of the students in course B. We suggest that the connection to other learning activities could be done to non-evaluation related activities for incentivising the students' freedom of thought and critical and analytical thinking.

Another similarity found between literature and the empirical data was the important aspects related to the way the guest lecture is performed and the characteristics of the guest lecturer. Between these two sources, there is a consensus in the idea that an online guest lecture needs to be relevant for the contents of the course. Moreover, it needs to have a clear purpose and a technical structure for transferring knowledge to the students. The technologies involved for holding the guest lecture should be known by all parts involved and easy to use. Then, it is recommended for the guest lecturer to be aware of the contents of the course and design the guest lecture in a way in which it has a clear connection to the course. Additionally, it is important for the guest lecturers to be familiar with online lecturing, have good communication skills and be aware of the importance to interact with the students.

Overall, from perspectives, the onsite guest lectures are preferable and suggested to have a more effective knowledge transfer and more interaction between students and external partners than its online peer. However, there is a potential to use guest lectures with an online modality connected to other learning activities. This could facilitate the administration of the guest lectures while still providing the students with opportunities to deepen their knowledge.

CONCLUSION

This pre-study suggests that onsite and online guest lectures have the potential to reduce the gap between theory and real-life. They provide students with experiential learning allowing them to broaden and deepen their knowledge on the course contents. They also provide opportunities to make more informed career choices in the future. Nonetheless, from a students and course directors' perspective, the onsite alternative is preferable. This is attainable to the interaction possibilities from onsite learning.

Online guest lecture can be more resource effective from an administrative point of view, but it might require additional learning activities linked to it for having a considerable effect in the students' learning.

However, this pre-study has some limitations. First, the empirical data was gathered from three courses within an industrial engineering and management program in one university. Second, the perspective of guest lecturers themselves was not included in this pre-study, but only the perspectives of course directors and student. Indeed, more research is needed for strengthening online guest lecturing. We suggest the need of additional teaching activities to support online guest lecture. Therefore, the adequate type of teaching activities that best support online guest lecturing should be investigated. This should be investigated from an administrative, technical, and educational point of view. Moreover, it is also interesting to look into pedagogical quality of guest lectures related to guest lecturer's competence and as sociated learning activities could be assured in practice.

Regarding the implications of this pre-study, we suggest that it can be a basis for developing a bigger study that involves more students and course directors. We anticipate that a study could have great impact on the available information about online guest lecturing. Moreover, it would be of great support for course directors and guest lecturers in the tasks of planning, designing, performing, and evaluating online guest lectures at a university level. In addition, this study involves an elaboration on the CDIO Standards 7 and 11. In particular, our study concerns integrated learning experiences, as well as learning assessment related to online guest lectures.

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DEVELOPMENT OF PROFESSIONAL CAPABILITIES IN A CHALLENGE BASED LEARNING ENVIRONMENT

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ABSTRACT

Often industry expects university graduates to hit the ground running. One way to deal with this expectation is to offer our graduates opportunities to collaborate with the industry—a collaboration to acquire theoretical skills and acumen in engineering practices and how a business works. Challenge-based learning environments intimated by the CDIO principles, which focus on real-life experiences, external stakeholder involvement, complex problem solving, and a focus explicitly on knowledge application, offer a rich environment that may allow the needed preparation. One of the proposed outcomes for students is the improved acquisition of professional capabilities. However, it is not established yet, whether these professional skills are acquired or strengthened in CBE settings. Professional capabilities focus on four levels; knowing oneself, critically thinking about the problem, collaborating, and having contextual and ethical awareness.

In this study, we surveyed if students perceive improvement in applying professional skills. We particularly questioned professional skills enabling behaviors based on validated questionnaires of EPFL and Univ. Sydney. Additionally, we have gathered and analysed the peer feedback within teams on personal leadership. Contrary to the expectations, leadership skills and professional capabilities are unrelated.

KEYWORDS

Suggest approximately 4 - 6 keywords, separated by commas. The last keyword **must** be “Standards” and include a numerical list of the particularly relevant CDIO Standards, e.g., Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

The 21st-century workplace shows an increase in complexity, digitisation and diversity (Kamp, 2020). These trends challenge higher education institutions to deliver students capable of dealing with new ways of working. One must have an overview of critical issues in a company and beyond; continuously renew, by collaborating with other disciplines, one's knowledge and use this for new practical applications and interact with different scientific and non-scientific disciplinary stakeholders (Peters et al. 2019), (Dorst, 2017). These critical issues require higher engineering education students to effectively cope with unpredictable circumstances, develop their professional capabilities, deal with complexity and personal development, and meet workplace situations' demands (Lizzio & Wilson, 2007).

The Joint Interdisciplinary Project (JiP) aims to prepare Master's students for entry into the workforce after their studies. In JiP, a ten-week 2nd-year master course contributes to solving impactful, real-life technological challenges provided and supervised by renowned companies. Interdisciplinary student teams are guided by a company coach and are offered academic and industry expertise. The course objectives are:

- LO 1. The ability to integrate (scientific and practical technological) knowledge from different disciplines to solve complex problems
- LO 2. The capacity to evaluate the ethical, scientific and societal consequences of the proposed innovation
- LO3. The ability to create reasonable and relevant research or design, according to the academic and technological standards of the involved disciplines
- LO 4. Demonstrate behavioural competences and skills relevant for teamwork and effective communication with different stakeholders
- LO 5. To carry out regular reflections on professional and personal development and being able to improve upon those reflections

The course in itself follows the CDIO characteristics of the flexible curriculum, diversity of disciplines, culture and academia vs industry, as a point of departure, R&D innovation or design offering reflection on technology and personal Development (Malmqvist et al., 2019). Students work in interdisciplinary project teams and are reviewed by 360 panels of experts on their work. During the course, students reflect on personal leadership skills, the values/beliefs of culture and company, and the team process during the course. Equally, they receive peer feedback from their team members on their leadership skills, and sometimes the company coaches also provide input on the team process. However, the purpose of this paper is not to explore the course design but the perception and measurement of professional capabilities and leadership skills by students in different types of courses.

THEORETICAL FRAMEWORK

Many heve tried to capture the professional capabilities needed to thrive in an academic to a professional environment. Attributes for effective professional development are self-reliance and courage, social understanding and professional consciousness ((Lloyd et al., 2001, Trevelyan, 2019)). Another set of attributes is social competence, collaboration and negotiations with various people, having an eye for new opportunities, taking continuous initiative and functioning in a group, e.g., high participation in group discussions, ability to work in a team, good presentation of information and knowledge, proactive attitude, and taking responsibility for the successful functioning of the group (Semeijn et al., 2006) and Professional capabilities are identified and related to communication, collaboration, contextualisation and responsible behavior, beyond the knowledge of content, methodology and tools (Picard et al., 2021).

In this paper, we have chosen to use the definition of Trede (2017) of the "deliberate professional", as its' description is applicable across various disciplines and allows for a coherent interpretation of the plethora of the many different attributes mentioned in the previous paragraphs. She poses; that "a deliberate professional consciously reflects on who he/she is and acts in the world, making deliberate choices, taking up a position and acting responsibly with deliberation about the consequence of their actions". This description is the result of four characteristics that need to be acquired during higher (engineering) education and is ideally related to a challenge:

- Being aware of the complexity of the workplace practice, cultures and environments
- Being realistic about what can be done concerning existing and changing practices
- Positioning oneself in the field as well as making technical decisions
- Being aware of the consequences of doing and acting in relation to a particular practice.

We have interpreted this as knowing oneself (personal development), realising agency – acting from a conscious act of reasoning, collaborating in context and understanding the contextual environment and responding in an ethically sensitive way.

The central question is:
- **To what extent did students perceive to have acquired professional capabilities in this course?**

Furthermore, leadership skills are currently used for the personal development reflections; we felt this might enhance the professional capabilities, and therefore, the second question is
- **What is the relation between professional capabilities and leadership skills?**

METHODOLOGY

In this study, we have questioned whether students, through reflectional activities and course activities, felt better able to perform particular behavior related to professional capabilities.
The questionnaire has been developed to measure these professional capabilities across various contexts in two Master's programmes of an Engineering School, besides the interfaculty course referred to in this article. All of the Sample contexts include:
Reflective activities on personnel and skills development, some challenges – ranging in openness of the design briefs and "real" life cases, involvement of stakeholders, a level of flexibility in students' choice and a Master's level.

Professional capabilities are measured at four levels:
1st: Personal Development: knowing oneself, Emotional reflexivity and Resilience
2nd: Agency: skills to critically think about the problem at hand and take a stance; evaluate information at a professional level, such as evaluative judgements
3rd: Collaboration, consisting of interprofessional competencies and teamwork.
4th: Contextual Insight concerns contextualisation and ethical sensitivity.
.
The overall model components are derived from Trede's model on professional capabilities explained in her book the Deliberate Professionals (Trede, 2009). Such as having an informed vision, emotional reflexivity, resilience, and taking a stance. Questionnaire questions have been taken from existing and validated questionnaires or qualitative studies, amongst others from the IMPQ (Picard et al. 2021), which investigated professional teamwork skills. Furthermore, the critical thinking white paper from Davies & Stevens (2019) Pearson's talent management offers evaluative judgement and critical thinking as elements.

The response level was 54 out of 180 students taking part in the course, which was relatively low, around 27%, indicating a broader trend of decline in questionnaire responses over the past decades (Fosnacht et al., 2017, Morton et al., 2012). However, Morton (2012) points out that results need not be less accurate, but we need to be aware of the risk of limited validity.

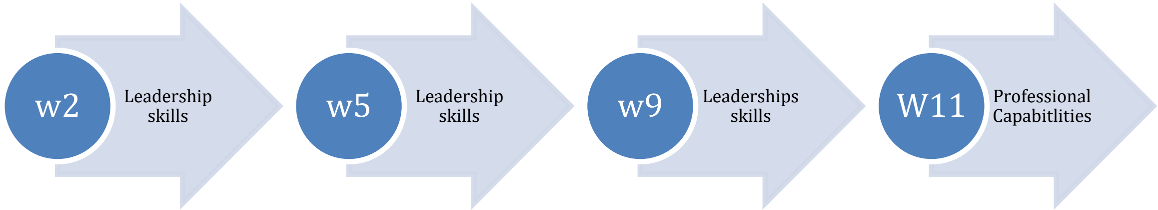
Of these 54, there were 36 males and 18 females. Most of them were Dutch 40% with Indians 20% and other cultural backgrounds like Chinese, Sudanese, Greek and Italian. In the sample populations, there are 12 different nationalities. The average age group of these 2nd Year Master students was predominantly between 23- and 27, followed by 27- and 32. Very few of them are over 32, and none are under 23. The majority of the students have a background in Mechanical Engineering N= 15. The other backgrounds range from Electrical Engineering, Mathematics, Aerospace Engineering to Industrial Design.

As measured by Cronbach's Alpha, the reliability of the entire questionnaire is .92, which is representative of a highly reliable questionnaire that validly measures the proposed constructs (Nunally, 1978). The separate Cronbach's alphas for each construct are listed below. Despite the somewhat low scores on Self and Communication < .65, we have decided to report on them separately to provide maximum insight into the results.

Table 1. Professional Capabilities- Reliability of Constructs

	items	Cronbachs' alpha	Source
Part 1 – Personal Development		**.87**	
Self	N = 4	.64	Trede
Emotional Reflexivity	N = 6	.74	Trede
Resilience	N = 8	.80	Trede
Part II Agency		**.68**	
Evaluating Information	N = 5	.67	Critical
Critical Stance	N = 4	.66	Critical
Part III Collaboration		**.80**	
Communication	N = 5	.62	IMPQ
Interprofessional Competence	N = 5	.77	IMPQ
Part 4 Contextual insight		**.82**	
Informed Vision	N = 7	.78	Trede
Ethical Sensitivity	N = 4	.85	IMPQ

The students are asked for self-perception of their professional capabilities.



We also used aggregated peer-reviewed data to infer whether they acquired these skills. During the course, students have filled out a leadership questionnaire based on leadership model competencies from the H.R. department of the University; these have been translated into interdisciplinary competencies. Each team member was scored three times during the course on their leadership skills in an online instrument called buddy check by all other team members, resulting in a spiderweb for each team member and provided verbal feedback on how they were doing in the team. The measurement was in W2,5 and 9 of the ten-week course.

The verbal feedback was not captured. However, the aggregated results on cluster level of the week three scoring are available, providing some zero measurements regarding students' professional capabilities. There were 7 clusters, each with different amounts of teams and team members. Only aggregated results are presented from the two most significant clusters, Aerospace and Energy transformation and offshore, containing roughly a representative number of students and equal to those who answered the questionnaire.

The Leadership skills are measured in the following scales

- Innovation: Having a positive Mindset to change
- Innovation Results: Taking responsibility
- Interdisciplinary integrations: open to learning from others and taking initiative
- Interdisciplinary collaboration: working together effectively
- Critical thinking: impact and influence on others
- Reflection: able to reflect on personal performance based on feedback

Note that these labels have been tweaked for practicality's sake in this context. They will be further explained in the results section.

A word of caution on reading the interpretation of the results should be incorporated. This research is very data-driven. Meaning data collection was executed in a natural setting. More importantly, the instruments have been designed for other purposes than researching the particular question raised in the introduction. On the one hand, this provides us with more raw data, which is a good thing. On the other hand, we may find that these data do not entirely satisfactorily yield the needed data to answer the research question.

Hypothesis

The hypothesis is that the leadership's peer feedback questionnaire would provide some sort of zero measurements to establish what students were already capable of doing. The professional capabilities questionnaire would hopefully demonstrate the increase in the acquisition of professional capabilities behavior.

RESULTS

In the results section, we will first look at the aggregates of professional capabilities. In the second part, we will look at the peer review results on Leadership skills. We assumed the leadership skills are likely to correlate with the Professional Capabilities and can be used as a baseline measurement of the Professional capabilities acquired in this course.

Professional Capabilities

We have explicitly not chosen confirmatory factor analysis to analyse the results, as the number of data points does not warrant such an elaborate statistical procedure. We have taken the mean aggregates with standard deviation on the construct level. The reason is that almost all the scores are above 3.8 and below 4.40; a considerable agreement exists between the students on the acquired professional capabilities. As the alpha scores are relatively high, we trust that the data are representative of the students' perceptions. There are slight differences between females and males on average construct scores, with females scoring higher on critical stance, ethical sensitivity and interprofessional competence and males on all the other constructs. Resilience, in particular, shows a significant discrepancy score Means 4.3 for males and 3.9 for females (sign .019 on one way ANOVA). They are showing women to be less resilient.

It is unclear whether the relatively high and homogeneous scores result from learning in this course or because there is a selection bias at the start of the course. Students have to register with a motivation letter to participate in the course and may already be more prepared for this course. We presume, however, it is partly due to the course as the questionnaire has also been released in other Master courses where reflection and challenges played an important role. We found more varied and lower results in the perception scores of students, notably on personal development in the other courses. To further investigate this course, we will now look at the peer-review data that have been collected in week 2 of the course. (For both questionnaires, the list of questions is included in the annexe).

Table 2. Professional Capabilities – Aggregated Means/SD

Professional Capabilities	Mean Average	SD
Part 1 – Personal Development		
Self	4.27	.44
Emotional Reflexivity	4.21	.49
Resilience	4.17	.47
Part II Agency		
Evaluating Information	4.23	.35
Critical Stance	4.26	.41
Part III Collaboration		
Communication	4.22	.48
Interprofessional Competence	4.26	.50
Part 4 Contextual insight		
Informed Vision	4.15	.53
Ethical Sensitivity	4.14	.57

Leadership Skills Peer Review Results Week 2

Table 3 shows the Peer review results of week two on the students' leadership skills. Note that the Means/S.D. are the aggregate of the constructs used in the leadership skill questionnaire. Only cluster Aerospace and Energy and Offshore Engineering have been presented in table 3 as **MEANA** = Aerospace and **MEANE** = Energy. The Energy teams consist of 10 teams of N=40 students, and the Aerospace teams consist of 7 teams of N-34 students. Each team member has an aggregated score of all the team members, including their self-score. Each sub-score thus represents, on average, four persons. The students' self-score could only be retrieved in terms of a differentiation score as opposed to the team score. The differentiation scores range from .99 to 1.18 of the individual score in contrast to the team score. These individual scores have been aggregated further into a mean cluster score across all the teams in a cluster and are presented in table 3.
.

Table 3. Leadership Skills – Aggregated Means/SD for Aerospace and Energy Clusters

	Leadership Skills	**alpha**	**MeanA**	SD	**MeanE**	Sd
	Innovation Skills					
1	Mindset	.80/.87	4.09	.33	4.35	.31
2	Results	.89/.82	4.09	.32	4.6	1.83
	Interprofessional Competence skills					
3	Collaboration	.82/.88	4.19	.35	4.37	.31
4	Influence (critical Thinking)	.80/.88	4.28	.25	4.44	.26
	Empathy					
6	Integration (initiative)	.81/.82	4.19	.27	4.35	.30
7	Reflection and Feedback	.68/.88	4.21	.21	4.39	.31

We notice that the average scores of the Energy Cluster tend to be slightly higher than those in the Aerospace Cluster. An independent sample t-test shows the clusters Aerospace and Energy significantly differ on the construct innovation Mindset (.001), Reflection (.005) and Influence (critical thinking) (.007), with cohens' d effect Sizes of .32, .27 and .25, respectively, suggesting a very moderate impact. However, we observed that teams tended to give team members more or less the same score and relatively higher than lower. Meaning the results are pretty biased. Written feedback notions, such as you should score high to get a good grade or let's encourage each other in the team process and not score too low. It must be emphasised that the buddy check was used only as an instrument to stimulate reflection and not for grading. The reflection was graded based on what they learned from the feedback from the buddy check.

To establish whether the students' did acquire professional capabilities during this course, we intended to use the leadership questionnaire as a zero measurement. Whether we can compare the two questionnaires depends, however, to what extent some of these scales are related to one another. To find out, we conclude with a correlation matrix on the aggregates to see how much these initial scores on leadership corroborate the professional capabilities perceptions of students.

Included in the table is the Pearson Correlation. Only significant correlations are reported. In the blue space, we find the correlations of the Professional capabilities Questionnaire. As we see, the constructs are almost all significantly and positively correlated within the professional capabilities' questionnaire. Meaning there is a positive linear relationship between the variables of the Professional capabilities' questionnaire.

Table 4. Pearson Correlations – Professional Capabilities Variables

	Self	ER	Res	EI	CS	Com	IC	IV
Self								
Emotional Reflexivity	536**							
Resilience	631**	633**						
Evaluative Information	4.98**	-	391**					
Critical Stance	447**	-	330*	484**				
Communication	457**	377**	437**	556**	623**			
Interprofessional Competence	325*	-	281*	448**	556**	646**		
Informed Vision	333*	306*	620**	373**	407**	500**	420**	
Ethic Sensitivity	321*	-	332*	350*	498**	456**	676**	480**

**** correlations is significant at the 0.01 level (2-tailed)**
***correlation is significant at the 0.05 level (2-tailed)**

When we examine the Pearson correlations with the leadership variables, we find that none is significantly correlated to any professional capabilities' variables.
The Pearson correlations for the leadership variable are shared in the table below. We see a strong positive correlation between all the variables except for Innovative Results, where low or no significant correlations could be found.

Table 5. Pearson Correlations – Leadership Skills

	Mindset	InResults	Integration	Coll	CT	Reflection
Mindset						
InRes	265*					
Integration	766**	-				
Collaboration	822**	258*	803**			
CritThin	738**	256*	730**	752**		
Reflection	751**	-	817**	808**	849**	

**** correlation is significant at the 0.01 level (2-tailed)**
***correlation is significant at the 0.05 level (2-tailed)**

We must conclude that the intention we set out at the beginning to use the Leadership Peer review as a zero measurement is not opportune as the measured constructs are unrelated. However, these are all exciting findings we did not exactly set out to find.

DISCUSSION

In this study, we looked at professional capabilities as defined by the model from Trede (2013). Results suggest students perceive themselves at the end of this Challenge-based and interdisciplinary course as being emotionally self-aware, thinking about their work critically, working collaboratively, and they are contextually aware. Although self-perception is perceived as a reliable measure (Picard et al., 2021), we do not have enough information to compare data from a control group or a baseline measurement. Therefore, we do not know whether these data result from the course or are based on self-selection prior to entry into this course.

To mitigate this problem, we intended to use the Leadership skills peer-review results, which we expected to correlate with the professional capabilities. Surprisingly, they did not.

Although students were very positive about their leadership skills and their team members as well at the beginning of the course, it did not predict or relate to the professional capabilities we hoped they would acquire during the course. This latter is quite a finding as professional capabilities and Leadership skills tend to be often mentioned under one breath; they appear to be very distinct features. So contrary to being able to say something about the professional capabilities' students acquired in this course, we can say the questionnaire instruments helped validate two questionnaires for Engineering Higher Education, yielding specific outcomes for both professional capabilities and Leadership skills.

In the future, we will use a time-series analysis to analyse the peer review's leadership skills and their development during the course. The idea is that different clusters may have different levels of expectations. Furthermore, we recommend using professional capabilities across several different courses, as Picard et al. (2021) did in their research, and obtaining sufficient data points to perform confirmatory factor analysis.

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Annex 1

Professional Capabilities Questionnaire

Measured on a 5 point likert scare from 1 strongly disagree to 5 strongly agree.

Personal- Part I
Self - Trede

- Q1 I am aware of my engineering role(s)
- Q2 I have become aware of my passions
- Q3 I have been able to make choices that fit my personal values
- Q4 I can articulate what I need to personally grow

Emotional reflexivity - Trede

- Q5 I tend to reflect and discuss positive/negative experiences
- Q6 I feel more confident
- Q7 I feel more independent – in control
- Q8 I stay calm when under pressure
- Q9 I am better able to make decisions
- Q10 I can empathize better with people in different (professional) positions

Resilience - Trede

- Q 11 I am better able to ask for help
- Q 12 I ask more questions based on my reflective activities
- Q13 I feel confident to share my ideas
- Q14 I have learned from my own mistakes
- Q15 I feel engaged with the offered learning materials
- Q16 I am proactive in seeking new learning experiences
- Q 17 I recognize the need for professional boundaries
- Q 18 I persevere in difficult circumstances

Part II
Informed vision - Trede

Q1 I feel committed to sustainable development goals such as; equitable economic opportunities, environmental awareness, sustainable production etc.
Q2 I am able to envision alternative futures for the improvement of my disciplinary field
Q3 I am aware of the historic development of my disciplinary field
Q4 I am aware of the wider (societal/academic/technical) system in which my discipline operates
Q5 I am aware of the political, national/global contexts
Q6 I am aware how these context shapes individual lives
Q7 I am aware of the different stakeholder perspectives

Evaluating Information – Pearson Critical Thinking

Q8 The ability to evaluate the quality of information presented
Q9 I am aware of the assumptions I make with respect to the problem at hand
Q10I recognize assumptions others are making with respect to a problem discussed
Q11 I validate the inference I make from data (truths or falsification)

Q12 I am aware when certain conclusions are drawn following from information in given statements

Critical Stance – Pearson Critical Thinking
Q13 I interpret and weight evidence and decide if generalization or conclusions are warranted
Q14 I recognize relevant and irrelevant arguments given to solve a particular problem
Q15 I make judgement on the basis of accumulated evidence and reasoning
Q16 I find it easier to establish what to do or what strategies to adopt to the problems we are solving.

Communication – IMPQ (picard)
Q17 I am good at trying to understand the perspective of other team members. D
Q18 I am good at making sure that all the necessary information is shared with other team members. D
Q19 I am good at explaining my ideas in ways that other people can understand. D
Q20 When someone disagrees with me, I am good at paying close attention to see if I can learn something from their alternative perspective. D
Q21 I can normally work productively with another team member even if I am angry or frustrated with them. D

Interprofessional Competence – IMPQ (picard)
Q22 I am good at recognizing the knowledge and skills of different professions involved in a project team. E
Q23 I am good at being sensitive to the way in which different professions may use the same word. E
Q24 I am good at clarifying with people from other professions how their knowledge and skills contribute to each stage of a project. E
Q25 I am good at identifying the skills or knowledge that other professions in the team have, which I should try to develop. E
Q26 I am good at sharing responsibility with the other professions in the team for the overall success of a project. E

Ethical Sensitivity – IMPQ (picard)
Q27 When working on a project, I am good at asking myself if a project like this could have a positive impact on someone else's life. C
Q28 When working on a project, I am good at asking myself if a project like this could have a negative impact on someone else's life. C
Q29 I am good at putting myself in the shoes of someone whose life could be affected by a project's results. C
Q30 I am good at identifying all the people who could be impacted by a project, no matter how directly or indirectly. C

LEADERSHIP SKILLS

PEER REVIEW on Leaderhsip skills

	Innovation Mindset– alphaA .80/alphaE .87	MeanA	SD	MeanE	SD
1	Sets strong goals for themselves	4.14	.46	4.34	.47
2	Consistently achieves the goals they've set for themselves	4.15	.40	4.35	.37
3	Is innovative and resourceful in doing whatever it takes to get the job done well	4.15	.40	4.39	.43
4	Maintains a positive attitude when dealing with unexpected challenges	4.12	.38	4.42	.30
5	Puts the needs of the greater good above their own advancement when necessary	4.08	.38	4.26	.46
6	Initiates activities and takes the lead	3.96	.68	4.19	.39

	Innovation Results alphaA .89/ alphaE .82	MeanA	SD	MeanE	SD
7.	Is continually learning and improving their leadership and performance	3.96	.37	4.19	.39
8	Persuasively and effectively communicates his/her ideas	4.05	.49	4.36	.38
9	Maintains an appropriate balance of immediate needs and longer-range focus	3.96	.40	4.07	.37
10	Makes good decisions	4.07	.28	4.28	.48
11	Is accountable: does what they say they'll do when they say they'll do it	4.28	.38		
12	Prioritises action items and their work, in general, and then, follow through on the priorities they set	4.07	.38	4.27	.47

	Interdisciplinary Integration alphaA .81/alphaE .82	MeanA	SD	Mean E	SD
13	Inspires and supports others to do their best work	4.17	.34	4.25	.43
14	Treats others with respect	4.5	.29	4.78	.24
15	Is resilient in the face of adversity	4.24	.36	4.41	.45
16	Is bold in taking risks when needed	3.98	.38	4.07	.45
17	Understands the needs and priorities of others and is proactive in communicating to others the information upon which they depend	4.07	.40	4.24	.45

	Collaboration alphaA .82/alphaE .88	MeanA	SD	MeanE	SD
18	Is effective at coordinating their tasks with other team-members to increase their effectiveness	4.16	.36	4.29	.48
19	Is good at planning	4.10	.48	4.23	.38
20	Attends team and other meetings in a timely fashion on a regular basis	4.34	.52	4.46	.45
21	Is a constructive force in group work-	4.28	.41	4.49	.30
22	Builds strong relationships with others-	4.18	.45	4.46	.43
23	Understands and highlights the broad outlines of the group's objectives, within the wider context	4.13	.34	4.3	.36

	Critical Thinking alphaA .80/alphaE .88	MeanA	SD	MeanE	SD
24	Understands where their influence lies and how to leverage it	4.15	.34	4.32	.35
25	Generates good ideas	4.23	.32	4.42	.38
26	Is a person of integrity	4.35	.27	4.59	.26
27	Understands why other people act the way they do	4.21	.47	4.29	.38
28	Knows how to navigate between personal and professional relationships	4.36	.28	4.4	.28
29	Is candid and honest when dealing with others	4.37	.37	4.64	.29

	Reflection alpha A . 68/alpha E .88	MeanA	SD	MeanE	SD
30	Listens well to others	4.22	.37	4.47	.39
31	Makes it easy to give feedback to them	4.23	.35	4.44	.40
32	Is effective in providing helpful feedback to others -	4.20	.31	4.38	.34
33	Understands themselves and why they act the way they do	4.24	.23	4.35	.42
34	Is able to act independently/doesn't seek constant approval of others	4.17	.29	4.35	.36

BIOGRAPHICAL INFORMATION

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TEACHING DESIGN: FROM DUELING TO ‘DUALING’ THRESHOLD CONCEPTS

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ABSTRACT

Engineering students encounter many threshold concepts as they learn the design process. These troublesome yet transformative concepts can hinder learners as they transition from novice to informed designers. A parallel and dueling effect can occur as engineering design educators learn to surmount their own threshold concepts in their journey toward proficient and expert teaching. Until educators develop Design Pedagogical Content Knowledge (D-PCK), their students may continue to struggle as they work to overcome the troublesome elements of design. This paper proposes a framework to support the professional learning of engineering educators as they develop D-PCK. Acquiring this competency helps facilitate a shift from dueling to ’dualing’ threshold concepts where educators who make the effort to overcome their own teaching-related threshold concepts become better equipped to support learners as they become better informed designers.

KEYWORDS

Engineering education, threshold concepts, design education, educational development, evidence-informed teaching, Standards: 10

INTRODUCTION

Although engineering design is an integral and requisite part of undergraduate engineering programs, it is inherently difficult for students to learn and educators to teach. Students struggle with seemingly ambiguous processes required to solve open-ended and complex problems in an educational system where they’ve been taught to analyze and seek out the one ‘correct’ solution. Similarly, engineering educators are encouraged to break away from the lecture-based instructional approaches ingrained in higher education and move toward more student-centered approaches. These coinciding challenges set up an environment where both students and educators are simultaneously expected to radically transform their ways of thinking and doing. This is not an easy undertaking since reluctance (or resistance) on either or both parts can set up conflicting interests, a duel of sorts.

Systematically designing solutions to complex, open-ended engineering problems is an holistic process that requires students to demonstrate competence in specific design strategies, many of which are difficult and troublesome. Educators must bring their own professional design experience to the process, along with a reflective understanding of how they themselves learned to think through, and talk about, design problems. With appropriate guidance, both students and educators can thrive during these transformative experiences. Students need an effective learning environment for design, and educators need discipline-specific educational development to teach design effectively. This paper presents a framework that 'duals' the support required by both to provide a rich and rewarding design experience.

SCHOLARSHIP OF INTEGRATION

Frayling suggests there are three types of design research: (1) research *for* design where design is the purpose and the focus is on a product, (2) research *into* design where design is the subject and the focus is on design itself, and (3) research *through* design where design is a method and the focus is on learning about what you design (Frayling, 1994). As engineers we typically do research *for* design using that research to prepare for and inform our solution. As engineering educators we need to broaden this thinking to include research *into* design so we are cognizant of the practices, methods and tools that support students as they learn to become designers. We must also tap into the work of those doing research *through* design that informs how design can be taught.

Teaching engineering design requires the integration of findings from each type of design research. Those findings come not only from our own disciplines, but also from cross-disciplinary areas such as design, and education. For this reason, scholarship of integration is used as the foundation of this work. Its purpose is to interpret and integrate the research findings from other disciplines to create and share interdisciplinary solutions to existing problems (Ream, Braxton, Boyer, & Moser, 2016). This study integrates the findings of research in: (1) design, (2) threshold concepts, (3) engineering design education, (4) pedagogical content knowledge, and (5) faculty development.

DESIGN EDUCATION

Schon, in his design-constructivism model for higher education, suggests that design is "learnable but not didactically or discursively teachable" (in Waks, 2001). He proposes that design is best learned through practice, where students acquire and apply tacit knowledge and discipline-specific language in a setting that emulates the work place. This process requires experienced practitioners to supervise and coach students through graduated, level-appropriate, authentic problems as they experiment, assess, think, and discuss.

Over the past three decades design thinking has emerged as a way to question current states, conceive what does not exist and to help address "wicked" problems (Buchanan, 1992). When faced with these vague, ill-formulated problems with no definitive conditions or limits, designers must draw upon key attributes such as creativity and innovation, user-centeredness and involvement, iteration and experimentation, and tolerance for ambiguity and failure (Micheli, Wilner, Bhatti, Mura, & Beverland, 2019).

Engineering design students face additional discipline-specific challenges when faced with wicked problems (Lönngren, 2017). The highly-paradigmatic nature of engineering limits their ability to see multiple viewpoints and perspectives, which is necessary for problem formulation, solution approaches and solution evaluation. Students also consider knowledge as 'certain' or factual and, as a result, expect unambiguous problem descriptions that should have "correct" solutions. This can create a reluctance to act when faced with uncertainty, ambiguity, and expectations beyond the discipline. It is only when students cross this threshold and can tolerate being in this state of uncertainty that they become confident to challenge wicked problems (Osmond & Turner, 2010).

Many of the challenges associated with wicked problems are considered threshold concepts. These discipline-specific concepts or skills must be mastered, but because of their nature, present unique learning challenges for students (Meyer & Land, 2003). A threshold concept has five characteristics that distinguish it from a core concept: (1) it is uniquely troublesome, challenging the way learners think, often making the concept intellectually and emotionally uncomfortable to master, (2) it is integrative, pulling discrete concepts and ideas together into new ways of thinking or understanding, (3) it transforms the way learners think about their discipline, (4) it is considered irreversible, and (5) it is bounded to one's discipline and dependent on context. Mastering a threshold concept is different for each learner. The experience of moving from not knowing to knowing is called liminality and can be quite disorienting for learners (Meyer & Land, 2003). Crossing these thresholds can make the difference in a student's ability to merely carry out engineering tasks versus thinking and acting as an engineer.

Engineering educators have identified a number of discipline-specific threshold concepts, design being one of them. They are curated in an open-access repository of interdisciplinary threshold concepts (Flanagan, 2020). A multi-year study by an Australian research team created a separate inventory of foundational engineering threshold concepts and capabilities grouped into three main categories: (1) learning to become an engineer, (2) thinking and understanding like an engineer, and (3) shaping the world as an engineer (Male, 2012). The 'shaping the world' category includes threshold concepts associated with design and problem solving. This research team identified troublesome features such as variability in the real world, approaching open-ended problems, justifying answers, and integrating multiple topics and sources of information, all of which are required to address wicked problems.

Many engineering educators do not use the term threshold concept, but recognize them as key concepts and skills that are considerably more difficult to learn and that should be emphasized. Over the years, educators have identified a number of design-related cognitive processes and soft skills that make design difficult to learn. Students must tolerate ambiguity and easily switch between divergent and convergent thinking. They must focus on the big picture and frame problems instead of trying to solve them. Their design process must be managed, iterative and reflective. Students must generate many ideas and balance benefits and tradeoffs to make justifiable decisions. They must also perform diagnostic troubleshooting, and unbiased tests and experiments. They must think and work as part of a team and communicate their ideas and design using different representations and languages such as verbal/textual, graphics, mathematics and numbers (Dym, Agogino, Eris, Frey, & Leifer, 2005) (Crismond & Adams, 2012). Engineering design educators must be aware of and modify their teaching practices to support students as they encounter these troublesome elements of design.

TEACHING DESIGN

Engineering education research also suggests that teaching design requires a paradigm shift for educators (Heywood, 2005) (Woods, 1996). It requires changes in the way content is delivered and learning is assessed, and shifts the focus from product-driven "right answers" to process-driven optimal solutions. As a result, educators need to hone facilitation and coaching skills as part of their teaching practice.

Connecting research on how to design with research on how to teach identified nine design strategies, contrasting patterns of novice and informed designers, relevant learning goals, and instructional approaches that support student learning. Each design strategy corresponds to an aspect of the design process such as understanding the challenge, representing ideas, and troubleshooting (Crismond & Adams, 2012). Their Informed Design Teaching and Learning Matrix suggests that design educators must develop their own pedagogically-sound way of teaching design so that learners can overcome these difficult and troublesome elements.

The concept of Pedagogical Content Knowledge (PCK) has evolved since it was introduced by Shulman in 1986. Initially described as the integration of content knowledge and pedagogical knowledge, it helps educators recognize what makes concepts easy or difficult to learn, package content for optimal learning, and help students organize their learning (Shulman, 1986). A recent literature review of PCK in science suggests that the development of PCK is actually more complex than first thought (Azam, 2019). It proposes a conceptual framework where PCK is an amalgamation of topic-specific PCK formed through experience and reflection when teaching-related knowledge integrates with conceptual knowledge. The nine dimensions of pedagogical knowledge (student learning, assessment, curriculum, goals, instructional strategies, resources, technology, student diversity, and contexts) are closely related to teacher-related threshold concepts.

Many engineering educators don't recognize that they too encounter threshold concepts that can hinder their individual journeys to becoming effective educators. These can be clustered into four actionable areas in which educators can grow: (1) pedagogy, (2) learning, (3) assessment, and (4) educational technology (Nelson & Brennan, 2021c).

Crossing pedagogy-related thresholds requires educators to develop Pedagogical Content Knowledge (PCK), the ability to teach one’s subject effectively (Shulman, 1986). This means identifying the "ways of representing and formulating the subject to make it comprehensible to others" (p. 9). One such threshold concept is simply acknowledging the existence of threshold concepts. Educators who cross this threshold recognize that there are specific concepts that are essential to thinking and practicing within their discipline (Adler-Kassner & Wardle, 2015). With this comes the need to adapt teaching practices to support students as they shift from doing discipline-specific things to becoming practitioners (O’Brien, 2013).

To cross learning-related thresholds, educators must learn more about how students learn, find ways to better engage and motivate them, and explore ways to provide choice in how learning is demonstrated. Crossing the assessment-related thresholds requires moving from norm-referenced to criterion-referenced evaluations. This depends on the successful alignment of assessments, clearly enunciated learning outcomes, and meaningful learning opportunities that provide supportive and informative feedback to students. To cross the teaching with technology thresholds educators must acquire Technological Pedagogical Content Knowledge (TPACK) to stretch their current teaching practices to include appropriate educational technology (Koehler & Mishra, 2013).

The LENS (Learning Environments Nurture Support) model for engineering faculty development emerged from the integration of transdisciplinary research (Nelson & Brennan, 2021b). The model, shown in Figure 1, uses a systems approach (Henkin, 2007) to shift the focus of educational development from teaching to that which best supports learning. Its six ‘lenses’ correspond to the elements of an effective learning environment (Nelson & Brennan, 2019), each featuring the dimensions of pedagogical knowledge required to master teaching-related threshold concepts.

	Focus	Common Strategies	Evidenced Strategies
Academic Rigour	• maintain standards	• transmission-based classes • content-driven • exams, labs, homework • 'integrating' exams	• active learning • meaningful content • expected levels • higher-order thinking
Focus on Learning	• done 'by' students • active & collaborative learning • skill development • learning strategies	• worked examples • labs • homework	• active learning • collaborative learning • deep learning • purposeful practice • high-impact learning
Instructional Support	• done 'for' students • methods and materials • classroom experience • learning opportunities • learning resources	• lecture • textbooks • prescriptive labs	• manage learning load • meta-learning strategies • build feedback loops • process over product • problems vs questions
Quality of Teaching	• teaching practices • clarity • organization	• dependence on slides • fast pace • feedback from SETs • TA-run tutorial	• pedagogy-based classes • ongoing feedback • clear instructions • passionate
Relationships	• faculty-student interaction • student voice • learning communities • accessibility to students	• prof – TA - student • maintain distance	• student voice in course policies • accessible outside class • supportive • respectful and caring
Student Engagement	• motivation • time and effort put into studies and activities • institutional student success initiatives	• grades as motivator • assumed learning strategies • student's responsibility	• value, learning and/or long-term benefits as motivator • learning strategies • shared responsibility

Figure 1: LENS framework for engineering faculty development

DUAL FRAMEWORK FOR DEVELOPING DESIGN PEDAGOGICAL KNOWLEDGE

Crismond and Adams identify Design Pedagogical Content Knowledge (D-PCK) as a design specific form of PCK that characterizes the way teachers use teaching techniques to convey design thinking knowledge and help students develop as design thinkers (Crismond & Adams, 2012). Their general suggestions for developing D-PCK include clearly articulating and scaffolding learning, finding meaning and providing guidance in the way one teaches, breaking the fourth wall to create a teaching moment when appropriate, and allowing students to figure things out on their own. While they suggest specific teaching strategies for each of the nine design patterns, their model does not consider the 'duel' between educators challenged to master teaching-related threshold concepts, and learners encountering the troublesome aspects of design.

The DUAL (Design Unleashed through Adept Leadership) framework addresses these dueling threshold concepts (see Figure 2) by examining four distinct, yet related, elements of engineering education: (1) the learning space, (2) the students, (3) the engineering design educator, and (4) the faculty development for those educators. Prior to exploring each level, it is important to recognize that engineering students are typically conditioned to learn in their engineering science courses, the majority of which are teacher-directed and lecture-based (Nelson & Brennan, 2018).

The left side of the DUAL framework shows the teaching and learning elements of a conventional engineering science course. The learning space is a classroom or lecture hall in which students listen to lectures. Assessments are traditional (exams, tests, assignments and labs) where problems have one "correct" answer. Students must demonstrate the knowledge (K) and skills (S) needed to pass the course, and acquire the attitudes (A) required to be a successful engineering student. Most of these engineering science courses involve at least one discipline-specific threshold concept that students are expected to grasp and integrate into their conceptual knowledge base. The educator, depending on their experience and commitment to teaching, brings PCK to the learning space. The quality of that PCK depends on how many of the teaching-related threshold concepts have been mastered. Research shows, however, that many engineering faculty choose not to develop their teaching skills, even though institution-wide and/or school-specific faculty development units offer myriad opportunities to do so (Felder, Brent, & Prince, 2011). This may explain why national student engagement surveys rank the effectiveness of the undergraduate engineering experience lowest among the disciplines (Nelson & Brennan, 2021a).

The right side of the DUAL framework shows the elements of an effective engineering design experience, each of which is encompassed by an aspect of professional practice. Here the learning space is design-focused with students learning the performance dimensions related to informed design, and educators modeling discipline-specific language and practices. There are concepts to be taught and modeled, and skills and processes to be learned. Assessments stretch beyond the traditional to include regular, formative feedback on design-related tasks. The design space emulates an engineering workplace where the educator takes on a technical leadership role, mentoring and coaching students as they work to become informed engineering designers.

Students are asked to design solutions for authentic, level-appropriate engineering problems in this design space. They must show that they can apply the knowledge and skills they've learned in their engineering science courses, including the discipline-specific threshold concepts they may or may not have yet mastered. They are expected to demonstrate knowledge and skills beyond the technical body of knowledge, recognizing that employability-related and professional skills are instrumental for effective engineering design. These aspects of professional practice include, but are not limited to, communicating and defending engineering decisions, team work, and project management. Students also encounter new design-specific threshold concepts as they take their design skills from beginner to informed designer.

To support design learning, educators must specialize their PCK to include D-PCK. This requires ongoing development within each of the nine pedagogical knowledge dimensions, and efforts to cross the pedagogical, assessment, learning, and technology-related teaching threshold concepts. It also requires development of solid facilitation skills, a key requirement in effective technical leadership. This includes asking leading and open-ended questions, helping students reflect on their design experiences, monitoring student progress, challenging student thinking, raising issues that need to be considered, and establishing a environment where students feel safe to ask questions and make mistakes (Woods, 1996). To this point, facilitation has not been identified as a specific teaching-related threshold skill although myriad researchers identify it as required to support students as they encounter threshold concepts in their disciplines (Flanagan, 2020).

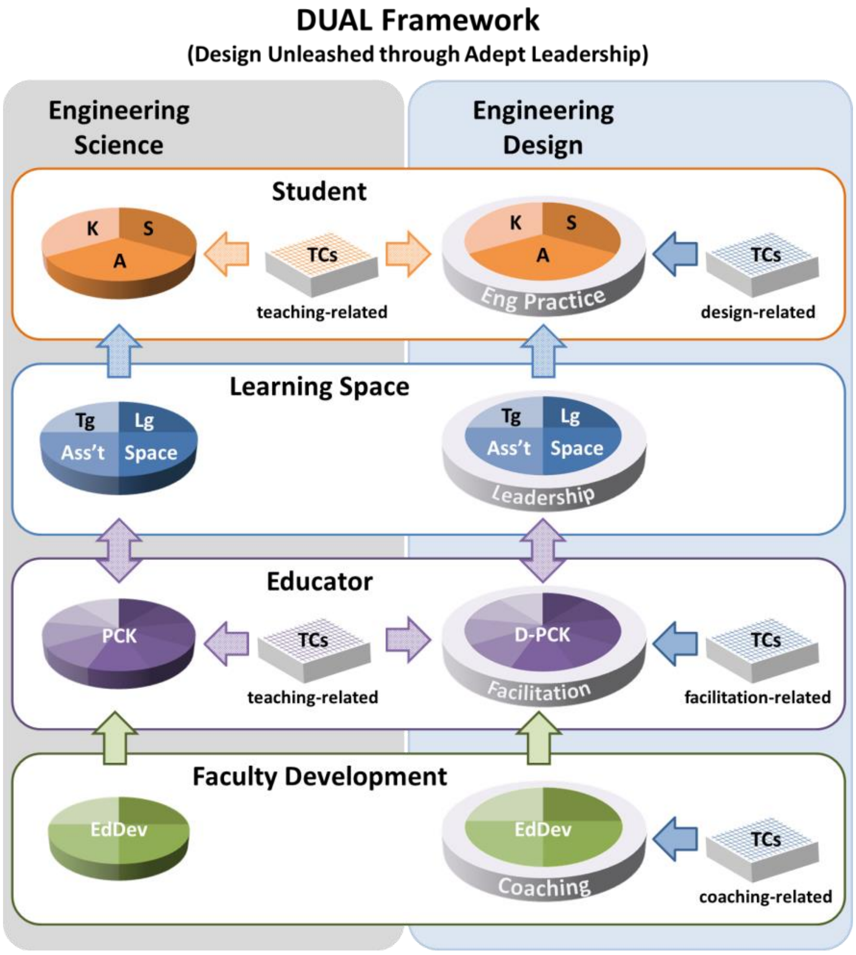

Figure 2: DUAL Framework

Most educational development units focus on five key areas: (1) teaching and supporting learning, (2) professional learning and development, (3) mentorship, (4) research, scholarship, and inquiry, and (5) educational leadership. The professional learning and development area supports the growth of educators' PCK, but rarely includes learning opportunities to develop the facilitation or coaching skills required for design education. Mentoring from industry advisors, sponsors or engineers-in-residence would be the optimal way to acquire and practice these facilitation skills. Workshops could provide similar benefits for engineering design educators, should mentoring not be feasible.

The DUAL framework examines the teaching and learning challenges associated with engineering design education. Initially assumed to be a 'dueling' of teacher- and design-related threshold concepts, the contrasting of four aspects of engineering science and engineering design classrooms brings to light other significant and challenging facets that must be acknowledged. First, the learning space must be a safe and supportive environment facilitated by educators who are well-practiced in engineering design. These educators must develop and use adept technical leadership skills to support students as they attempt to master design-related threshold concepts. Next, engineering design courses cannot assume students are equipped and able to apply and integrate discipline-specific threshold concepts and/or skills associated with professional practice. Learning opportunities and resources should be prepared and in place should students need additional support. Finally, educators must continually develop their PCK and D-PCK through focused and supportive faculty development. These learning opportunities should be tailored for engineering educators and extended to provide evidence-informed graduated support related to teaching, discipline and design-related threshold concepts, leadership, and facilitation.

FUTURE WORK

Each aspect of the DUAL framework provides avenues for further study. At the student level, work can be done to explore the dueling of discipline- and design-specific threshold concepts. This could determine whether the choice of design problems that assumes mastery of discipline-specific threshold concepts affects students' abilities to master design-related threshold concepts. At the learning space level, further work could measure the type and adeptness of technical leadership supporting student learning. This would refine the definition of D-PCK and help shape the development of technical leadership in engineering education. Further work can also be done to examine the impact differing facilitation skills have on the students' design skill development.

The DUAL framework also suggests facilitation skills, and the educational development of these skills, may be threshold concepts. Further work could determine if either or both meet the five associated criteria.

Finally, the LENS model for engineering faculty development will be enhanced to include a focus on recognizing design-related threshold concepts, developing D-PCK through facilitation and technical leadership, and recognizing the effect dueling threshold concepts have on student learning. Use of this engineering design-specific model, LENS-ED, could be monitored to determine its impact on the continued pedagogical growth of engineering educators involved in transforming students from novice to informed designers.

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BIOGRAPHICAL INFORMATION

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RETHINKING ENGINEERING INTERNSHIPS IN TIMES OF DISRUPTIONS

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ABSTRACT

Internships represent an important opportunity for students. It is an opportunity to develop a feel of the engineering work and profession, to be engaged in learning that enables them to observe experts at work, apply and practice knowledge and skills gained in the classroom and for many, it subsequently informs their decisions on further education and/or career options. The internship therefore is a bridge between two different phases, namely, education and work. Aligned with the theme of the CDIO conference on thriving and surviving, the challenging situation brought about by the Covid-19 pandemic on a global scale affected the way work and learning were conducted. Students' internships were canceled, postponed, or reduced to virtually participating in a company, hampering their professional development through hands-on experience. This paper aims to make sense of this disruption by using the work of Bourdieu on habitus and field to examine the transition process and the ways in which the interns develop an understanding of their internship experience and adapt to the changes amidst the disruptions brought about by the pandemic. Bourdieu's work is significant here because it sees education and practice beyond the explicit transferal of knowledge by highlighting the importance of practical and embodied experience, something which was affected in internships during the pandemic. The research was conducted through digital focus group discussions with 22 students. Here, we present the story of 2 students that provide insights in how students experienced and managed disrupted internships. This is especially crucial as for most of these interns, the internship is an initial foray into the world of work, providing them with an insight into engineering in practice that guides their understanding and decisions relating to their future. Together, this paper contributes to advances in the theory and practice of CDIO by reinforcing the need for closer alignment between education and industry.

KEYWORDS

Disruptions, Digitalisation, Internship, CDIO Standards 1, 2, 3, 5, 6, 7, 11

INTRODUCTION

Internships, also known as industrial placements, work integrated learning among other synonyms represent an opportunity for tertiary students to gain authentic workplace experiences in the specific role and industry related to their field or discipline of study. In the context of this research, third year polytechnic students pursuing the Diploma in Chemical Engineering (DCHE) went on a 22-week internship to fulfill part of the requirements of their diploma programme. In terms of 'vocational intent,' (Brennan, 1985), DCHE, with its strong alignment with CDIO standards, aims to provide students with the knowledge and skills needed by the vocation and industry (Clark et al., 2011).

The DCHE curriculum prepares graduates to work in wide ranging areas of the energy and chemicals sector, e.g., petrochemicals, pharmaceuticals, biopharmaceuticals, specialty chemicals, advanced materials, engineering and services, and environmental safety and health (ESH) protection. Graduates work in a range of roles such as process technicians, technical executives, laboratory technicians, and ESH officers; and carry out key tasks in operating and supervising process plants, assisting engineers in process development, quality control, handling effluent treatment, and waste and energy management. More than 50 per cent of DCHE graduates continued or planned to continue their education by enrolling for advanced diploma or degree courses. Those who did not pursue further studies went directly into employment although not always in the job role that they are trained for such as in technical sales. This is often seen as presenting "leakage" issues in the eyes of the chemical industry, and challenges for the educational institutions. The internship experience for DCHE students is often seen as key to enabling a smooth transition from education to industry.

While the above represents the ideal progression from education to the workforce, reality might tell a different story. Given Singapore's labour market challenges brought about by a rapidly ageing workforce and a shrinking talent pool (National Population and Talent Division, 2021; Platon, 2021), internships become an important platform in enabling the transitions of trained students to professional settings. Chin et al. (2020) stressed the importance of leveraging tertiary-level internships as a platform to support the development of professional identity in students who will continue to undertake further education and/or become part of the industry that they have been trained for and that it would support the retention of the students in their specific field or industry. Using Bourdieu's work related to habitus and field, the former concerning an individual's inherent disposition (i.e., as a student or intern) and the latter concerning structured social spaces with norms, rules, and accepted patterns of behaviour (i.e., the engineering field and profession), we will examine the ways in which interns navigate through their disrupted internships. Further, we argue that the internship experience is critical for the development of professional identity. Thus, one of the key purposes of the internship component is to help students to translate their skills learned in school to the workplace and thereby enhancing their employability (Jackson, 2016) and facilitating the integration of different types of knowledge and skills (Bowen, 2018). However, in an era marked by disruption and with companies increasingly having less resources for internships, effective transitions from polytechnic to university and/or industry has become more and more challenging.

Polytechnic education represents an interesting and critical phase in that while most research on transitions from education to graduate work tend to focus on universities, more needs to be done at the polytechnic level where there are two viable options following successful completion of the students' diploma programme. One option would be to pursue a university degree in the same or different field, or the second option would be to join the workforce in a related or unrelated field to their polytechnic diploma. Given Singapore's strong alignment between its educational policy and planning to the needs and demands of the economy and its workforce, the issue of leakages from the field that the students have been trained for must be addressed accordingly. This research adds to the literature in that we examine the transitions experienced by students and its impact on their future decisions pertaining to their further studies and career options. Specifically, we look at this from the context of the Covid-19 pandemic and how this has impacted the internship placements of students. Arguably, the development of professional expertise has been much more challenging during the pandemic. Consequently, this research aims to examine the ways in which students evaluate their internship experiences against their expectations and its subsequent impact on their future decisions.

THEORETICAL FRAMEWORK

To examine the above issues, we propose to draw on the work of the French sociologist Pierre Bourdieu, specifically his work which pertains to the role of modern education. In brief, educational systems, for Bourdieu, are systems of 'reproduction' where specific existing social and cultural structures are being taught, thereby reproducing these within students who come to embody these structures and so forth. In other words, education is at least as much about learning how to behave and to learn the implicit values and norms of a social group as that it is about developing knowledge and the right skills. As his view aligns with how we see the development of professional identity of students through internship programs, we decided to use Bourdieu's work - specifically his concepts of 'field' and 'habitus' - to analyse and interpret our data.

Bordieu's work on habitus and field (Bourdieu, 1977, 1990) enables us to understand the ways in which students experience and evaluate their transitions from polytechnic education and their progression into practice via the internship component. In brief, habitus is defined as 'the system of durable and transposable dispositions through which we perceive, judge, and act in the world' (Wacquant (2008) in Clark et al., 2011, p. 137). Arguably, the individual habitus is informed by what the students have experienced throughout their lives, built, and shaped by what they have experienced, seen, heard, practiced, and reproduced' (Corrêa Junior et al., 2017, p. 155), 'structured by past and present circumstances' (Clark et al., 2011, p. 137) which subsequently affect their perceptions, practices, beliefs, and feelings. This can cause tensions when interns transit from one field to another. Based on an understanding of the concept of 'field' as 'a structured social space with autonomy to establish rules, patterns of normal behaviour and forms of authority' (Clark et al., 2011, p. 135) or as a game with players required to adhere by specific rules governing their interactions and actions which can evolve and change (Clark et al., 2011; Corrêa Junior et al., 2017), this research outlines two possible changes in terms of 'field' that the students experience in their internship. Firstly, it refers to their transition from an educational institution to a professional setting, namely, the engineering field. These represent two separate yet interrelated fields, the former being a precursor and a preparatory stage for the latter. Secondly, such transitions especially in the current context of disruptions arising from the digitalisation, which was accelerated by the Covid-19 pandemic affects the engineering field where their experiences might not be aligned with what they have come to expect and as such, requires the students to be flexible and adaptable to change.

In using both of Bourdieu's thinking tools: habitus and field, we can better understand this transition process by examining the interactions between them (Bloomer & Hodkinson, 2000; Bourdieu, 1977, 1990; Clark et al., 2011; Xu et al., 2021; Yang, 2014). Despite criticisms about Bourdieu's work being deterministic (Bloomer & Hodkinson, 2000), Yang (2014) contends the potential of its application in the context of change. In particular, she discussed the possibility of a mismatch between habitus and field as well as the 'structural gap' that ensues when the two are 'out of sync' or when the field undergoes any change. As such, it allows us to understand the impact of disruptions arising from the Covid-19 pandemic and/or digitalisation on the students' internship experiences, their individual habitus in managing the transitions and their thoughts on further studies and career options following their graduation.

In this transition they move gradually from the educational field into the professional field, but this transition is a liminal one: interns are neither fully part of the education field anymore and neither full participants of a professional field yet. In terms of habitus, they need to align the 'rules of the game' of being a student with that of being a professional, thereby not only having to socialise within the new field but also unlearn some of the rules of the old field that may have become sedimented and embodied in a student's identity. The learning potential in such liminal transitions can be powerful (Irving et al., 2019), thus the internship experience is an important period in which students are able to develop their professional identity and become part of a professional community.

However, the Covid-19 pandemic has affected the internship for many students. For those students whose internship continued, they entered a workplace that itself was in transition; it arguably is challenging to learn the rules of a game while those rules are being reconstructed. For others, the internship was canceled altogether, making it difficult to develop a professional sense of identity and make the leap from the educational to the professional engineering field. For many, however, the internship continued but in a different format (e.g., virtually), thereby reducing the possibility for personal interactions. Given that habitus requires not just 'knowing' the rules of a field intellectually but by embodying them and becoming part of one's structure, virtual internships in this respect can be seen as a suboptimal substitute. In the findings, we explore different kinds of experiences via two vignettes of students, thereby highlighting what a disrupted internship may mean for students transitioning into a professional field.

METHODOLOGY

The data presented in this paper is part of a larger study on the digitalisation of the engineering profession in Singapore for which a report outlining the full methodology was published by SkillsFuture Singapore in 2021 (Poon et al., 2021).

During our engagement with engineering students embarking on their internship, the Covid-19 pandemic hit Singapore and we were forced to halt all physical interactions in our research. As a result, we decided to engage with the interns in a virtual way. In total, twenty-two students from the DCHE course at the Singapore Polytechnic participated in this part of the study. They were about 18-19 years of age. Out of the 22 students, 16 were male, and 6 were female students, which was somewhat representative of the student population enrolled in the DCHE programme.

We created two groups on the online messaging platform, WhatsApp, with 5-6 students and two researchers acting as moderators. Every week, we would share a question in the group where we asked students to elaborate on their internships or on specific aspects that pertained to the research. There were two runs of this, so this part of the research involved a total of four groups of students. They were final year students and were required to complete an internship for a duration of 22 weeks as part of their diploma course requirements. Participation was on a voluntary basis and written consent was obtained from each participant prior to the start of the DFG discussions. Further, students' identities and responses were also kept anonymous and confidential aligned with ethical requirements set by the research institute.

With each group of students in each WhatsApp group, we conducted a digital focus group (DFG) discussion via a digital platform at three junctures namely, at the start, mid-way and at the end of the internship. The DFG discussions which lasted between 60 to 80 minutes per session were conducted in 2020. These were recorded and subsequently transcribed verbatim. During the DFG discussions, the interns were asked to discuss their preparation and expectations of the internship experience, tasks, and projects that they worked on, work environment, preferences in ways of learning, knowledge of the organisation and industry, relationship with mentor and colleagues at work as well as their future plans and aspirations. Such discussions provided them with an avenue to reflect and become more aware of the development of their professional identities (Bowen, 2018). During some of the DFG sessions, they also participated in activities that required them to reflect on their experiences. For example, they discussed ways of learning during the internship and ranked these based on their preferences. Some of these were based on individual input while others required them to discuss as a group and provide responses that were based on their discussion and reaching a consensus. This provided an insightful way of gathering data based on individual experiences as well as data that were obtained through the DFG participants' discussions where they were able to share specific experiences, come to an agreement or disagreement in terms of their responses and to provide relevant justifications where necessary.

DATA ANALYSIS

Open coding was done based on the transcribed DFG discussions without any imposition of preconceptions on participants' responses to the questions that were asked in each session. In this way, the codes remained close and true to the meanings intended by the participants. Subsequently, axial coding was done to examine possible linkages between the codes, and these were then developed into themes. The process was undertaken by two researchers. Upon completion, the third researcher was able to examine the codes and themes and provide further suggestions where necessary.

From the analysis, it was evident that the internship experiences were very varied, providing some parallels and contrasts. For example, on one extreme, there was an internship experience that was prematurely terminated due to the pandemic, leaving the intern feeling 'lost' and 'demotivated' as compared to his peers that were able to continue in their internship albeit in varied ways such as via reduced workloads, remote working among others. On the other extreme, there were interns that were not affected by the pandemic while there were others that were able to continue with their internship but had to contend with other forms of disruptions such as digitalisation and having to undertake work that was considerably different from their academic training in the polytechnic. Through these varied examples, we selected two cases which were disrupted both in terms of the pandemic and the impact of digitalisation on work and learning, because they provided a contrast in terms of the ways in which they managed the disruptions to the internships. Other interns who had experienced disruptions and tend to exhibit similar tendencies in the way they managed and/or adapted to it.

FINDINGS

The two cases selected had one thing in common with their other peers that underwent the internship and who had participated in this research. They had similar expectations for their internship, which was to gain experience of working in the industry, and through that, learn, apply and more importantly, expand their knowledge of the industry pertaining to chemical engineering and inform their future decisions.

DIGITALISATION: NEW SKILLS AND NEW PATHWAYS

Digitalisation disrupts work and industry in that it introduces new ways of work, opening up new job roles requiring new skill sets. X, an intern in a multinational company in the petrochemical industry, was working remotely and assigned to develop a dashboard using Power BI, a data visualisation software application. It was an area of work that he recognised to be new and different, *"actually this intern work (that) I was given right, past SP interns never* *do (it) before. So, it's like kind of (I am) the first one."* X shared about his reservations of being assigned to a role that was not quite what he expected, given that he would have liked to explore the more traditional engineering aspect of working in a plant which he opined would allow him to make a future decision based on his fit/compatibility with the industry, *"I guess I would rather have a more chemical engineering related work. So that I'm able to like, experience this industry better first. I guess, to like ask myself (if) I would like to continue in this industry."* In other words, X expected to enter a different kind of professional field which was more aligned to his academic training.

Despite X's reservations, and the complexity of the task at hand, *"actually, I wouldn't say (that) it's easy, but it requires all sorts of problem-solving skills,"* he was able to persevere by deploying various ways of learning which was self-directed and independent to complete the development of the dashboard, *"so, the learning wise, the supervisor won't tell you step-by-step, because he has his own work to do. So, it's all mostly he will say what he wants, like he wants to display this data like this. And must be able to, like, choose some options for it. And that's it, he will show a final product, but he won't show the steps on how to reach it. So that part, I have to learn it myself, through online. Sometimes, you have to ask for help online, like (in) community forums, to get like, those experts' help. Then, also, sometimes (I) have to ask other interns that are also new, also working on similar projects, using Power BI, for their help. At the same time, I also help them based on my experience."* While he acknowledges that the organisation provides training, his status as an 'intern' sets the limitations of the resources he can access when it comes to learning, *"but if you want to pick up that skill, we require, like a business reason. Because these skills require professional help and will cost money, you need to ask your supervisor to approve these kinds of skills, which I probably won't do."* Evaluating his internship experience after 22 weeks, X still felt that he should have had more opportunities to gain direct exposure and experience working on-site, to shadow an engineer working in the plant and experience *"a day in the life of an engineer."* Despite that, his internship experience opened up new areas of interests which he perceived to offer good prospects for his future, *"like make me lose interest a bit in chemical engineering, then make me more interested in the digital area,"* and led him into wanting to pursue a computer related degree at university in future.

INTERNSHIP DISRUPTED

Like most interns, Y shared that "*before the start of the internship, my goal was to learn as much as I can, because from what I know, from what my supervisor told me, this company is a good place for interns because it's what I really learnt in SP."* Eager to step foot into an actual plant, with *"those distillation columns and reactors, and all that,"* he was disappointed when Covid-19 affected the experience by first limiting him to working remotely with virtual learning sessions with his mentor which then slowly dwindled over time, *"basically I don't have communication with him that much, but then after – because I had to do stay home notice and all, then I couldn't see him"* and *"he also doesn't check in."*

Despite having a disrupted internship which confined him to working remotely and having limited tasks assigned to him, Y's academic training at the polytechnic combined with his interest for the industry shaped his understanding and expectations of the work and industry and this seemed to come across when he talked about different aspects of engineering work. Although he was disappointed with not being able to gain the internship experience that he envisaged for himself, he was "*assigned (with) things to do, (and a) project. Like just now, I already mentioned. Creating the procedure. And I did that. But I did it slowly. There's no time frame either."* Reflecting on the ability to apply what he had learnt, *"I can say that I have learnt it before in poly (polytechnic). I mean, we have all learnt it before in poly (polytechnic). Just that I can finally apply what I learnt to the company because they also don't have the (process) that's what I observed from the SOPs (standard operating procedures)."*

Out of the 22 weeks of internship, Y was able to return to the plant for about 8 weeks of his internship and he enjoyed being able to *"see familiar faces"* but the limited time spent on site had impacted his outlook on the industry and he reiterated the importance of the internship in allowing students to gain an insight about the work and industry, *"because whatever we learnt in school is just the basics. When you start work, you go into the industry, that's where you find – that's where you are exposed to more things and real-life things that will happen. Because (for) the polytechnic, they have practical, but they don't really have advanced, you know, the things we have never seen before."* In assessing the important aspects of internship, socialisation was critical, and this was probably due to his limited opportunities for professional socialisation where he reiterated that, *"I should communicate and network with the people there more because you never know when you need them in the future, when you are working in the industry. For example, my supervisor, maybe his testimonial will help you in the future, you would never know. So that's why networking is important."* Overall, the disrupted internship has an impact on his future decision, *"I don't really see myself in this industry also. After what I have experienced. I didn't experience much but I can observe. So, it's not really… basically like personal experience, you have to try it for yourself."*

DISCUSSION AND CONCLUSION

We highlighted two cases where students experienced disrupted internships but had different ways of managing it which led to different outcomes. While the initial expectations of the students were quite similar, how their internships actually happened and how these were experienced were rather different. This was, we have shown, in part due to the pandemic with companies radically changing their modus operandi. Arguably, internship experiences will always be different and dependent on a number of factors such as the quality of guidance received (from hosting companies and schools), the tasks and responsibilities given to the intern, and the alignment between expectations and realities. We zoomed in here on the pandemic, however, because this posed a particularly relevant breach in what students might have expected from their internship and how this was actually experienced.

This breach can be better understood via the work of Bourdieu as we laid out in our theoretical framework. An internship, we have argued, is a specific case of a transition between fields, from student to professional. In turn, during such a transition the habitus of students are challenged and expanded. A student's habitus, as the internalised habits and dispositions of a social field that in turn shapes how people behave thereby reproducing the structures of that field, is a source for developing professional identity. When the structures of a field themselves break down (e.g., companies changing their modus operandi or realigning visions and goals), this poses challenges to what extent students can try and test with their different identities and grow as a professional. Now, to be sure, this does not mean that developing professional identity is impossible in times of disruption, but it does imply that it brings certain challenges to the table. As such, in terms of specific improvements that can be considered for the internship that would allow students to deepen their understanding of the engineering field and develop their professional identity and habitus include some approaches adopted by Paul et al. (2016). The author highlighted benefits arising from the introduction of online lessons and personalised feedback focusing on students' professional development while they were on their internships. The aim was to develop students' self-awareness skills in order to encourage them to reflect on their learning experience during the internships thereby contributing to the development of their professional identity.

The interaction between field and habitus is significant in developing an understanding of transitions from one field to another (i.e.: education to professional practice). Further, in examining the impact of changes in the field especially as new rules of the game were being constructed due to the disruptions from both the pandemic (move from physical locations to remote working) and digitalisation. The latter meant that the new job roles and associated tasks were somewhat misaligned with what the interns had come to expect as a result of the polytechnic education. In this regard, it reinforced the importance of practical and embodied experience in professional identity development. There are two implications here. The first one relates to the important role of industry in the internships and its alignment with the educational institutions. For example, Rouvrais, et al. (2017) suggested to extend the CDIO framework by adding 'Industry Partnership' to systematically include work-based learning (WBL) as integrated activities in educational programmes to better match graduates' skills and competency development with industry requirements. Kamp & Verdegaal (2015) had earlier reported on the relevance of selected CDIO standards to internship for a Masters' programme at TU Delft, for a range of learning outcomes including better understanding of employment options after graduation and developing a good sense of ethical accountability and social responsibility. Calling it 'Industry Engagement', Cheah & Leong (2018) also argued for a new CDIO standard which they described as 'actions that educational institutions undertake to actively engage industry partners to improve its curriculum.' The authors highlighted an area that can benefit from such a standard is in enhancing student learning via the internship component.

Secondly, the disruptions arising from the Covid-19 pandemic where the interns' expectations of the internship may not be fully realised were mitigated and/or mediated by their habitus. For instance, the polytechnic had strongly emphasised on self-directed and independent learning but for many, their student habitus meant that they were not able to fully relate nor see the need and relevance of self-directed and independent learning as much as it became pivotal in enabling them to adjust to the disrupted internships. This was particularly important given that access to mentors/supervisors, guidance from colleagues, organisational resources were less available as a result of working remotely, and they had to rely on other sources of knowledge and guidance to complete their assigned tasks and projects.

Aligned with existing literature, the data presented here suggests that the internship is an important and pivotal point in students' experiences. It is their first real glimpse into the professional field and a moment where their habitus as a student is challenged and they may find room to expand this in becoming a professional themselves. The experience of this transition is, especially during disruptive times, contingent on a number of factors that may shape the extent to which a student can feel empowered to develop a professional sense of being. This indicates, from the perspective of the educational institutions, that it is a process that must be carefully managed and where students' expectations are realistic from the start and, moreover, aligned with practical reality.

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BIOGRAPHICAL INFORMATION

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INTEGRATING GENDER EQUALITY, DIVERSITY, AND EQUAL CONDITIONS, IN ENGINEERING EDUCATION

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ABSTRACT

In engineering education, as well as in the society at large, there is an increasing focus on sustainability and sustainable development. The CDIO Standards and the CDIO Syllabus has been substantially updated to meet and drive these changes. Progressive engineering programs have by now made substantial progress in integrating environmental aspects of sustainability and sustainable development into the curriculum. However, the integration of social aspects is generally considered to be more difficult and is therefore lagging behind. This explorative research paper provides insights in efforts to integrate elements of gender equality, diversity and equal conditions (GDE) in three courses on bachelor's, master's, and doctoral level. The focus is on the development and implementation of reflective assignments, where a theoretical framework is used for characterizing different levels of reflection. The work has been performed by use of an action research approach that has involved close dialogue and collaboration between researchers, pedagogic developers, teachers, students, and education leaders. The paper hereby contributes with multiple perspectives on GDE integration, and significant challenges are discussed. The paper also contributes with concrete examples of reflective assignments, learning activities, and literature that can be useful also in other contexts.

KEYWORDS

Gender equality, Diversity, Equal conditions, Sustainable development, Reflective writing, Optional standards for sustainable development, Standards: 1, 2, 3, 7, 11

INTRODUCTION

With the increasing awareness of the urgent need for societal transformations to ensure sustainable living conditions for ourselves and future generations (e.g. UN 2015, IPCC 2018, WWF 2020), and the crucial role of engineering in such transformations (e.g. UNESCO 2021), there is an increasing focus on improving the future relevance of engineering education with regards to sustainable development (e.g. Thürer et al, 2018; Fenner & Morgan, 2021). The updated CDIO Standards 3.0 and CDIO Syllabus 3.0 have established sustainable development as central in the CDIO concept and the new "optional" CDIO Standard for Sustainable Development provides extended objectives and guidance (Malmqvist et al, 2020a&b; Rosén et al, 2021; Malmqvist et al, 2022).

Since 2006 sustainable development has been explicit in the overarching learning objectives and degree requirements for engineering degrees in the Swedish Higher Education Ordinance. The KTH Royal Institute of Technology has had institution-wide objectives and systematic approaches for integrating sustainable development in the engineering education programs for more than 10 years. Evaluation of the current status shows clear progression regarding general aspects of sustainability and environmental sustainability whereas the integration of social sustainability, and therewith related issues such as gender equality, is lagging behind (Hermansson & Rosén, 2021).

In 2016, the Swedish Government commissioned all Swedish universities to develop plans for gender mainstreaming in order to contribute to achieving the national gender equality policy goals (Nationella sekretariatet för genusforskning, 2016). KTH developed a plan for *Gender equality*, *Diversity* and *Equal conditions* (GDE), which includes the following education related goals: 1) increase knowledge and awareness of GDE throughout KTH in order to be able to challenge and change unequal structures and cultures; 2) the integration of knowledge about GDE must be done both in terms of content and in practical action in all education programs; 3) increased awareness of GDE must be related to social sustainability and values in a comprehensive way (KTH, 2017). Further, in the KTH Development plan for 2018-2023, it is stated that gender perspectives must be integrated into all study and research programs (KTH, 2018), and KTH's new sustainability objectives for education for the period 2021-2025 highlights *equality* as an integral part of sustainable development (KTH, 2021).

However, as emphasized by Fitzpatrick (2017), integrating social aspects of sustainability is not an easy task for engineering educators, partly because it is perceived as "outside their discipline and comfort zone". Edvardsson et al (2015) came to similar conclusions as they found that engineering faculty had difficulties implementing issues of social sustainability in the curriculum, partly explained by the fact that faculty members found the concept of social sustainability hard to grasp. Further, the normative aspects of social issues can be challenging to handle, both when complex discussions emerge in the classroom and in assessment and grading.

This paper provides insights in efforts to integrate GDE in three courses on bachelor's, master's, and doctoral level, with particular focus on the development and implementation of reflective assignments. The work has been performed by use of an action research approach that has involved close dialogue and collaboration between researchers, pedagogic developers, teachers, students, and education leaders. The paper is outlined as follows: First, an overview of the concept of reflections is presented and related literature is briefly reviewed. Next, the research setup and approach are presented, followed by a description of three case studies including an overview of the status before this study, the interventions conducted through the study, and the observations and reflections made along and after the interventions. Then follows a discussion of the findings, concluding remarks and future work.

STUDENT REFLECTIONS

The focus of the project presented in this paper was on developing and implementing reflective assignments that combines learning activities and assessment, as means for integrating GDE in the three course modules. The aim of student reflections, in general, is to support students in their learning. For example, Boud and Walker (1985, in Kember, 1999, p. 22) state that "reflection in the context of learning is a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations." Rogers (2001, p. 41) argues that "the intent of reflection is to integrate the understanding gained into one's experience in order to enable better choices or actions in the future". Moreover, student reflection has the potential to support active learning as the students need to be actively involved in the subject content or problem, contextualize it with their own experience, and thereby construct meaning and learning (Freeman et al., 2014; Prince, 2004). Hence, reflections can be used in teaching and learning as means for students to elaborate on a particular field of knowledge with the intention for them to learn and widen their perspectives, with the overall goal to support students to make better future decisions.

In their work on characterizing student reflections, Hatton and Smith (1995) identified four different types, or levels, of reflective texts: (I) descriptive writing, (II) descriptive reflection, (III) dialogic reflection, and (IV) critical reflection, as presented in Table 1. In order to support the students to develop their writing beyond the descriptive type, these characterizations can be used to clarify what the students need to consider when writing reflections. This method has been used in several engineering education programs to support students' capacity to reflect (Cajander et al, 2011; Kann & Magnell, 2013). Hence, the use of reflections, including this type of scaffolding, seemed to be a feasible approach when designing the assessment tasks.

Table 1. Different levels of reflection (based on Hatton & Smith, 1995)

Level of reflection	Characteristic
I Descriptive writing	Description of events, not reflective
II Descriptive reflection	Contains reasoning and argumentation in relation to the theme
III Dialogic reflection	Contains alternative actions and their consequences
IV Critical reflection	Includes multiple, possibly contradictory, perspectives with consideration to broader societal contexts

Some common challenges around reflection include different understandings, thoughtless reflection, and concerns around ethics. To deal with these challenges, Bek (2012), Grossman (2009), and Hatton and Smith (1995), all argue that clear guidance is essential when students are asked to write reflective texts. Without such scaffolding, there is a risk that the students write descriptive rather than reflective texts (e.g., Grossman, 2009).

THREE CASES OF ACTION RESEARCH

The work presented in this paper was conducted using an action research approach that involved close dialogue and collaboration between three education researchers/pedagogic developers, two Deans of Education who are also active as teachers, one additional teacher, and several students. In action research, the aim is twofold and thus includes both knowledge production and achievement of change and improvements of different kinds (Brannick & Coghlan, 2007; Cohen et al, 2011). The action research process contains a *spiral of self-reflection* including *planning*, *acting*, *observing*, and *reflecting*, which is repeated in several iterations (Kemmis et al, 2014, p. 18). Three different cases are included in this study and each case is described in terms of the *status* of GDE integration before the study, the *interventions* performed through the study, and *observations and reflections* on the outcome of the interventions. Data was generated by planning learning activities, observing lectures, conducting interviews and a survey, and reading students' individual assignments. Other sources of data include the reflections of the teachers and researchers. Based on the findings, *further development* of learning activities, ILOs, assessment and grading, are suggested.

Case 1: A module on master's level

Status before this study

The first case concerns the integration of GDE in the master's level course *Research Methodology in Engineering Mechanics*. Already in the autumn 2016, a two-hour lecture on GDE was included in this course (Altimira & Casanueva, 2017). The lecture introduces concepts such as stereotype threat, homo-sociality, and implicit discrimination, and demonstrates that research methodologies are not inherently neutral or unbiased by showcasing research projects and innovations that failed for not considering diversity. The lecture also includes a discussion on how to recognize our unconscious biases, acknowledge them, and find strategies that mitigate their impact in our decisions. The teacher has a background in Mechanical Engineering and does not have any formal education related to GDE except for various standalone seminars on the topic.

Interventions

The aim of the intervention in this course was to establish a more comprehensive GDE module, not only consisting of a learning activity in terms of the lecture, but also including learning objectives and assessment, to enable constructive alignment and enhanced student learning. The intervention included development of a reflective assignment that is intended to complement the lecture with additional learning activities, reading and related assessment. The assignment encompassed reading the report "Gendered Innovations" (EC 2020), choosing one of the case studies in the report, and then writing a text of at least 500 words, briefly reviewing the chosen case and "*reflect upon (i.e., discuss and build on arguments from the text to illustrate) how consideration of equality, gender equality, diversity and inclusion among engineers can influence and/or contribute to research, innovation, and societal development. Identify two examples of such influence/contribution*." This assignment hence concerns reflections on level III and IV according to Table 1.

The reflective assignment was tentatively developed by two of the researchers in dialogue with the course teacher and the Dean of Education. To also include the students in the development of the full GDE module, this assignment was not mandatory the first course round it was implemented, but instead students were encouraged to do and submit the assignment voluntarily, both for their own learning but also to help developing the module for future course offerings. In total six students chose to do and submit the assignment.

Observations and reflections

To evaluate the first round of implementation of this new reflective assignment, and plan for further development, data was collected by the researchers observing the lecture, reading the students' assignments, conducting semi-structured interviews with four students (one group interview, I1, and one individual, I2), and a very brief questionnaire survey. The data collection was further complemented by the teacher's and researchers' reflections. We will here highlight some of the more significant findings that will be of value for the continuation of this study as well as for the integration of GDE in engineering education in general.

From observing the lecture, it could be seen that the students did not engage a lot in the discussions. Our assumption is that students may think that this can be a sensitive area where they do not feel comfortable and that might lead to polemic discussions. The teacher has perceived a substantial evolution of the students' basic GDE knowledge through the five years the lecture has been included in the course. This could arguably be attributed to his own learning that enables better evaluation of their knowledge and thus improves his interactions with the students during the lecture.

The few submitted assignments were of high quality. Hence, the suggested assessment task seemed to work as planned. In the interviews, the students expressed appreciation of the reading in the assignment, in particular the connection to research in engineering disciplines, but they would have preferred to not have as many cases to choose from. To improve the module, they also suggested that the text should be read *before* the lecture and that the teacher should focus on some of the cases in the lecture (I1, I2), thereby making the different parts of the module more aligned. The students also appreciated reflecting on consequences of considering, or not considering, aspects of GDE in research, innovation and societal development (I1). Some of them would have welcomed additional reading in order to include multiple perspectives (I1). Some students also suggested to complement the module further with some kind of group discussion in which the students, in smaller groups, can discuss and dig deeper into GDE (I1, I2).

Further development

This course module may be improved by enhancing the constructive alignment and thus aligning the teaching and learning activity and the assessment. As suggested by the students, the learning activity may include reading the report "Gendered Innovation" prior to the lecture, the teacher may include parts of the main message in the report in the lecture and also add group discussions in which the students will elaborate on consequences of considering, or not considering, GDE in research and how that may influence research, innovation and societal development. Intended learning outcomes also need to be developed.

Case 2: A module on bachelor's level

Status before this study

The second case is an already established module in the course *Management of Knowledge-Intensive Organizations* on bachelor's level in a computer science program. One of the learning objectives in this course stipulates that the student should be able to describe and critically discuss how knowledge-intensive activities can and should take social sustainability into account. The module includes learning activities and material in terms of a pre-recorded lecture by researchers specialized on gender and equality in industrial organizations, and recommended reading. The module was assessed by an individual reflective assignment where the students should write a text on "*how social categories both form the basis for* *creating inclusion and exclusion, and for stereotypes, prejudices and discrimination; what consequences equality and/or inequality can have for a knowledge-intensive organization; and how a company should go about to achieve equality, diversity and equal conditions*."

Interventions

The intervention in this course module included the researchers revising parts of the reflective assignment together with the teacher, aiming to clarify what the students should reflect upon, and adding the report "Diversity wins" (Hunt et al 2020) as reading. The revised reflective assignment was as follows: *"Reflect upon what consequences inequality and gender inequality may have in a knowledge-intensive organization, base your reflections on the lecture and the reading, build on examples from the report 'Diversity wins'",* and "*reflect upon how a company, preferably a potential employer, can accomplish gender equality, diversity, and equal opportunities, i.e., discuss different methods and processes".* This reflective assignment can be categorized as being on level II-III according to Table 1.

Observations and reflections

The evaluation of this module was based on teachers' observations of the students' submitted assignments, a semi-structured interview with one student, and the teachers' and researchers' reflections. We will here highlight some perspectives that are complementing the insights from the master's level module.

In the submitted assignments, several of the students acknowledged that the video lecture was very useful and interesting, focusing both on subjects they could easily relate to (inclusion and exclusion) and their own education at KTH. The students also emphasized that the report "Diversity wins" displayed a lot of interesting statistics.

The submitted assignments clearly showed that the students had gained a lot of knowledge from the video lectures and recommended reading. Most of the students were in the assignment able to integrate this knowledge into their reasoning on consequences of equality and inequality in knowledge-intensive organizations, and how the organizations can handle this. It should be noted that students in this program are used to writing reflective texts and, consequently, the assignment was not considered to be challenging.

In the interview, the participating student argued that an exercise that increases awareness of how people are discriminated would have been welcome, but also reflected upon the risk for students feeling uncomfortable in such exercises, if they are required to be personal and share their own experiences (I3).

Further development

This module may be improved by adding group discussions in which the students can elaborate on consequences of inequality and gender inequality in organizations before they submit the assignment.

Case 3: A module on doctoral level

Status before this study

The third case considers the establishment of a new GDE module in a mandatory course on sustainability for the doctoral program in *Technology and health*. The course consists of a series of half-day workshops aiming at contributing to an overall orientation about the different research areas included in the PhD program and development of necessary skills. One of the intended learning outcomes of the course was for the PhD student to be able to: “reflect on what the concept of sustainable development can mean in their own PhD project, as well as in Technology and Health, based on social, economic and ecological aspects”.

Intervention

The intervention in this case concerned development and implementation of a completely new GDE module, consisting of a workshop and a reflective assignment, with focus to raise awareness about GDE among the PhD students. The workshop was planned and held by GDE experts, whereas the assessment was to be done by the examiner of the course. The workshop started with a short introductory lecture to GDE. After the lecture, the students did a group assignment about discrimination legislation. The workshop also included a role play (*Privilege walk).* Finally, the students discussed in pairs in what ways GDE can be integrated in their area of research, and in what ways GDE issues could be taken more into account in their work environment. In the individual reflective assignment, the students were asked to: 1) *Reflect on how, at least two, shortcomings in gender equality, diversity and equal conditions are expressed in your academic environment, and on your own role in creating an inclusive environment,* and 2) *Reflect on how your PhD project, as well as the fields of Technology and Health in general, benefit from integrating/considering GDE, and how these fields in turn can contribute to GDE.* This assignment hence concerns reflections on level I, II and III according to Table 1.

Observations and reflections

The evaluation of this module was based on interviews with participating PhD students (I4, I5), the workshop leader, the course responsible, and the researchers’ reflections. We will here highlight some perspectives that are complementing the insights from the master’s and bachelor’s level modules.

The course responsible was satisfied with the workshop. However, the interviewed PhD students responded somewhat critically, not for including GDE in the course, but on how it was implemented in their program, primarily because it was considered superficial (I4, I5). They suggested that it would be better if GDE was included in the mandatory courses on ethics and theory of science, and not only as a workshop. They also expressed preferences that someone with GDE expertise should lead the discussions together with a teacher within the engineering discipline.

The informants stated that the assignment did not contribute much to learning, particularly not on how to integrate GDE perspectives in their own research. One informant suggested that it would have been interesting to discuss the literature a bit more during the seminar, both in small groups and with whole class (I5). Another suggestion for the learning activity was to implement a wicked problem approach, “I liked the 'dilemmas' format from the sustainability seminar better than the group exercises in the gender and diversity seminar - we discussed how different sustainability goals might conflict with each other. I think it could be interesting to do a similar exercise with gender and diversity” (I5).

Further development

The module and its learning activities and assessment could be more integrated and thus connect more strongly to the students’ research. The reflective assignment could also be revised to encompass critical reflection in which the PhD students are required to consider consequences of GDE, and lack of GDE, in their research and the broader societal consequences. This integration may be developed together with the PhD students as they are experts in their own research fields and on their needs. They may also have knowledge that goes further than the teachers'.

DISCUSSION

As described, the modules on bachelor's, master's and doctoral level differ: the first contained a lecture followed by a voluntary individual reflective assignment; the second contained online material, literature and an individual reflective assignment; and the third was mandatory and contained an introduction lecture, group discussions and exercises, reading, and an individual reflective assignment. On an overall level, all respondents emphasized that they appreciate the initiative to enhance GDE in education. Several of them, however, had previous knowledge and interest in the topic and stated that they did not learn much new and emphasized the importance of providing an interesting learning activity to all students, regardless of their previous level of knowledge. Moreover, the interviews and the survey indicate that there are several challenges involved in integrating GDE in engineering education.

One issue that we have identified considers the scope of these kinds of modules: should it be broad to provide a general overview and cover numerous aspects of gender, ethnicity, religion, etc., *or* deep, and should it in addition to knowledge also develop skills and attitudes? The students we interviewed seem to have found the modules to be somewhat superficial and too broad. Instead, they seem to prefer a deeper approach where they also get tools for handling and improving inequalities in working life and, for the PhD students, in their research. Based on these findings, we recommend focusing on those students that already have some GDE knowledge letting the other students work a bit harder to catch up.

Another question concerns who should be teaching; should it be a regular engineering teacher *or* a GDE expert? The interviewed students seem to prefer GDE experts. However, relying on external experts is costly and will most probably result in weaker integration with the specific subject or discipline. If possible, it could be good to both involve a GDE expert who can ensure depth and is more comfortable with facilitating value-related discussions and a regular engineering teacher who can contextualize GDE in the engineering subject and discipline, at least in early stages allowing the regular teacher to develop GDE knowledge and then gradually becoming confident (e.g., Fitzpatrick, 2017). Teaching GDE is difficult for teachers who have neither GDE knowledge nor tools to analyze their teaching and course content from a GDE perspective. Now, however, all programs at KTH must integrate elements of GDE for students to be able to contribute to a more sustainable and equal world. The proposal to use reflective assignments as a method for learning, is aiming to lower the threshold and provide support. However, reflection is a learning activity that may be new for many regular engineering teachers, where teaching often consists of lectures, labs and exams, and less often of (reflection) seminars. It requires courage and creativity from teachers and course leaders, and the three programs in this study have approached it differently in how they have set up the GDE modules. The role of the students should also be emphasized, where the teacher by taking a learning facilitator role rather than a content expert role, can invite the students as co-creators of the GDE integration. Our hope is that everyone who is involved in teaching and education in various ways can, regardless of the degree of GDE competences, contribute to integrating GDE in the education so that students can learn for a sustainable world.

The aim of this paper was primarily to share experiences from the development of course modules integrating GDE in two engineering programs and one doctoral program. The primary focus was put on the reflective assignments, i.e., the assessment, and the results of the study show that the proposed reflective assignments seem to have worked as intended. For the reflective assignments to become "intellectual and affective activities" leading to "new understandings" (Boud and Walker, 1985, in Kember et al, 1999, p. 22) and "better choices or actions in the future" (Rogers 2001, p. 41), we recommend including group discussions in GDE related teaching and learning activities. Hence, a missing ingredient to enhance the learning about GDE is a structured seminar. This missing link point to the importance of constructive alignment (Biggs, 1999) and the need for focusing on what the students should do to reach the ILOs, for example by including learning activities in which the students can actively work on and discuss their reflective texts.

CONCLUDING REMARKS AND FUTURE WORK

The paper has given multiple perspectives that contribute to the understanding of how to integrate sustainability and sustainable development in general, and social aspects of sustainability and GDE in particular, in engineering programs. The paper also contributes with concrete examples of reflective assignments, learning activities, and literature that can be useful also in other contexts. The presented course developments and establishment of reflective assignments, as well as the applied action research approach, are concluded to be feasible. There are however opportunities and needs for further development where additional cycles of action research, including *planning*, *acting*, *observing*, and *reflecting* (Kemmis et al, 2014), could be conducted and more data generated for enhanced understanding and evidence. The studied cases are not only at different levels, but they are also in different subjects, which may affect whether reflection as a method is embraced as there may be different teaching traditions in the different disciplines. Additional trials in courses across various engineering disciplines, interviews with students, and discussions with faculty members, need to be conducted in order to further develop all included aspects and to support the development of GDE integration in engineering education programs for a sustainable future.

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COACHING PRACTICES IN CHALLENGE-BASED LEARNING: CHARACTERISTICS IN STUDENTS' PROJECTS

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ABSTRACT

Coaching students in CBL settings requires specific approaches. Although CBL has similar characteristics as Design-based learning (DBL), the educational concept and approach applied in the engineering programs at the Eindhoven University of Technology for over the past twenty years, CBL evolves from the DBL concept to emphasize the importance of addressing the sustainable development goals in education. Despite the fact that DBL coaching characteristics have been investigated, it becomes interesting to research these practices in CBL settings. The aim of this research study was to investigate coaching practices and explore differences among experienced coaches versus novice coaches, and the influence of the project set-up (e.g. group versus individual projects). The study was conducted in the department of Industrial Design, where students work on open- ended and hands-on challenges in groups or individually in the squad, an educational organizational form, where education and research come together. Project coaches and teacher coaches support the students to gain and apply knowledge and in the supervision of self-directed learning. The research method consisted of observations of coaching sessions (N=9), and semi-structured individual interviews with coaches (N=13 coaches) of various levels of experiences. Semi-structured interviews with individual (N=14) and groups of students (N=3) took place. Data were analyzed using thematic analysis and categories within the framework of coaching in Design-based Learning by Gómez Puente (2013) and the theoretical framework of Cognitive Apprenticeship by Collins (1991). Results indicate that the 3 most frequently used coaching practices are a) asking open-ended questions; b) providing feedback on progress in technical design and design process; c) encouraging students to explore alternatives for problem solving using different perspectives. The results are in line with teaching the discipline as design process are embedded in uncertain and creative undertakings in which students are motivated to think big in proposing solutions. Novice coaches focused more on technical design while more experienced coaches encouraged students to reflect on their learning process and to become more self-regulated learners.

KEYWORDS

Challenge-based learning, Design-based learning, Coaching, Integrated Learning Experiences, Standards: 1, 5, 8, 9

INTRODUCTION

Engineers in the industry and professional designers perform tasks with uncertainty and shape the process of developing a product by making relations between experiments, iterations in the design, making judgements to justify decisions, and communicating (Atman et al., 2007). Engineering problems in education are complex in nature and are designed based on challenging assignments. Students go through the process of solving problems by discovery and experimenting. They learn to analyze, synthesize, reflect and evaluate in loops while explaining the reasoning from findings in order to make decisions. In addition, practising the theory learned in courses or alike fosters cognitive retention (Karaman & Celik, 2008; Cavanaugh, 2004).

Coaching students to develop expertise as professional engineers and to gain an identity as designers require facilitating the process of learning to acquire and apply knowledge on the one hand. On the other hand, learning solving problems in complex and ambiguous settings ask for self-direction to address learning needs, identify objectives and search recourses (Findley, 2009; Lunyk-Child et al, 2003).

Design-based learning (DBL) and challenge-based learning (CBL) are suitable active learning methods that expose students to the nature of real life complex problems both in engineering and design-alike projects. DBL has been the educational concept and approach at the Eindhoven University of Technology (TU/e) for over the past 20 years (Wijnen, 1999; Gómez Puente, 2014). DBL has been applied in engineering study programs to teach students to look for answers to engineering problems while discussing and sharing knowledge in multidisciplinary teams that support learning in a meaningful manner. The characteristics of DBL and its effects on students' yields and projects' results have been investigated in the field of engineering education (Gomez Puente, 2014; Mehalik & Schunn, 2003; Apedoe et al., 2008). Following world-wide trends to incorporate the United Nations Sustainable Development Goals (SDG) in engineering programs, the concept of Challenge-based Learning (CBL) represents a suitable approach to educate engineers in developing technological solutions to current engineering and societal problems. Within the current developments and the emphasis of the United Nations SDG, Challenge-based learning is becoming a world-wide concept in engineering education. Within the context of the TU/e, CBL evolves from DBL and its characteristics and lies the emphasis in addressing the sustainable development goals in educating the new generations of engineers. Despite the fact that DBL coaching characteristics have been investigated, it becomes interesting to research these practices in CBL settings.

We conducted this study in the department of Industrial Design (ID) of Eindhoven University of Technology between February 2021 and June 2021. The ID department has almost 20 years of experience with organizing small-scale and design-based education. The organizational structure at the department of ID over 20 years has been the formation of educational communities, the so-called 'squads'. 'Squads' are defined as 'collaborative learning communities' that share an interest in a specific application domain. Within the squads, students work on open- ended and hands-on challenges in groups or individually. Vertical learning takes place in the squads where students from different bachelor and master years who work in projects and exchange experiences in a community of practices (Lave and Wenger, 1991). Students are guided by coaches, PhD staff and experts from the industry, the so-called, hybrid teachers.

Coaching is one of the pillars of the educational model of the department of ID. Students develop competencies, design own goals and drawn plans to achieve their identity and vision as designers. These core values of the ID educational model are essential to guide students in their growth as designers. The underlying principle is to support students to become self-directed learners and to reflect on competences development while designing and acquiring professional skills. In every project there is a project coach and a teacher coach supporting the students to gain and apply knowledge and in the supervision of self-directed learning. Students work for a semester and meet their coach weekly or bi-weekly.

Following the insights from the research literature on coaching of students' development, the focus of this investigation is to identify coaching practices in CBL and explore differences among experienced coaches versus novice coaches, and project set-up (e.g. group versus individual projects). We formulated, therefore, the following research questions for this study:
RQ (1) - What are the characteristics (indicators of behaviour) of coaches, when coaching students to support learning?
RQ (2) - What are the project characteristics that influence coaches' approach in coaching?
RQ (3) - What is the coaching style of experienced versus novice coaches to support learning?

THEORETICAL CONSIDERATIONS

There are numerous empirical studies associated with educational theories such as cognitive apprenticeship (Collins, Brown, & Newman, 1989; Collins, 2006) and situated cognition (Lave & Wenger, 1991) that highlight interesting results in students' performance. These theories are of interest in particular to create meaningful learning environments reproducing complex and real-life professional practice with authentic tasks. Specially, in the context of coaching, cognitive apprenticeship provides an excellent platform to supervise students' learning by *learning-through-guided-experience on cognitive and metacognitive skills by which students learn the problem-solving processes that experts use to handle complex tasks* (Gómez Puente, 2014, p. 186).

When embedding cognitive apprenticeship in educational settings, the role of the teacher is exemplified as a coach to facilitate the learning process of novices by experts. Examples from the literature illustrate the actions of the coach through modelling, coaching, scaffolding, stimulating reflection, articulation, and exploration (Collins, Brown, & Newman, 1989; Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007). In scaffolding, we find instances of coaches in prompting open-ended questions to model and frame engineering thinking, facilitating the exploration of the design problem from different perspectives; stimulating critical reflection on the engineering and design process, promoting articulation on the design choices; and, providing feedback, pieces of information in a just-in-time form and tailor-made to the needs of students (Maase & High, 2008). Furthermore, the coach's role goes beyond supervising content-wise learning process as examples of guided instructional approaches focusing on meta-cognitive activities are also commonly employed (Massey, Ramesh, & Khatri, 2006). Likewise, when embedding situated learning scenarios the role of the coach is found as a customer, user, or expert in education (Martínez Monés, Gómez Sánchez, 2005).

Moreover, consulting the literature research within the context of (engineering) design we found characteristics of actions in coaching deeply related to the discipline of design. In these studies coaching actions are related to encouraging students to gain conceptual knowledge (design judgement, i.e. aesthetics coherence, feasibility, interactivity), design tasks (i.e. problem framing, balance trade-offs, valid experiments, focused diagnostics iterations and reflection), and strategies (procedural knowledge) as well as design process management strategies by using codes (i.e. complexity management, risk management, time management, etc.) (Ryan & Bernard, 2003).

For the purpose of this study we make use of a framework of coaching actions and behavior validated by the literature and empirical research within the context of DBL and alike in engineering education (Gomez Puente, 2012). This framework consists of an adaption of cognitive apprenticeship methods, situational learning strategies together with approaches to coaching students in design reviews (Adams, Forin & Joslyn, 2017).

METHODOLOGY

Research context and participants

The aim of this research study was to identify coaching practices in CBL and explore differences among coaches' experience (expert coaches vs novice coaches) and project set-up organization (e.g., group versus individual projects). Our study was conducted in the context of the squad, which included several projects with a great variety in terms of student's characteristics (e.g., students of bachelor or master level) and project organization (team or individual projects, open ended etc.).

The participants of this study were coaches of all squads of ID (See Table 1). All participants were informed via email about the purpose of the study and were invited to participate. In accordance with the Ethical Review regulations applied at the university, both coaches and students were asked to sign a consent form in case they agreed voluntary to participate in this research including participating in observations and interviews.

Table 1. Overview of research method, research instrument and participants

Qualitative	Instrument	Total N	Descriptive characteristics
	Observations of coaching sessions	9	Individual projects:5 Group projects: 3
	Interviews with coaches	13	Male: 9 Female:4 Expert:11 Novice: 2

Research methods

We collected data on coaching interactions using the following methods:

Observations of coaching sessions aimed at attaining an overall understanding of the coaches' behaviours during those interactions. Due to COVID-19 all activities (e.g. coaching sessions, students' group work, workshops and presentations, etc.), took place online. Thus we asked coaches and students to record their coaching sessions and shared the video with the researchers. Participation was voluntary and we asked participants to share examples of their coaching sessions during the project process, i.e. initial phase, project implementation, and final phase of the project. Observations were facilitated by recording the coaching sessions using the program Microsoft TEAMS after students and coaches provided their consent for recording.

Interviews with coaches were conducted at the end of the semester to gain in depth understanding of their own behaviour with coaching in CBL. We conducted interviews with coaches who had extensive experience (> 7 years) in coaching (expert coaches) and less experienced (<5 years) (novice coaches). Interviews with coaches were guided by the framework of Adams (2016). Coaches were asked for concrete examples of how they coach students across different design tasks and processes and asked to indicate differences in their coaching style depending on students' level of education and project characteristics. Likewise, coaching approaches on identity and vision were also collected. These interviews lasted approximately 60-90 minutes.

Data analysis

Data collected via video-recorded observations were analyzed using the framework of coaching in Design-based Learning (Gomez Puente, 2013) as guide to identify coaching behaviors. Table 2 provides an overview of the coaching behaviors coded during observations. Two independent researchers at the beginning of the data analysis phase coded independently using the same 1 video framework. Then they discussed and compared their coding approach and agreed to a common strategy. After both researchers coded their videos, they both cross-coded each other's 1 video for validation purposes.

Table 2. Overview of framework used for the analysis of coaching sessions and interviews

1. The coach formulates open questions to -FOQ
2. The coach acts as an expert, customer; gives information on specifications – AEF;
3. The coach provides feedback on progress on presentation skills, team work – FPS;
4. The coach reviews progress on plans, proposal, etc., RPP;
5. The coach provides feedback on evolving efforts (e.g. coaching on progress in technical design, design process, data collection, testing methods) PTD;
6. The coach supports students in reflecting on and explicating rationales for technical design, argument formulation, and decision making, RER;
7. The coach supports students in case of difficulties (just-in-time teaching) JIT;
8. The coach uses methods/tools (worksheets, drawings, examples, etc.) to guide the team, UMT;
9. The coach encourages students to articulate engineering terminology during regular meetings and presentations, AET;
10. The coach encourages students to look back on previous actions/tasks and reflect what they learned from them; EAP
11. The coach encourages students to learn from other students' plans, learn from experts knowledge application in problem solving experiments, LEE;
12. The coach observes students during implementation of activities, OIA;

Data collected via interviews were analyzed using thematic analysis, which consisted of the following steps: familiarization with data, coding, generating themes, reviewing and defining themes (Clarke and Braun 2013). In our analysis, we followed a deductive, theory-driven approach and the theoretical framework of Cognitive Apprenticeship by Collins (1991) and the framework of Adam (2016) in coaching processes were used as guides to formulate our themes.

RESULTS

Analysis of video- recorded observations

Results indicate that the 3 most frequently used coaching practices included: a) asking open-ended questions, b) providing feedback on progress in technical design and design process and c) encouraging students to explore alternatives for problem solving using different perspectives. In Figure 1, an overview of the coachers' behaviors, the frequencies in terms of the number of times coaching behavior actions were performed are included.

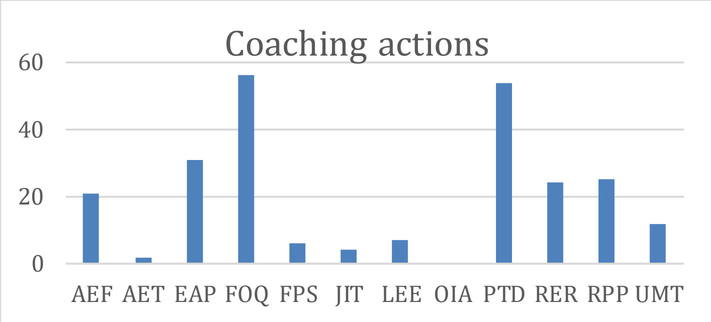

Figure 1. Overview of coaching actions performed during coaching sessions

Coaching actions during design process: the influence of project and student characteristics: Coaches reflected on the different aspects that can influence their coaching. Three aspects seems to play an important role namely: a) the level of education of students b) whether the project is a group project or individual and c) whether the project is open-ended or it is an existing project with some predefined constraints. Table 3 provides some details and quotes.

Level of education: According to coaches, students at the beginning of their bachelor, pre-master and master students who have done their bachelor studies in other faculties, they need more guidance and support in the design tasks and process as they are used in ID. On the other hand, final bachelor students and master students, who have also conducted their bachelor studies in ID, are considered more independent due to the fact they have conducted multiple design projects and they are more familiar with ID processes. In addition, depending on their level of education, students find different aspects of the design process more difficult. For example, students in earlier years of bachelor might need much more guidance at the beginning of the project to develop ideas, while more experienced students need more coaching to balance their focus on a specific idea, while keeping the bigger picture of their project in mind.

Group versus individual projects: Whether students work as a group or individually also plays a role to coaching. In groups, coaches prefer not to interfere with group dynamics and let the group choose what direction they want to follow in their project. In individual project students do not have other peers to brainstorm their ideas or feel insecure about making final decisions so coaches choose to support students in this direction by thinking along with them and encouraging them in decision making by linking it to their overall vision and professional identity.

Open ended versus defined project: The type of project also plays a role in coaching. When students start with a very open-ended project they need more coaching at the beginning to narrow down their focus and objectives. This is especially true for Final Bachelor Projects, which are individual projects. When the project is very detailed and concrete, the challenge for coaches is to help students to be creative and learn things within the constraints of their project.

Table 3. Overview of project and student characteristics influencing coaching actions

Students' level of experience	*In the lower year, during idea generation, coaching is very much needed. In the last part, where they're they' re building prototypes and stuff, there is less coaching needed, because it's mainly it's clearer what needs to be done. And in the higher year projects, it's mainly seeing the bigger picture and making them see the bigger picture and have them not drown in details, elements of the process or in detailed expertise areas (expert coach).*
Group versus individual projects	*So I think with group projects, it's just easier, like students have more experience doing group projects. And if it's individual projects, you really have to think along with them. Right, like, so what did you do before on your prior projects? What are your interests? What did you like about them? (novice coach).*
Open ended versus defined project	*So they get a specific brief on what they have to design. And very easy when it's very detailed. But it depends on the level of students, right? bachelor, they need more guidance masters a bit less, If it's really broad, you need to definitely guide them a bit. Give them at least two three different options on what they could do (novice coach).*

Analysis of interviews

Coaching actions during design process: *coaches' views based on their coaching experience:* Interviews with coaches showed that apart from student characteristics and project characteristics, coaches' own experience can also influence their approach. Table 4 gives some examples of the themes identified.

Using open-ended questions throughout design process: Despite years of experiences, all coaches in this study reported that asking open and critical questions to students was their main coaching approach to encourage students to elaborate and explain their thoughts, justify their design decisions and monitor and evaluate their design tasks and actions. This result is not surprising as the design process relies on uncertainty and ambiguity in which creative thinking plays a major role.

Coaching on time planning and time management: One common characteristics among all coaches was the emphasis on time management. They suggested the importance of supporting students to make a good plan at the beginning of the project but set frequent checkpoint to revise this plan during the project. In this aspect novice coaches reported to be more active in supervising students planning more actively, warning them for possible setbacks to ensure that students can finish their project within time.

Coaching students on decision making: One of the most difficult aspects during coaching according to novice coaches is helping students to become more autonomous and empower them to make decisions. Experienced coaches actively abstained from deciding on behalf of the students and usually the most commonly reported coaching approach was to provide them with some options. Encouraging students to detail the pros and cons of different options and discuss them with their coach, was a commonly mentioned approach by both experienced and novice coaches.

Encouraging student to reflect on their design process
Crucial to the process of design is to help students reflect and learn from that experience. Especially expert coaches emphasized the importance of frequently taking a step back and evaluating their progress and reflect on it.

Coaching students to perspective from doing to learning
Expert coaches during their interviews put a much larger emphasis on helping students through the project to develop their professional identity and shift their focus from doing a project into learning compared to novice coaches.

Coaching students to balancing big picture with details
Expert coaches reported more interventions where they actively zoomed out to help students have the bigger picture of their project in mind. The importance of keeping in mind the big picture is relevant in all stages of the project according to expert coaches. Novice coaches tend to help students to start from more concrete projects and guide them on a technical level more closely without making explicit references in their interviews about reflection during the project on the bigger picture.

Coaching students to different perspectives
Novice coaches reported the importance of exposing students to a diversity of ideas early in their project as a way to avoid guiding to students in only one direction. Expert coaches also encouraged students to contact other experts but at a later stage when students need more technical support on a specific area.

Table 4. Overview of coaches' actions

Using open-ended questions throughout design process	***Open question to justify decisions*** *"If you press the push notification locker opens? Is that the flow you're envisioning?"(expert coach)* ***Open question to articulate reasoning*** *So some of the students will stick on a very specific idea, usually the first idea they had. So that means they didn't the dig much survey on this domain. So that's why as a coach, I will ask a lot of critical questions for the student to explain, "why you want to do this?" and maybe suggest he can go some different directions (novice coach)*
Focused on students' professional vision	***Start from students' motivation*** *"I start from students motivation because this is what matters after all" (expert coach)* ***Try to understand who the student are*** *"what did you do before on your prior projects? What are your interests? What did you like about them?(novice coach)*
Coaching on time planning and time management	***Set expectations from the start*** *"There are multiple iterations. Plan them out. You have to sit down and unpack with each other. Think of the methodology, the other job is to develop a mechanism of what you have done and what you're going to do…"* (expert coach) ***Constant revising of plan***

	"I know that at the beginning time planning is perfect but delays and other things happen during the process so we set checkpoints and we ask students to reflect on their plan and revise it if needed" (novice coach)
Coaching students on decision making	***Think along with student*** *"You come into an ethical 'split' if you speak on behalf of a child. A child is has autonomy and is wise, and you can't have a device who thinks for the child, and you can't forget the parents. The opinion and feelings of the child needs to be taken into consideration."(expert coach)* ***Suggest many different options*** *But I also always try to then come up with a richness of possible ideas. Because if I come up with one suggestion, you know that next week, they have adopted that idea and come up with should take over your idea and continue with that. Whereas it's not meant to say this is what you should do (expert coach)*
Encouraging reflection on process-how you learn	*"How do you probe you're the locker?...You said QR code but I want to use remote unlocking through Bluetooth. This has consequences for interaction and that's missing from your argument…" (expert coach)*
Coaching students to perspective from doing to learning	*"So I think that's, that's one of the first things to changing that perspective, that you're not doing it to pass to pass courses, but to develop your to develop yourself and to see, what you want to what you want to learn from it, and how its contributes to your, to your development" (expert coach)*
Coaching students to balancing big picture with details	*"It's mainly firstly challenging them to see the bigger perspective or provide them with a bigger perspective and have them reflect on okay, how important is that thing that I'm working on? In the larger in the larger part?" (expert coach)*
Coaching students to different perspectives	*"We have the cross coaching so I really like that because that means the student can get the different perspectives from different coaches is not like the only gather the people from my side because of the usually the mono feedbacks really kind of, well, we'll only direct them to the one specific direction but I think it's important at an early stage to explore the diversity of the idea". (novice coach)*

CONCLUSION

Results indicate that the DBL coaching framework used is a suitable instrument to analyze coaching situations in DBL/CBL contexts. The comprehensive framework facilitates the visualization of coaching practices and contributes to shed light on experience coaches' behavior. For educational practitioners and more specifically for organizations to set-up training programs for novice coaches, the framework acts as a guideline for the professionalization of teachers (e.g. A buddy system so that the novice coaches can learn on-the-job and observe many different coaches; to make implicit ID experience more explicit; to encourage peer reflection; to adjust coaching to students' level; to develop own coaching identity; and, to understand that if students fail that is not due to personal failure).

Finally, this study has opened up new opportunities for further research. Next steps include exploring longitudinally the effect of coaching practice on students' knowledge acquisition, application and overall professional development in the context of the squads.

Limitations of this research study

Despite the sound research approach planned for this study, the research encountered some limitations. First of all, this study has been conducted during the COVID-19 pandemic period. This has had serious consequences for the implementation of the study as coaching sessions between students and coaches were conducted online and no face-to-face meetings took place. Although online meetings were recorded and the researchers had access to the information, observations of coaching sessions alive count with more value to perceive optimally, for instance, how feedback is processed by the students and the effect on their work. Secondly, despite the fact that the coaching sessions were recorded with the consent of students and coaches, not all coaching sessions were recorded throughout the implementation of the semester projects. This impeded to follow the coaches and the students' group in all phases of the design process. Only some recordings of coaches were made available, and in some cases only one recording was delivered. Therefore, we are careful to make strong conclusive judgments of the findings of this research study.

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DEBATE AS A TOOL IN ENGINEERING AND SUSTAINABILITY EDUCATION

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ABSTRACT

Debate is an active education tool which is widely used to teach undergraduate students in social science and humanities courses, but less common in Engineering and Computing courses. Debate, in this context, refers to the establishment of contradictory positions on a topic or question and inviting students to form 'teams' or parties each tasked with the responsibility of promoting those positions to an audience through mediated oral discourse. A well-integrated debate can help students to improve their understanding of the subject, improve their critical thinking, increase the retention of the information gained, enhance communication and teamwork skills, promote their confidence and help them to better construct their ideas and thoughts in a logical and sound structure. It is well known that integrating this approach in an active learning environment will promote a student's engagement and motivation to learn. In this paper, the practice of integrating the debate on the climate change response pathways (Adaptation, Mitigation and Geoengineering) in a final year course taken by Mechanical Engineering students will be presented. The effect of using this practice on students' engagement, module feedback and marks will be highlighted.

KEYWORDS

Debate, Sustainability education, Active learning, CDIO Standards: 1, 2, 3, 11

INTRODUCTION

Compared with traditional didactic teaching, it is accepted that active learning strategies produce increased content knowledge, greater enthusiasm for learning, development of critical creative thinking skills, and an improve in students' engagement with the topic taught. Several active learning strategies are popular in engineering disciplines such as real-world problem solving, group projects, student presentations and peer response polling systems. The use of debate as a mode of active learning mode was found to be far less popular in engineering courses when compared with other disciplines such as humanities and social sciences.

Debate is regarded as an educational tool to systemise discussion between students on specific topic or question, where teams with contradictory positions on that topic will attempt to make the audience accept their position. A well-planned and integrated debate can help students to increase their understanding of the subject, improve their confidence, communication and team-working skills, enhance their reflection and critical thinking practice, and learn how to construct their ideas and thoughts in a sound and logical structure. Furthermore, it will lead to increased student retention of the information learned, as it is interest-based learning that engages the mind thoroughly.

In this paper debate as an education tool will be described, mentioning its benefits and drawbacks when applied to different subject areas. A brief literature review will be used to investigate its impact on different educational metrics such as attendance, engagement, knowledge depth, retention of knowledge and soft skills. Furthermore, integrating this educational tool in the teaching of a module (course) in the Mechanical Engineering programme at Aston University will be outlined, highlighting the effect of such intervention on students' experience and marks.

LITERATURE REVIEW

As an education tool, it was claimed that one of the most important benefits of debate is that it promotes working together in teams and having a positive and constructive interaction when performing a collective task (Zare and Othman, 2013). Students who learn using cooperative approaches such as debate showed greater academic ambition and improvement, longer retention of the knowledge gained, higher level of critical thinking, higher self-esteem and more constructive communication. Furthermore, when compared with other individual study activities, this collaborative learning activity results in higher-level reasoning, more creative solutions and greater transfer of knowledge within the team itself and the wider classroom environment. Aiming to measure the students' perception about educational debates, it has been found (Goodwin, 2003) that while a few students reported distress and anxiety about the competitive nature of debates, the majority expressed positive feelings claiming that the debate encouraged them to explore the content of the course deeply and that it promoted independent learning for themselves.

In engineering courses, it was noted that non-mathematical courses such as material science can be mainly theoretical, leaving the educator with fewer options to encourage active learning. As a result, Hamouda and Tarlochan (2015) incorporated team debating as an education tool in the Materials Science module, in which students claimed that the applied method was very enjoyable, encouraging them to attend and to engage highly in the course, and enabled to let them reflect on higher levels of Bloom's Taxonomy. Moreover, it is stated that the students improved their time management and team working skills and student grades and attainment increased significantly. In a study conducted by Alford et al. (2002), it was claimed that using debate as a teaching tool in engineering course, such as Artificial Intelligence was highly supported by students. Authors recommended choosing a controversial topic within the subject to let students share and evaluate different viewpoints. To support their arguments, it was noticed that students needed to do independent research and to improve their verbal communication skills.

It has been mentioned by Snider and Schnurer (2002) that applying debate approach in education was found to push students to adopt a greater responsibility for comprehension of the subject and to invest more serious study effort. In learning controversial subjects, debating was found as a great tool to allow students to appreciate the complexity and the multi-faced nature of subjects. This education tool can provide students the opportunity to synthesize course information, encourage related research, improve critical thinking, and develop verbal communication skills. Debate sessions were introduced to 2nd year medical students by Mumtaz and Latif (2017), where over 180 students participated in opening argument, rebuttal, formal debate, and in closing remarks from each side. It enjoyed an overwhelmingly positive reception with 78% of the students agreeing that it improved their critical thinking, 80% agreed that it helped them understand the importance of listening to different views, and 75% agreed that it helped them to realise different strategies to convince others. The public nature of the debate appears to motivate the students to perform well naturally (Aclan, Noor and Valdez, 2016). Moreover, the effect of this approach on soft and transferrable skills is greatly appreciated by students with communication and team-working skills seeming to receive the greatest benefit from this approach.

METHOD FOR THE ENGINEERING EDUCATION INTERVENTION

The intervention took place in the academic year 2018/ 2019 as a part of the Engineering Design and the Environment module, which was delivered for the 136 students studying in the third year Mechanical and Design Engineering Programmes. The module aims to outline how engineering designs impact on the environment and to give an in-depth account of impacts in climate change and ocean acidification. Life cycle assessment is introduced as a method of categorising and quantifying impacts. In particular, students learn about the three main pathways of responding to the climate change issue, namely adaptation, mitigation and geoengineering. While adaptation focus is on building defences to limit damage occurred by climate change, mitigation aims to reduce the greenhouse gases, ideally to effective zero, and geoengineering has been seen as a radical response where mankind effectively take control on the climate using different artificial interventions. While these pathways are very different from the technical perspective, ethical considerations and social perception are at the core of the pathway choice. The module is assessed using an individual exam (70%) and a group presentation (30%) based on the group project in the three after mentioned pathways.

Following a brief scientific background on how climate change is happening, and the effect of greenhouse gases on the climate, the three pathways responding to the global issue are introduced. At that point, students are be given the opportunity to express their views on which approach is more effective, and indeed to choose their group project under that pathway. It was found that students were almost uniformly split into the three pathways. While group projects were made by 6 students in each group, the students were found to almost uniformly split into the three pathways. By implementing the debate as an education tool, the team aimed to increase the students' engagement, reflection and retention of knowledge associated with sustainability and responding to climate change.

While lectures give a detailed account of sustainability and support learning of different technologies under each pathway, the debate between students in different pathways serve as the backbone of the module. Students have a 10 mins window in each lecture to bring up new data/ perspective to enrich and stimulate the debate of the three pathways building on the students' independent research and their progress in the respected group projects. At the end of the module, a public session was made where each group presented on their project and how their approach to climate change is more efficient than others. A space for question and answers followed each presentation where other students tried to contradict the presented view. A following conclusion lecture was used to show the advantages of each approach, and how all different approaches are needed urgently, and side by side, to deal with this global and major matter.

The intervened students' attendance, satisfaction and attainment were compared with the 2017/ 2018 data where a similar delivery and assessment format were used. Therefore, it is proposed that the studied intervention is the primary drive behind the change in the measured metrics.

RESULTS

Instead of teaching different pathways used to respond to climate change using traditional lectures and tutorials, the new approach has used the educational debate as the backbone of the module which encouraged students' attendance and engagement throughout the module sessions. It has been noted that there was 32.5 % increase in student attendance at lectures and group projects sessions compared with the last version of the module, making this particular module one of the most attended ones in the final year. Feedback gained from students via an online survey at the end of the course also improved as compared with the data from the previous year, with special improvement of over 20% on the students 'encouragement and participation in the classroom. An improvement in the students' retention and level of the knowledge can be noticed with 8% higher average mark and 5% improved pass rate achieved. Other verbal and written feedback showed that a majority of students was found to be highly motivated to research beyond the lecture notes, to understand the multi-faced nature of problems, and to appreciate the collaboration value inside the team, and in between other teams. The public debate session which was held by the end of the group projects was also seen by students as a great way to practice public communication with unspecialised audience.

DISCUSSION AND CONCLUSSION

From the results achieved, it is clear that implementing the debate as an education tool helped to improve the students' motivation, engagement, depth and retention of knowledge gained, and soft skills. Although using such approach is not typical for Engineering Education, the subject itself where students have the room for different views, along with briefing recent research projects under each pathway, helped the students to facilitate their choices and debating based on rich and accessible literature in the field.

There is generally a dearth in critical thinking development in engineering programmes, partly due to the increasingly crowded curriculum and the demands for developing technical competence and other professional skills. It is clear from the higher engagement and improved module feedback found in this study that there is a real need for developing critical thinking skills more deeply. The authors suggest a longitudinal approach to embedding critical thinking development throughout engineering programmes. With debate as one proven tool to help with this, future work is planned to use a similar approach in other modules taught in the same programme, namely, the major projects based learning modules and the final year project module.

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EMBRACING FAILURE AS AN INTEGRAL ASPECT OF ENGINEERING EDUCATION

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ABSTRACT

In Engineering education, failure is generally considered unacceptable: catastrophic failures are typical horror stories relayed to students. This attitude is pervasive enough that many students become unwilling to explore creative ideas, or they may make seemingly unreasonable design decisions driven by their fear of failure. Students choose to remain in the space of Vincenti's "normal design" where they know the operational principles and can manage all risks. They avoid the innovation space of "radical design" for fear of an unacceptable result and lack of guidance from teachers about how to navigate such high risk spaces. We believe that experiencing failure in a safe environment is a necessary part of transformative learning in line with the intentions of CDIO. Opportunities to explore tangents that may result in seeming failure need to be built into the curriculum, else the possibilities for creativity and discovery are reduced. The concept of what failure means and the value derived from it need to be examined. A safe space for failures must be created within the Engineering classroom for students to discover their innate courage to explore, innovate, and create. We propose specific methods for fostering such an environment, including implementing version control and documentation of project milestones, a non-hierarchical classroom environment, Non-Violent Communication, and self-designed success criteria.

KEYWORDS

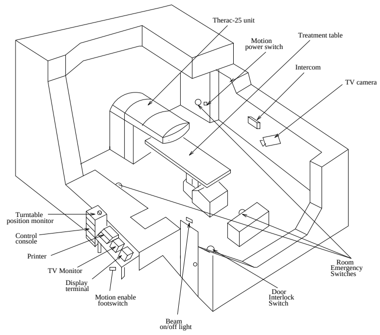
failure, non-hierarchical classroom, transformative learning, radical design, fear, non-violent communication, Standards 4,5,6,7,8

INTRODUCTION

Failure is used as a teaching example in many fields (Figure 1). In dynamics, we consider the collapse of the Tacoma Narrows bridge (von Kármán, 2005). In mechatronics and software engineering, echos of the deadly Therac-25 still cause shudders (Leveson, 1995). The classic structural textbook "To engineer is human: the role of failure in successful design" by Petroski describes the deadly collapse of Pemberton Mill in 1860 (Petroski, 1992). In more modern days, the Hyatt Regency Hotel in 1981 had a walkway collapse, killing many and changing how

(a) Tacoma Narrows Bridge Collapse (Encyclopaedia Britannica, 1940)

(b) Hyatt Regency collapse floor view (Lowery, 1981)



(c) Therac-25 instrumentation layout (Leveson, 1995)

Figure 1. Examples of disasterous classical engineering failures often presented to students.

civil engineers design buildings (Marshall et al., 1982).

The commonality of attitude towards failure in these cases is that it needs to be avoided in order not to suffer the negative consequences. A belief is clung to that by avoiding failure at all costs and at every step along the way (including during the educational process), we can prevent such tragedies altogether.

However, this desperate clinging to avoiding failure has a serious downside: lessened understanding of the inner workings of a system and how to debug errors. In addition, it is an unrealistic ideal; with a long enough view, all components and systems will eventually experience failure. The question to ask is therefore not “Will it fail?”, but rather “When will it fail and how?”

Rather than closing off from failure altogether and clinging to an unrealistic ideal, would it not serve us better to acknowledge failure’s existence as well as the existence of our own fear about it? Is it not crucial to openly examine our attitudes towards failure together with our students, the future engineers who will build the bridges and design the next medical products? By knowing failure better, we can modify our designs and make adjustments to the use and lifetime of our products, which may ultimately result in fewer tragic consequences.

To address the limited thinking around failure, we propose here a shift in academic Engineering education. An educational system built on an attitude of failure avoidance produces students unwilling to take risks and explore new ideas as fully as they might otherwise. Their creative process is limited by the fear of failure and its consequences (ex. low grades, judgment from fellow classmates and/or teachers), and possibilities for discovery and innovation are reduced.

By acknowledging the presence of fear in the Engineering student, we naturally move away from the more traditional model of education as the mere passing down of information from teacher to student. We turn in its place to models that embrace the wholeness of the student (and the teacher) and allow learning to take place on many different levels of the human experience. In particular, we draw here from the ideas of Transformative Learning Theory (Cranton, 2016; Slavich & Zimbardo, 2012), applying some of its principles to create a safe space for Engineering students to explore their creative ideas without being punished or judged for failures.

This paradigm shift will not happen without us, the teachers, playing by the same rules and finding the courage within our own selves to stand in the presence of fear. For the author's own journey, we drew inspiration from Parker Palmer's ideas in "The Courage to Teach" (Palmer, 1998) and the words of Mahatma Gandhi from 1913:

> "If we could change ourselves, the tendencies in the world would also change. As a man changes his own nature, so does the attitude of the world change towards him... We need not wait to see what others do." (Gandhi, 1964, p. 158)

Accepting the invitation to begin with our own selves in order to create the change we wish to see mirrored in the world, we set off on an exploration of questions such as: How does fear show up for us as teachers? Where are the places that require us to step outside of our comfort zone and how do we respond when we find them? Where might we ourselves encounter failure and can we open to that possibility? What does it even mean to fail?

As teachers, we guide the way for our students. And as authors of this position paper, we do the same by allowing ourselves to step outside of the comfort zone of the traditional model of Engineering education and be inspired by the experience of teachers in non-academic environments, most notably yoga. We share here ideas learned from our explorations in other territories and propose ways they can be incorporated into Engineering education within the walls of academic institutions. Ideas such as holding space, anchoring, and Non-Violent Communication (Rosenberg, 2015) are joined with concepts of non-hierarchical classrooms and documentation to create safety checkpoints. All this in service of creating a safe space for Engineering students to discover their innate courage to explore, innovate, and create, a goal explicitly stated in the CDIO standard (CDIO, 2020, Standards 6–7).

RADICAL DESIGN AND DEFINITION OF FAILURE

Before defining failure, let us consider Walter Vincenti's two modes of engineering. The first is "normal design", described by Vincenti as: "The engineer [. . .] knows at the outset how the device in question works, what are its customary features, and that, if properly designed along such lines, it has a good likelihood of accomplishing the desired task." (Vincenti, 1993, p. 7)

The second is "radical design", which Vincenti defines as: "How the device should be arranged or even how it works is largely unknown. The designer has never seen such a device before and has no presumption of success. The problem is to design something that will function well enough to warrant further development." (Vincenti, 1993, p. 8) Radical design is the space for significant innovation.

A teacher can only share what they know. In the traditional top-down educational model, the student only comes into a direct relationship with the teacher, not the object being studied. Thus, it is not surprising that education focuses mainly on normal design. The students study existing designs, learning the operational principles of devices and their customary features. How could they study what the teacher can only imagine?

Furthermore, normal processes are easy to grade and evaluate because we measure similarity to existing, tested solutions. Processes without clear metrics or definitions of success are much more time-consuming and subjective to evaluate. How would one even generate a rubric?

In the section 'Non-hierarchical Classroom", we address some of these questions and share an alternative to the top-down education model. The student does come into a direct relationship with the subject of study and can therefore derive knowledge about it independently of what the teacher herself knows. Under this model, radical design becomes a real possibility.

Let us now turn to definitions of failure itself, and examine them in light of normal and radical design. Suh's complexity theory considers failure a critical point in developing a quantification of unrobustness he defines as Information content (I). An optimally designed system's Information content (I_{sys}) would be: (Equation 1)

$$I_{sys} = \sum I_i = -\sum_i \log_2 p_i \tag{1}$$

where p_i is the probability of meeting Functional Requirement number i given a list of such requirements (Suh, 2005, p. 39). More simply, in an optimally designed system, the Information content (chance of it failing) is dependent on the probability of each required function being met. The desirable situation is to minimize Information content, which Axiomatic Design calls the "Information Axiom".

In the context of normal vs. radical design, we observe that the Information content of a system is only known after its probabilities of success are measured. If we want to maximize success, i.e. minimize Information content, we choose designs with *high probability* of meeting Functional Requirements. How do we accomplish this? We choose what has worked in the past (i.e. normal design).

With radical design, we lack the required information. Our probability of meeting Functional Requirement i is very low, if not 0. We lack the experience to expect to meet the requirement because nothing similar exists. Our design thus has a large, if not infinite, information content. The main experience of radical design is failing, addressing the failure, and improving the design iteratively.

To students, failure has different meanings still. In project-based courses, failure may mean that the device they built does not do what it was required to do, what they might like it to do (or think it "should" do). Failure may also mean simply getting an undesirable grade in a course. This grade may have negative consequences such as having to retake the course, delayed graduation, and possibly loss of scholarships or loans. The theme here is that the failure of a design reflects poorly on the student's perceived ability. Therefore, is it so surprising that students are unwilling to be daring, step into the realm of radical design, and innovate? We hold here that a change in perspective on the part of teachers and academic institutions is called for. If we wish to encourage students to dare to innovate, we must not judge or shame them for failures they may encounter. We must detach the failure of the design from the ability/personality of the student herself, embracing failure as an opportunity to learn.

THE SECI CYCLE OF KNOWLEDGE CREATION

Gilbert Ryle distinguished two kinds of knowledge: "knowing that" and "knowing how" (Ryle, 1949) to differentiate between verbalized intellectual activities and their applications. Traditional education systems focus on "knowing that", which is easy to test. There is less focus on teaching "knowing how". Evaluating "knowing how" is challenging. Students must explain and justify their processes and decisions. "Knowing how" is *tacit knowledge*, a knowledge that we cannot verbalize easily. A classic example is riding a bike. We learn how to ride a bike, but when we are tasked with *explaining* to somebody how to ride a bike, we can only say: "practice". One does not learn to ride a bike by reading physics textbooks. One learns by riding the bike, failing, and trying again. Michael Polanyi formalized this tacit knowing by observing "We know more than we can say." (Polanyi, 1958, p. 4)

Polyani argues that we do not learn many skills through formal processes. Tacit knowing is a product of life experience. How do we transfer such knowledge acquisition to Engineering classrooms? Our students will not even mount the proverbial bike for fear of failing.

Nonaka and Takeuchi see tacit knowledge as a strength of the East-Asian way of thinking:

> "Japanese companies, however, have a very different understanding of knowledge. They recognize that the knowledge expressed in words and numbers represents only the tip of the iceberg. They view knowledge as being primarily "tacit"–something not easily visible and expressible. Tacit knowledge is highly personal and hard to formalize, making it difficult to communicate or share with others. Subjective insights, intuitions, and hunches fall into this category of knowledge. Furthermore, tacit knowledge is deeply rooted in an individual's action and experience and the ideals, values, or emotions they embrace." (Nonaka & Takeuchi, 1995, p. 8)

An important dimension of tacit knowledge to engineers is skills such as choosing a particular design or estimating the probability of the design's success.

Nonaka and Takeuchi observe four distinct processes in knowledge creation: Socialization, Externalization, Combination, and Internalization (SECI cycle). Their model proposes ways to transform the individuals' knowledge into an institution's knowledge, allow an institution to expand on it, and teach this knowledge to new individuals. In the CDIO context, the institutions are the universities and the *community* of engineers and researchers, and the individuals are the students, teachers, engineers, and researchers.

Socialization refers to informally transferring tacit knowledge. For example, in a master/apprentice relationship, the apprentice will follow the master's instructions or observe the master. These activities result in the apprentice learning what the master expects. *Externalization* refers to codifying tacit knowledge, for example, by writing instruction manuals. The purpose is to preserve an individual's knowledge in the institution and archive it. *Combination* generates new knowledge by combining externalized knowledge. Exchanging information through documents, systemizing it, storing it in databases, and reconfiguring it are examples of knowledge combination. Nonaka and Takeuchi (1995, p. 67) observe that: "Knowledge creation carried out in formal education, and training at schools usually takes this form. An MBA education is one of the best examples of this kind." *Internalization* is assimilating externalized and combined knowledge into the learner's tacit knowledge. It is closely related to "learning by doing". The learner performs instructions from a manual, often guided by a teacher, and learns how to practice this knowledge. They may reexperience other people's experiences by reading the material or performing the instructions.

Consequently, we learn "knowing how" primarily through socialization, a process employed in teaching situations outside the academic environment (such as in yoga and martial arts studios). Typically, a teacher or master demonstrates the activity, and the learner imitates it. The teacher may offer corrections, enquiries or specific points to focus on. Alternatively, learners create knowledge in group work. They propose, discuss, try, and evaluate methods in classes, workshops, or projects.

In contrast, most teaching at the university level focuses on combination and internalization: knowledge is passed through lectures and derived from textbooks. Universities teach very little about "how to learn from failure", and "how to view failure as opportunity". Because the consequence of failure is often a low grade, students typically experience failing negatively. They do not reflect on the reasons for failure or develop skills to avoid failures in the future. They will not learn to gauge success probabilities.

To make successful learning of such skills possible, the teacher's role as we understand it needs to change. The teacher must create space for learning through socialization. Our proposal of "Non-hierarchical classroom" below is one way such space can be created. Through witnessing the teacher make room for failing in such a classroom, facilitate reflection on failures, and value the externalization of failures of radical design choices as highly as the ones of success, students may — little by little — be willing to stand in the presence of fear of failure and begin to make different choices.

TRANSFORMATIVE LEARNING AND TRANSFORMATIVE TEACHING

Transformative learning is a theory formulated by Jack Mezirow in the late 20th century (Mezirow, 2012). The theory presents an alternative to the traditional view of education as mere means of acquisition of knowledge delivered by a figure of authority. Instead, it offers that true learning takes place when meaning is made out of a lived experience by comparing it to a past set of assumptions (called "frames of reference" by Mezirow), questioning and adjusting these assumptions to integrate the experience into the wholeness of the self. This leads to a process of transformation at the inner self-level and may show up as shifts in thoughts, emotions, speech, and actions. Sometimes, the transformation is apparent immediately. At other times, it may not happen until years or decades later after the learning experience had planted the initial seeds.

We extend the idea of transformative learning to include transformative teaching, which we define as teaching from a place where the teacher shows up as her whole self in the classroom and, just like the student, opens herself to the possibility of transformative change through the experience (Palmer, 1998, Chapter I – II), (Cranton, 2016, Chapter 10). We offer that by subjecting herself to the same process she invites her students into, the teacher takes the first (and perhaps most important) step towards creating a space within which the students can set out on their own explorations.

CREATING A SAFE SPACE THAT FOSTERS EXPLORATION

With the introduction of the idea of transformative learning and teaching, we have illuminated the gateway to a different model of student-teacher interaction, a stepping stone from which the Engineering student may be willing to take a step into unfamiliar territory despite any fear of failure. In the remainder of this paper, we present specific areas of focus and offer examples of practical tools for the teacher to create and hold safe the space for the student's explorations.

Non-hierarchical Classroom

In "The Courage to Teach", Parker Palmer offers a visual representation of two models of the classroom (Palmer, 1998, Chapter IV). The first is an objectivist model, consistent with the traditional model of top-down education. Here, the object of knowledge resides at the top. The object is examined by experts (teachers) and knowledge derived from the experts' examinations is passed on to amateurs (students). The flow of knowledge takes place in one direction only, with barriers in place to prevent any backflow that may contaminate the object of knowledge with subjective experiences. The student never comes in direct relationship with the object of knowledge itself; it is accessed only through the teacher as the figure of authority.

Palmer calls this model the "objectivist myth" and goes on to offer an alternative, which he calls the "community of truth". This is a fluid model where teachers and students alike gather in a community (as "knowers") around a subject of common interest. This model offers a direct pathway for each student to come into a relationship with the subject as well as with the teacher and other students. The flow pattern of knowing and learning is in all directions.

Palmer's definition of teaching as "the creation of space in which the community of truth is practiced" (Palmer, 1998, p. 90) aligns well with our thesis of creating a safe space for the Engineering student to explore within, daring to follow interesting tangents with the intention of knowing the subject of common interest. By virtue of creating a community, space for such excursions from the "home base" is held not only by the teacher, but collectively by the entire community. At times, the explorations may lead to fascinating discoveries that enrich the experience of all members of the community. At other times, they may end in what we might term "failures". Here, the community functions as an anchor line, helping to bring each member back to "home base".

A question that offers itself for contemplation with Palmer's model of the "community of truth" is in regards to the role of the teacher. Parker's quote would imply that the main role of the teacher is to create the space for the practice of this model of learning. We can translate this as designing a course in such a way that brings the students in direct contact with each other, the teacher, and the subject of common interest. Some practical ideas may include creating opportunities for dialogue and discussion (in small groups of students alone as well as with the teacher), giving and receiving frequent feedback (both from teacher to students and from students to teacher and to other students), participating in goal-setting and evaluation (of self and others), designing physical spaces in ways that represent the model itself (for example, with the teacher seated in a circle amongst the students rather than standing in the front on a podium). For our topic of fear of failure, in particular, the teacher may offer their own experience with fear and share stories of their own failures, to normalize the experience for the students. The need for these interactive elements is described in CDIO Standard 8 Active Learning.

A crucial part of creating a safe space for the students' explorations is the design of appropriate boundaries. The space must be open enough to allow freedom to explore, yet bounded enough to maintain focus on the subject of common interest and to ensure safety. If our intention is to allow for failures to be experienced, it is our responsibility as teachers to ensure (within our best abilities) that the student and their classmates remain safe — physically, mentally, emotionally — throughout their explorations. In the same way that we would not let a 3-year-old child loose to explore the kitchen knowing that the knife drawer is within their reach, we bound the teaching space appropriately so as to prevent the re-occurrence of scenarios such as the Stanford Prison Experiment (Zimbardo, Maslach, & Haney, 2000).

Once an appropriately bounded space has been created, the teacher's role turns to the maintenance of this space: making modifications as needed to respond to the course's unfolding and holding space for the students' experiences within the boundaries of the course. In the best possible scenario, the teacher becomes a mentor to the student for the duration of the course or even beyond.

We conclude this section of our paper by sharing a description of the role of a mentor from Donna Farhi. Farhi's quote captures within it many of the ideas explored in this paper: holding space for the student and any fear that may show up for them, Parker's model of teachers and students gathering in community around truth, and the process of tacit knowledge creation through internalization:

> "A mentor assists the birthing of the student's dreams, visions, and hopes, and most important, what the student has not yet dared to imagine... A true mentor does not cultivate the student's dependence on her insight but facilitates the student's trust in his own inner promptings. This is the beginning of independence and true freedom." (Farhi, 2006, p. 16)

Non-Violent Communication

Non-Violent Communication (NVC) is an approach developed by the clinical psychologist Marshall Rosenberg (Rosenberg, 2015). The method is built on the principle of non-violence — not causing harm to oneself or others — and is employed in a wide range of disciplines including healthcare, parenting, yoga, business settings, and education (Lasater & Lasater, 2009), (Rosenberg, 2005).

We bring in NVC as a technique to create and maintain the safe space for the students' explorations previously discussed. NVC offers an alternative to the very common form of communication involving asserting one's power over other people or situations. It replaces this with respect and choice. To offer an example, reflect whether you have ever tried to will a tight muscle to release its tension or verbally force a toddler to go to sleep. If you have, you may have experienced that trying to assert your power and impose your will in this way does not yield the desired results. No amount of forceful words, threats, shaming, or punishment will result in the muscle relaxing or the toddler drifting peacefully off to sleep. The muscle remains tense, the toddler remains awake, and the situation may go on to escalate.

The same principles hold true in the teacher's communication with students. Attempting to force students into doing something — be it speaking up in class or setting off to explore some unknown territory they are uncomfortable with — will most likely result in similar resistance. Direct conflict may or may not arise, but either way, the student and teacher are locked in a battle of wills.

Through the practice of NVC, we have the opportunity to experience a different outcome. Non-violent, permissive language that encourages inquiry may create that sense of safety in the student that enables him or her to venture beyond the boundaries of fear. Such language lets the student know that they have a choice in how far they venture, that they can turn back at any time and will not be judged for it, that they may encounter failure and will not be punished for it (through, for example, receiving a low grade). NVC helps to foster a safe environment within which to explore and begins to unravel the patterns of fear within the student, allowing him to walk down creative avenues that may turn out to be dead-ends and safely return from such explorations.

Building Safety Checkpoints into the Curriculum with Documentation and Version Control

In the previous discussion, we had raised the idea of the community acting as an anchor line to bring any member back from failed expeditions. We extend now the idea of anchors to include creating "safety checkpoints" along the way, something to return to if failure is encountered in the process of creative exploration.

Fear can often be the emotion that grips a student as they consider investigating a "risky" endeavor. This can be adding a new feature to a CAD drawing or reworking an existing part of the software. If the idea does not work out, the entire system may become nonfunctional. What is effectively needed is some sort of "time-machine" so that investigations that do not pan out do not doom the project altogether. Thankfully, software engineers have been grappling with this exact worry for decades, which has resulted in the concept of version control tools. When one uses Subversion, Git, or other version control tools, the entire history of the files is saved in a manner that can be played back and forth with annotations. For non-software-focused disciplines, this can seem a bit like magic; many of them are used to keeping files with dates in their names to make sure that they can always get back to a previous state. Needless to say, the manual method becomes extremely cumbersome and problematic when a team is working together in a common storage location. Modern version control tools (particularly git) even have a concept of "branching", allowing development to continue down different paths before merging back up or being abandoned (Chacon & Straub, 2014). The use of this paradigm provides a safety checkpoint whereby a student can feel free to take risks knowing that she can always return to somewhere familiar with minimal effort.

In project design classes following our paradigm, we allow students to choose their difficulty level as part of the project proposal process. During this early planning phase, they must align the risk of failure with the ambition of what they want as an outcome. On the other hand, heavily structured project courses start with a clear set of requirements that the students must develop a working solution to or risk a poor grade. In this situation, the students may choose safer and more conservative approaches, sacrificing innovation for a guarantee of a passing grade. Within the new paradigm, students are given constraints to the possibilities of their projects, but the development of metrics and requirements they must meet is left as an exercise to them.

These requirements and metrics are evaluated as to how realistic they are to the stated goal but otherwise left for the students to manage.

A traditional artifact developed as part of project courses such as Engineering X at RU described in Foley and Vafells (2022) can also provide a measure of safety: documentation. This comes in the traditional format of a final report, which is again, traditionally graded and never examined again. In our "embracing failure" approach, we have techniques to improve the utility of documentation and show the need for iteration. First, students pass in a draft of their report, get feedback and a lower-weighted grade, then are given the chance to review it and add supplementary material. Second, milestone presentations are part of the curricula to remind students to collect data, images, and other relevant information as they proceed. Third, students develop design notebooks to document their progress throughout the project (similar to the method described in Foley (2016)), and the notebooks are regularly assessed with detailed feedback. Finally, the teams create an instructional video and manual before the end of the course to demonstrate the functionality of the device at that phase. This video artifact came about due to many projects suddenly malfunctioning the night before the final presentation, resulting in students being unable to demonstrate it with any functionality at all.

CONCLUSION

We hold that the careful design decisions presented in this paper exemplify applying many of the CDIO standards (CDIO, 2020) to create a safe space to experience "failure" in an environment conducive to transformative learning. In Standard 4 (Introduction to Engineering courses), failure must be clearly defined as a methodological issue to be addressed, rather than the outcome of an experiment or prototype. Standard 5 (Design Implement Experiences) describes a "range of engineering activities" that vary in "scope, complexity, and sequence": the use of the word complexity identifies the possibility that outcomes may not match what was expected. Standard 6 (Engineering Learning Workspaces) requires resources to be allocated to entice students to try out their ideas in experiments by being "user-friendly". An interpretation of "user-friendly" might also mean "failure-robust" such as regular documentation of their process as they go along. Standard 7 (Integrated learning spaces) asks institutions to provide such opportunities to grow through hands-on learning and a "personalized learning experience". We describe design courses that have students choose their approach and develop their own requirements to address this. Finally, Standard 8 (Active Learning) desires to engage students by providing a safe environment for "manipulating, analyzing, and applying idea" which is more likely if the students can acknowledge their fear of failure and courses include interactive elements.

A question in the mind of the reader may linger: In embracing failures, are we proposing recklessness? Are we suggesting that the lives lost in tragedies such as the collapse of the Tacoma Narrows Bridge, Pemberton Mill, or the Hyatt Regency Hotel walkway are irrelevant? No, we are not. We are not proposing negligence: letting the students loose without any guidance from us, to fail spectacularly in ways that endanger themselves, their fellow classmates, or anyone else.

What we propose is neither reckless abandon nor a closing down in the face of fear of failure. What we propose is a middle way. A safe, appropriately bounded environment where students may pursue and test creative ideas without fear of punishment or judgment. A place of innovation consistent with Vincenti's definition of "Radical Design" that opens possibilities and creates opportunities. A safe space held by teachers acting as mentors where ideas can be openly shared within a non-hierarchical community gathered together around a common subject of interest.

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Markéta Foley received B.S. in Biology and B.S. in Chemical Engineering from the Massachusetts Institute of Technology (Cambridge, USA) in 2000. After 7 years of putting her engineering skills into hands-on practice within the pharmaceutical industry, she returned to the academic teaching environment (first at MIT, USA, and later at Reykjavík University, Iceland). Here she spent another 7 years designing and teaching hands-on courses for both undergraduate students as well as industry professionals on topics ranging from molecular biology to fermentation and cell culture systems. Most recently, Markéta splits her time between independent consulting in the fields of toxicology, nutrition, and food safety and teaching movement and mindfulness as a certified yoga instructor.

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