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Technology Comprehension – Combining computing, design, and societal reflection as a national subject

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ABSTRACT

This article considers the implementation of a new learning subject "Technology Comprehension" into lower secondary schools in Denmark, as part of an initiative by the Danish Ministry of Education. The subject consists of learning objectives related to computing, design, and societal reflection and was first introduced as an elective course in 13 schools to investigate how it could be integrated into the Danish education system. We present four key findings based on school visits, interviews, an electronic survey, two questionnaires, and workshops including theme discussions: (1) teachers did not perceive Technology Comprehension as a distinct subject, but rather as a set of skills that can be integrated into other subjects; (2) teachers pointed out that Technology Comprehension opens up for interdisciplinary and engaging learning activities, but they need more scaffolding and support; (3) Technology Comprehension challenges teachers' existing competencies and there is a need for a framework that takes into account computing, design, and societal reflection as a whole; (4) Technology Comprehension appealed to various kind of students, not only those who are enthusiastic about technical matters. This study contributes to the previous research on making and digital fabrication by addressing how these endeavours are implemented on a national level through engaging with local teachers. We call for more research on scaffolding and supporting teachers to orchestrate meaningful learning activities to successfully integrate Technology Comprehension into the Danish national education.

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1. Introduction

This paper considers the implementation of a new subject – *Technology Comprehension* – across lower secondary schools in Denmark. Technology Comprehension (TC) is a translation from the Danish word "Teknologiforståelse" and consists of learning objectives related to computing, design, and societal reflection. A shorter version of the paper was presented in the Fablearn Europe conference and this version expands the original paper by carrying out a more in-depth literature review and by presenting additional results in Section 5.3 [1].

TC was initiated by the Danish Ministry of Education and it is currently offered as an elective course to Danish lower secondary education schools (13–15 y.o. students). TC is composed of the three major learning objectives to develop (1) basic skills in computing, such as programming, algorithms, pattern recognition, and abstraction; (2) skills to specify and articulate a problem and utilise an iterative design process to develop a digital solution; and (3) skills to reflect and evaluate the digital solution, its

applicability, impact, and ethical concerns with reference to the broader socio-political context within which it is applied.

The research project was initiated in October 2017 in a collaboration between the Centre for Computational Thinking and Design at the Aarhus University and the Danish Ministry of Education (Fig. 1). The research objective was to examine the response to the implementation of TC, and support its implementation across 13 Danish lower secondary education schools. In particular, we focused on three questions: (1) how teachers perceived their competency in teaching TC; (2) what opportunities and challenges teachers experienced when teaching TC; and (3) what type of students participated in TC. The research questions were investigated through school visits, interviews, an electronic survey, two questionnaires, and workshops including theme discussions.

Digital literacy is essential for preparing children for the opportunities and challenges of a fast-moving, globalised, and increasingly digitalising world [2]. Several initiatives have been established to support the development of students' digital literacy, including CS4all,¹ Code.org,² and Computer Science Teacher

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¹ CS4All, www.cs4all.io, retrieved 14.3.2018.

² Code.org, code.org, retrieved 14.3.2018.

- Trial period from 2017 to 2020
- 13 public schools in Denmark, selected by the Ministry of Education to represent different geographical areas and socio-economic diversities
- 20 teachers and 303 students in the first year of the project
- In 2019, 45 schools will have TC as a compulsory program
- In 2021, TC will be compulsory for K-9 students

Fig. 1. Specifications of implementing TC in Denmark.

Association³ These initiatives are inspired by *computational thinking*, which was first popularised by Wing [3], and later defined by Aho [4] as: “*thought processes involved in formulating problems so their solutions can be represented as computational steps and algorithms*”. For example, computational thinking has been just recently integrated into the national curriculum in the United Kingdom [5].

Through TC, we introduce an alternative approach to development of these skills by (1) integrating computing and design skills into the learning process as means, rather than viewing these skills as mere learning outcomes; (2) supporting creativity through the development of technology to understand the impacts of technology; and (3) to critically reflect the role of technology in the society more broadly. Thus, TC is grounded in the values commonly associated with Scandinavian participatory design [6], such as democracy and empowerment, and draws from previous research on the integration of design competences in educational contexts [e.g. 7,8]. Furthermore, TC builds on the previous Danish initiatives designed to promote digital literacy development, such as Fablab at School [7], Coding Class [9], and Coding Pirates [10]. TC is strongly connected to *making* and *digital fabrication*, as it involves computing activities, collaboration, prototyping, and iterative design to create digital artefacts and aims to promote self-cultivation and democratisation [8,11–14].

The paper is structured as follows: Section 2 provides background on four topics of TC from within a Nordic educational context. Section 3 describes TC more in detail, including goals and learning objectives that were defined by the Danish Ministry of Education. Section 4 explains how the study was carried out, including research questions, data collection procedures, and analysis methods. Finally, Section 5 presents the results, Section 6 discusses four themes that were derived from the results, and Section 7 concludes the paper and addresses study limitations and future research.

2. Background

The three core components of TC – computing, design, and societal reflection – have relevance to several research disciplines, including Educational Research, Human–Computer Interaction, and Computer Science. Computing and computational thinking are a particular focus in the fields of Computer Science Education and Computing Education Research [e.g. 15,16]. Approaches to designing with children, also in educational context, is a focus of the Interaction Design and Children community [e.g. 17–21]. Furthermore, societal reflection is related to research on empowerment and democracy in technology design [e.g. 22,23]. As the theme of this special issue is making and digital fabrication, this literature review focuses on these two topics.

Section 2.1 introduces making and digital fabrication in the formal education. In Section 2.2, we build context for TC by

examining national curricula of three other Nordic countries. Section 2.3 focuses on the teachers’ skills and competence because teachers were the main stakeholders in the study. Finally, in order to consider the impact of TC, Section 2.4 reviews previous literature about student engagement.

2.1. Making and digital fabrication in formal education

Making and digital fabrication have gained a lot of attention in recent years [see 13,24–26]. This endeavour was driven by a shift in focus away from mere skills to use technology towards digital literacy, need for creative and design skills in engineering, and the increased availability of prototyping equipment [13,14]. The idea is grounded in Dewey’s democratisation, Papert’s constructionism, and Freire’s critical pedagogy, which are actualised when connecting democratisation and empowerment with learning-by-doing approaches [13]. These activities are carried out at *makerspaces* or *fablabs*, where children aim to create meaningful and shareable artefacts [26].

Several scholars describe the benefits of making and digital fabrication for learning. Katterfeldt et al. [24] argue that it provides opportunities to interact with concrete objects-to-think-with, to link personal interests and learning activities, and to develop self-efficacy. Blikstein [13] states that it provides an environment for working in the design process with an interdisciplinary approach. Martin [26] proposes that it provides sophisticated tools to build and think, and a tolerant environment for experimenting, playing, and making errors. Chu et al. [27] found that through making children acquired technical skills, mental models about troubleshooting and problem decomposition, as well as means to share ideas and responsibilities. However, it has been criticised that these benefits are over-romanticised and do not necessarily actualise in the formal classroom context [e.g. 28].

Research on making and digital fabrication has recently been expanded into formal education contexts [e.g. 26,27,29–31]. According to these studies, there are several areas that require greater attention. Berman et al. [29] question how making could evolve beyond individual sessions to established, sustainable practices in the classroom, Martin [26] questions how making can align with the goals and needs of schools, whilst Eriksson et al. [31] call for an examination of the relationship between pedagogical practices and making activities. Furthermore, there is also need for research to explore applications of making in non-engineering contexts (e.g. social sciences and arts), because studies of making and digital fabrication occur predominantly in the context of STEM, Computer Science, or Natural Sciences [e.g. 11, 30,32,33].

The most seminal work related to implementation of TC was conducted by Eriksson et al. [31]. They investigated a national distributed Makerspace project and derived five main considerations for initiating and running a large-scale national project: (1) procurement practices, such as identifying appropriate tools and materials for schools, partnering up with companies to develop educational materials, and standardising maker kits for education; (2) professional training and knowledge sharing with mutual understanding between teachers and school leaders; (3) the need for informing national policy-making to support general management, for example, of joint teaching material and curriculum development; (4) creating equal opportunities for both genders, especially for girls; and (5) creating initial interest with simple activities and progressing towards more challenging and advanced projects.

³ Computer Science Teacher Association, www.csteachers.org, retrieved 14.3.2018.

2.2. National curricula in the Nordic countries

As the context of this study is the Danish national education, we consider the national curricula on three neighbouring Nordic countries of Denmark: Sweden, Norway, and Finland. Note that the curricula in these countries do not use making and digital fabrication specific concepts, but discuss digitalisation, digital technology, and information and communication technology in more general level.

The Swedish K-12 curriculum [34] was recently (2017, in action since June 2018) changed towards a stronger emphasis on utilisation of digital technology, opportunities and risks of digitalisation, and how digitalisation is affecting the development of society. In Norway, the curriculum addresses educational goals in a high abstraction level [35]. Technology, in the sense of its development and importance, is discussed in relation to a working human-being, ecological sustainability, and societal impact. In Finland, the new curriculum positions information and communication technology (ICT) as one of the seven embedded transversal competencies [36]. For the ICT competence, students should reflect how technology is related to sustainable development, to everyday communication and interaction, and even to political influence. As seen, these curricula have a holistic approach regarding the use of technology in education. Technology-related skills and knowledge are conceived as fundamental for well-being and self-realisation, instead of mere future working life capabilities.

When it comes to computing skills, Finland and Sweden differ from Norway. In Sweden, algorithmic thinking and programming are introduced in mathematics in the primary school – basics of programming for the grades 1–3, and introduction of algorithms and visual programming environments for the grades 4–6. In Finland, the embedded transversal competence of ICT is defined for grades 1–2, 3–6, and 7–9. Accordingly, students get acquainted with programming as early as in the first year of school and develop their computing skills from an abstract level towards writing programming languages. In turn, the Norwegian curriculum currently lacks the computing specific perspective, but there is an ongoing effort of examining how it is incorporated into education [37].

Swedish K-12 curriculum stands out from the two others with design-related skills, such as identifying problems and utilising a design process to develop alternative solutions. In contrast, Finnish and Norwegian curricula concentrate on the perspective of using technology for learning purposes, such as searching, processing, producing, communicating, and judging information in a digital form.

As a conclusion, the three Nordic countries share the view that learning technology should be firmly embedded within a broader socio-political context. Sweden and Finland specify that it includes at least the basics in computing, such as programming, whereas only Sweden outlines that technology education should provide opportunities to create new solutions and artefacts.

2.3. Teachers' digital competence

The Fablearn Fellows Program is an important channel for disseminating making and digital fabrication to schools. It provides open source curricular materials, guidelines, and support for schools [38]. Utilising these resources, however, still relies on individual teachers. The large survey among the teachers who belong to the Computing At School (CAS) network in the UK shows that after significant curriculum change, teachers encounter a diversity of challenges, including teachers' limited technological skills and knowledge, technical problems, didactic differentiation, a limited ability of students to understand the content, and lack of students' general willingness or ability to solve problems [16].

Teachers' technological skills and knowledge have been considered through the concept of digital competence. Based on a large meta-analysis, Ilomäki et al. [39] defined that teachers' digital competence consists of the technical competence, the ability to use digital technologies in a meaningful way, the ability to evaluate digital technologies critically, and the motivation to participate in the digital culture. Røkenes and Krumsvik also applied meta-analysis and defined four teachers' competence levels: basic digital skills, didactic competence, learning strategies, and *digital Bildung* [40,41]. While both of the digital competence frameworks take into account the societal impact of technology and its development, neither of them includes computing-specific skills, such as programming, or design-specific skills.

To orchestrate making and digital fabrication learning activities, teachers need knowledge in technical matters as well as the ability to foster learning through design. According to Smith et al. [8], teachers need to (1) foster students' reflection and knowledge construction, instead of focusing on functionality or aesthetics; (2) to view technology as flexible processes and materials instead of fixed products; and (3) to pivot between the roles of classroom teacher, design facilitator, and coach. Teacher support can be provided in the form of real-world examples, emphasis on problem-solving and hands-on experience, scaffolding, peer mentoring, and collaboration [16,42]. Teachers may also benefit from access to makerspaces, separated from students, where they could explore and learn without having to fear losing control or authority in front of their students [43].

2.4. Student engagement categories

The importance of *engagement* to counterbalance low levels of academic motivation and achievement is well understood in the literature [44]. Engagement can be divided to behavioural, emotional, and cognitive engagement, and thus, its application in research should be accompanied with a clear definition. [45]. For example, the contradictory role of student engagement in a fablab context was depicted by Blikstein [13, Section 4.1]. Finn and Zimmer [46] found that engagement can be facilitated through didactic arrangements that foster cooperative student–student interaction, in-depth inquiry and meta-cognitive actions, and authentic instruction to construct meaning beyond the classroom can facilitate student engagement. The engagement behaviours and profiles in the learning environment are responsive to teachers' and schools' practices [46].

In relation to student outreach, one can investigate how getting acquainted with Computer Science through making events, such as coding clubs and game programming workshops, raise interest and engagement in the subject [e.g. 47]. Based on the four-phase model of interest development as defined by Hidi and Renninger [48], Lakanen and Kärkkäinen [49] identified four K12-student categories and pathways characterising the longer-term impact of the computing activities. However, in this work, we focus on a short-term assessment of TC. In order to depict different types of engagement in learning through design, we utilise the framework that was recently developed in the context of FabLab schools in Denmark. There, Smith and Iversen [6] defined five archetypical student categories based on interviews and surveys with the students.

In the *design competent* category, students demonstrate the development of language, repertoire, and design literacies through problem-solving. The student profile in this category closely resembles Category I—“Confirmed career option”—in [49]. The *tech-savvy* students in the second category are engaged with technical challenges that, for example, programming provides (cf. [47], Category II: “Novel career option” in [49]). The *well-schooled* category represents students who have no troubles in

meeting the learning objectives, but who do not show interest in technology-related topics (cf. Category III in [49]: “Stick to other plan”). The *undecided* students are not convinced by the relevance of technology or design, other than part of school work, whereas the *not (yet) motivated* students feel that technology-related activities have little sense for them (cf. Category IV in [49]: “Confirmed not interested”). We apply these archetypical categories to consider what kind of students TC elective courses can reach, serving as a pre-step for investigating the impact of TC on students’ perceptions in the future.

3. Technology comprehension

We now draw the attention on the current initiative in Denmark, where the Danish Ministry of Education defined TC as a new subject for the lower secondary education. The curriculum was formulated by three experts in education. TC was first piloted in 13 schools as an elective course during fall 2017. The teachers, who were assigned to teach TC, had not received supplementary or in-service training to teach the subject. During 2018–2021, TC will be experimented in over 40 schools to investigate the three implementation options: An independent subject running from first to ninth grade; an integrated subject to existing subjects; or combination of both, where TC is integrated into other subjects from first to sixth grades and then thought as an independent subject from third to ninth grades.

The Danish Ministry of Education [50] has defined that TC needs to consider: (1) The implications of technology and automation on society, including an understanding of security, ethics, and consequences of digital technologies; (2) Computing as a knowledge area, including basic knowledge of networks, algorithms, programming, logic and algorithmic thinking, abstraction and pattern recognition, as well as data modelling and testing. (3) Iterative design process as an interaction between gaining an understanding of the world that is being designed to and gaining an understanding of the digital technologies that are being designed with. (4) Complex problem solving, where children create new digital solutions and, hence, learn to argue for their relevance through an understanding of design processes.

Consequently, TC includes [51] three major learning objectives: (1) Students learn how to produce and analyse digital products. (2) Students learn to develop, modify, evaluate, and refine digital products through work with remixing, refinement, and production. (3) Students learn the possibilities and role of informatics as a catalyst for changes in the society, in order to strengthen the capabilities for acting in a meaningful way in a democratic and digital society, including constructive and critical contribution in shaping the digital society.

TC has some intersections with computational thinking and especially with computational concepts, practices, and perspectives [as defined in 3,52,53]. However, TC differs significantly from computational thinking in the following areas: Firstly, it treats computing and design as equal competency areas. Secondly, these two areas are dependent on each other, in order to develop students’ capabilities to analyse, design, and develop digital products. And thirdly, it integrates the societal reflection, meaning the critical reflection of the societal impact of technology, as a part of the learning objectives. In this sense, TC is related to [12]’s “*Bildung*”, as a way of considering complex and sustainable learning. These three standpoints are all related to, but different from similar initiatives, such as CS4all in the United States, CoolThink in Hongkong, and Computing in the United Kingdom.

4. Methods

An overview of the research process is shown in Table 1. After the project was initiated, we started the research by sending an electronic survey to the participating schools. The survey asked about the teacher’s professional background, anticipated challenges regarding TC, and expectations of being part of the project. During winter 2017, we visited the schools and carried out semi-structured interviews with 14 teachers [54]. The interviews explored the teachers’ expectations (if not yet taught TC) and experiences (if already taught TC) regarding TC. For the teachers who had already taught TC, we handed the “*five archetypical student categories*” [6], described in Section 2.4. We presented these categories to the teachers, discussed what the categories stand for, and asked them to assign their students within these categories. We also observed TC teaching activities during the school visits, if it was possible. Based on these preliminary investigations, we clarified the research questions as:

RQ1: How the teachers perceived their competence to teach TC?

RQ2: What opportunities and challenges the teachers perceived when introducing TC?

RQ3: What form of student engagement the teachers recognised in TC classes?

Because one goal of the project was to support the teachers, we decided to arrange a one day workshop. The workshop had three-fold purpose: to provide support and training for the teachers; to involve the teachers to discuss possibilities and challenges of TC; and to gather data for this study. Before the workshop started, we informed all teachers about our data collection purposes and provided them with a self-assessment questionnaire. The workshop program consisted of familiarising with each other, examining the TC learning goals, and practical hands-on tasks with Micro:bits. After the workshop, the teachers answered to a feedback questionnaire (e.g. what did they learn in the workshop).

During the workshop, we also arranged a theme discussion about TC. The topics of the theme discussion were: What is TC as an elective course for you, how do you incorporate TC in your current teaching, how do you perceive the competency goals, and what should TC be in future? For the theme discussion, we supplied the teachers with a handout of TC learning objectives. The discussion was moderated by one of the researchers and recorded with two video-cameras.

The workshop was executed two times in different regions of Denmark, once in Aarhus and once in Copenhagen (see Table 2). In Aarhus, there were nine participants from seven schools (eight teachers and one pedagogical consultant). In Copenhagen, there was also nine participants (seven teachers and two school principals).

For the RQ1, the self-assessment questionnaire consisted of four Likert scale question sets [55]. The first set was accustomed from the digital competence framework [41], which examines teachers’ general competences regarding digital tools: using digital tools in spare time (e.g. online banking), using digital tools in work (e.g. office tools and presentation), using digital tools in instruction (e.g. learning resources in web), guiding students to improve their learning strategies with digital tools (e.g. reading screen-based text, note-making, mind-maps), and guiding students in ethical matters related to digital tools (e.g. plagiarism, social media). Because this question set does not consider programming, we added three questions about programming competence: visual programming language (e.g. Scratch), programming (e.g. Javascript), and debugging. The two other sets examined

Table 1
Technology comprehension research process.

Date	Participants	Activity	Data
October 2017	Representatives from the Aarhus university and the Danish Ministry of Education	Project initiation	Official documents (e.g. learning objectives and official documentation of TC)
October 2017	14 teachers from 13 schools	Electronic survey for schools	Survey answers
November 2017–January 2018	14 teachers from 13 schools and researchers	School visits	14 recorded interviews, field notes, student categories form
19th February 2018	8 teachers, 1 pedagogical consultant, and 3 researchers	Workshop in Aarhus (including theme discussion)	Workshop recording, self-assessment questionnaire, and feedback questionnaire
21 February 2018	7 teachers, 2 principals, 3 researchers	Workshop in Copenhagen (including theme discussion)	Same as in Aarhus

Table 2
Teachers' teaching background ($n = 18$).

#	Subjects	Teaching experience (years)
Workshop in Aarhus		
1	IT pedagogy	Over 10
2	Math, physics, chemistry, history	3–5
3	History, societal, physics, chemistry, IT	Over 10
4	Math, physics, chemistry, TC	Over 10
5	Languages, math, sports, household, nature and technology	3–5
6	Math, sports, IT/Fablab	Over 10
7	Math, nature and technology, religion, crafts and design, TC	Over 10
8	Danish, music, fablab	Over 10
9	Math, nature and technology, science	Over 10
Workshop in Copenhagen		
10	English, history, crafts and design	5–10
11	Nature and technology, TC	0–2
12	Music, English, TC	0–2
13	Danish, religion, sports, music, TC	0–2
14	History, religion, nature and technology, biology	0–2
15	Math, physics, chemistry, TC	5–10
16–18	Unknown	Unknown

the teachers' perceived capability to teach design and computing related concepts. The design concepts were idea generation, fabrication, and societal significance and the computing concepts were patterns, algorithms, data structures, coding, programming languages, and testing.

Answers to the Likert scale questions were analysed with IBM SPSS Statistics. All "I don't know" answers were treated as missing answers, and excluded from the analysis. The first analysis involved the calculation of frequencies, frequency distributions, and portions. The four question sets were transformed into four Likert scale constructs to calculate the means and standard deviations. However, the internal consistency of the constructs could not be verified due to the small sample size. We also compared the two workshops using the Mann–Whitney test and found no statistically significant differences between the workshops.

For the RQ2, we first translated and transcribed the theme discussion in English, because all authors are not fluent in Danish. Then, we carried out a collaborative content analysis of the theme discussion [55]: we negotiated the high-level objective of the analysis, watched the discussion recording, and made notes individually. Then we discussed different interpretations and constructed themes based on the research question. We triangulated the findings by analysing the answers to the electronic survey, self-assessment questionnaire, and feedback questionnaire.

For the RQ3, we analysed the student category forms, which were filled during the school visits and, in some cases, provided to us after the workshop. It needs to be noted that the student frequencies in these categories do not represent the students as such, but rather the teachers' perceptions how they would define the students who took part in TC. Moreover, the teachers stated

Table 3
Perceived competencies of the teachers ($n = 15$).

		1	2	3	4	\sum	Mean	SD
Digital competence	f	0	7	26	42	75	3.47	.48
5 questions	f/n (%)	0.0	9.3	34.7	56.0	100		
Programming competence	f	18	13	9	2	42	1.93	.64
3 questions	f/n (%)	40.0	28.9	20.0	4.4	93.3		
Teaching design concepts	f	3	11	27	1	42	2.62	.60
3 questions	f/n (%)	6.7	24.4	60.0	2.2	93.3		
Teaching computing concepts	f	27	30	28	2	87	1.76	.68
6 questions	f/n (%)	30.0	33.3	31.1	2.2	96.6		

Scale: 1 = not competent, 2 = little competent, 3 = competent, 4 = highly competent.

that determining the category that represented each student was challenging and should be considered as only a rough estimate.

5. Results

Here we present the findings to the three research questions.

5.1. RQ1: Teachers' perceived competency

Fifteen teachers answered to the self-assessment questionnaire. As can be seen in Table 2, seven teachers had more than ten years, four teachers had three to ten years, and four teachers had less than two years of teaching experience. The teachers had taught the following subjects: TC, math, physics, chemistry, history, crafts and design, social studies, IT, Danish, sports, Fablab, nature and technology, religion, German, music, biology, and food literacy.

The teachers perceived their competence to use digital tools in education high (Table 3). Altogether 90.7% of the answers to the five questions were either competent or highly competent. In the programming competence questions, almost all (14) teachers answered that they had at least some competence with visual programming languages, such as Scratch. On the other hand, most of the teachers (10) had no competence in programming with a text-based language. This reveals that while the teachers considered themselves as digitally competent, most had only expertise in using visual programming languages. We also asked how the teachers perceive their competence to teach TC concepts. Over 60% of the answers to teaching the design concepts were competent or highly competent. In contrast, only 31.1% were competent or highly competent regarding computing concepts.

Besides the presented competencies, it is worth noting that two of the teachers had been part of the expert group in the Danish Ministry of Education. The group had formulated the exact competency areas, competency goals, proficiency goals, and knowledge goals for TC. As a conclusion, the teachers perceived high digital competence and most of the teachers had a lot of teaching experience and from a broad range of subjects. The teachers considered themselves more competent in teaching design concepts than computing concepts.

5.2. RQ2: Opportunities and challenges of TC as a subject

Two of the Danish Government's implementation options position TC as an individual subject. Despite this, the teachers addressed TC as a component of some other subjects. For example, a teacher considered TC as mere programming skills: *"We created programming and maths course that starts in the first grade and runs through all grades. Programming is okay, but should not be a standalone subject, it should be part of the other subjects. A tool"*. Likewise, the teachers considered TC as a tool for learning other subjects: *"I think a lot about how it can be part of natural science subjects. Currently, I am also teaching crafts, where I think that it could fit in. But, as I said, I also think that having it as a part of natural science would be very exciting for me"*. This also became apparent when the teachers talked about the tasks that they involve the students in, as noted by a teacher: *"they [students] created math games"*. Another teacher had integrated other subjects, such as entrepreneurship, into TC: *"I tend to focus on the Design part of the subject because that is what I find awesome, this entrepreneurship and I try to keep asking the students questions if they claim that they are done 'Design a Logo', 'Find a company name', 'Create a business model'"*. As a conclusion, these perceptions indicate that the teachers lacked formalised ways of addressing TC as a distinct subject, as explicitly coined by one of the teachers: *"This new thing that is starting, I think about it as part of the existing subjects"*.

As indicated by the previous examples, when considering TC, the teachers displayed mainly episodic knowledge: the teachers' arguments derived from their own, or others, practices of using technology in education. Despite the fact that the learning goals of TC were provided to the teachers, the arguments for the subject reflected their personal beliefs, experiences, and interests. For example, the teachers with design background emphasised design goals, teachers with computing background computing goals, and teachers with humanistic background societal goals. Thus, the teachers did not have a mutual understanding of what TC was, or what it should be in the future, but instead relied on personal preferences and episodic knowledge.

Most of the discussed opportunities were confused with technology-supported education. The teachers referred to examples how technology can support students: *"I can have students that are creating a paper booklet, and right next to them another group that works with creating a blog. Both make equal sense. Then you do have students that are able to concentrate for more than 25 min because you have access to different technologies"*. Another example was using technology to engage students with special needs: *"I had an experience, where mother of a dyslexic child contacted me. Usually, when the girl had to make presentations, she was embarrassed by doing it. She used the computer to make the presentation and felt more capable of presenting due to the auto-correction tools"*. In addition, the teachers brought up the opportunity to motivate students, who use digital tools in spare time or to concretise abstract topics, such as perceiving the coordinate system using Scratch.

The teachers presented several narratives how TC engages different students. For example, a teacher said: *"We have had some boys that were very hard to engage in other subjects, that have been very engaged and therefore also very cooperative on this matter"*. This was followed up by an example in special education context: *"I have never gotten them to focus for more than 25 min, now they have been working for 90 min"*. In general, the teachers agreed on the fact that TC is an engaging subject, as concluded by a teacher: *"[TC] is fun, and a lot of students get engaged by it"*.

A recurring theme was that TC opens up for more student-centred learning. A teacher elaborated on the 9th graders' sense of ownership towards making math games to 1st graders: *"We were making math games with Scratch, it was obvious that older students*

had a sense of ownership to this assignment. The 9th graders were supposed to make a math game for 1st graders. The day before, 9th graders used their lunch break to go to 1st graders and check if the level was too hard. Then 9th graders went back and adjusted the games. That's very uncommon to 9th graders to do something like that in own time". This was also exemplified by another teacher, highlighting how TC integrates topics that are relevant to students: *"My focus is to have a starting point that the students can relate to, for example, in the Odense municipality we are establishing the new light-rail. The students were concerned about what if a blind person should cross the light-rail, can we be sure that the train will stop. So they tried to build some sensors with Micro:bits. This was the classical problem-solving setting that the students could relate to"*. These examples demonstrate the opportunity to actualise TC as a design process that integrates computing, the societal reflection, and problem-solving.

As illustrated by the previous quotes, the teachers appreciated the fact that TC combines computing, design, and societal reflection together. They pointed out that, normally, computing-related curricula are designed by people with the computing background. Hence, the learning objectives tend to address mere computing goals. TC opens up for holistic subject goals when it is designed by stakeholders from the various subjects.

Several challenges emerged from the data. The teachers' conceptions indicated uncertainty about the meaning of the societal reflection in TC. The teachers discussed the societal reflection primarily as a means to contextualise the subject with real-world problems. They referred to topics that were familiar from previous teaching experiences in other subjects, such as *"fake news"* in social media, election meddling, and the earlier example about the light-rail track in Odense. Thus, the teachers considered the societal reflection of TC as a means to contextualise classroom activities, instead of a learning objective as such.

The teachers described the varying digital skills of students as a major challenge to teaching. A teacher told that: *"I have some boys in my elective course and even before I started the teaching they had downloaded the files we should use. At the same time, I had a girl who did not know what a file is. The students had very different skills for participating in this field"*. Another teacher noted that if TC is first introduced in the seventh grade, the prerequisites of the subject are necessarily low. Otherwise, lack of basic skills, such as basic computer use, will prevent those students to pursue the actual learning goals: *"I would like to be better at presenting the students with a problem as a starting point, where they can analyse, design and develop. Currently, they have mostly worked with learning the different technologies"*. One teacher concluded that if the basic computing skills are to be taught in TC, it leaves less space and time for other learning objectives.

Another challenge was that students have different needs regarding the structure and guidance of TC learning activities. Some students want to be challenged and to be provided with less guidance, while others are incapable of acting without clear structure and instructions: *"Some of them expect to be challenged, some of them expect to get everything served on a silver plate. That is one of the biggest challenges I have to get them to be better"*. This indicates that TC, as a new subject, calls for a high level of individual differentiation of the learning activities.

Finally, we identified further challenges related to the gender disparities and teachers' need for time and peer support. As demonstrated by the earlier quotes, there is a gender disparity around students skills and interest in TC. For example, a teacher stated: *"A lot of students want to participate in 4–6th grade, in 7–9th grade, it is primarily boys"*. The teachers' conceptions distinct between boys, as being interested and knowledgeable, and girls as not necessarily interested, or engaged, in TC. The teachers pointed out that teachers need more time, peer support, and

scaffolded teaching instructions to be able to implement TC as a new subject. As concluded by one teacher: “[TC] is a new subject and a new way of thinking in primary school. It requires more preparation time than the ‘normal subjects’, where you can adopt a lot of existing teaching material from various learning portals into your own work”.

5.3. RQ3: Student engagement in TC

Teachers from 11 out of 13 participating schools reported back on their perception of students’ characteristics based on five archetypical student categories [8]. Two schools chose not to participate in this part of the interview or were unable to account for the student profiles. The number of students from each of the five archetypical categories is accounted in Table 4 in relation to the total number of students on each school.

Generally, each course had a very limited number (1–3 students pr. class) of *design competent* students. This is consistent with our hypothesis as technology comprehension is a new subject matter. Hence, students do not have any prior formal training in technology comprehension. However, there are three schools with significantly more students in this category; 6 design competent students at schools 7 and 9, which could relate to the teacher’s lack of knowledge of the students (one teacher had only known the students for a few weeks at the time of the interviews) and 15 design competent students at school 10 relating to the teachers own interpretation of TC as a subject (the teacher stressed that entrepreneurship and innovation was a part of the curriculum which it is not formally. The number of *tech-savvy* students was also very limited in the TC courses. Only 2–3 students per class were characterised by these competencies. The relatively low number of tech-savvy students came as surprise to the researchers. We expected to find a large number of tech-savvy students, who would sign up for the elective course, as this would allow them to work with digital technology inside the formal education).

The number of *well-schooled* students diverges significantly from school to school. Schools 3 and 6 reported that none of their students in the TC course can be considered as well-schooled, whereas school 4 categorised 10 (out of 31) and school 10 categorised 10 (out of 25) as well-schooled students. The *undecided* students were generally well-presented in the TC course. In some schools (1,4,5,11), teachers had done extra effort to recruit students from this category to the TC course. The teacher from school 5 emphasised that the reason for the large proportion of undecided students in the class (30 students) is directly linked to his own inability to explain to the students why TC is important, which inevitably makes the overall purpose with the subject unclear and difficult to engage in. In some of the schools, almost half of the course participants can be categorised as undecided. Finally, Table 3 accounts for the number of *not-yet-motivated*. Aside from schools 5 and 6, all TC courses engaged a number of not-yet-motivated students. In the school 4, 30 out of 40 students represented this category. The teacher from that school reported that the course description was designed to accommodate the interest of this particular category of students, which explains the high number of students from this category. Exactly the same phenomenon has been visible in the student outreach – related profiles (see [49] and Section 2.4). Overall, it must be considered that TC is an elective subject, and some students did not pick it as their first priority, but as a second or even third priority.

6. Discussion

Our findings derive from the first year of implementing TC as a national subject. Despite the fact that we are early in the process, the teachers provided us with important practice-based knowledge about TC and its further development. To discuss our findings, we have developed four themes: (1) teachers did not perceive TC as a distinct subject; (2) TC opened up for interdisciplinary and engaging learning activities; (3) TC challenged teachers’ existing competencies; and (4) TC appealed to various kinds of students.

Teachers did not perceive TC as a distinct subject. Our research is associated with current efforts of incorporating computing and design in formal education [7,27,31,42,53]. Our main finding was that teachers did not see TC as a distinct subject, but rather as a set of skills that can be integrated into other subjects. This may be due to the fact that TC is a subject coined by the Danish Ministry of Education and, thus, not well-known among teachers or in research. This relates to what Smith and Iversen [8] considered as the impediments of digital fabrication in education. Whereas they pointed out that teachers generally lack a sufficient understanding of design processes and complex problem solving, our study showed that teachers did not perceive computing, design, and societal reflection together as a distinct subject. Eriksson et al. [31] points to the need for informing national policy-making to support general management of joint digital fabrication teaching materials and curriculum development. Similarly, developing TC as a subject should not be left only to the teachers’ responsibility, but rather, to the responsibility of the entire TC initiative and ultimately to research.

TC opened up for interdisciplinary and engaging learning activities. We found that teachers identified several opportunities in TC: it encourages children to be creative with digital technology, to work with authentic and complex problems and to take responsibility for their learning process [cf. 24]. Moreover, the teachers thought that students perceive TC learning activities as engaging, inspiring, and fun [cf. 27]. TC shares [12]’s reasons for introducing digital fabrication in curriculum-based education: developing computing skills together with cultivating a digital citizenship. Hence, TC promotes digital competencies as critical and reflective personal skills that relate to *Bildung* [12, 40], computational empowerment [22], democracy and empowerment [13], and also to the computational perspectives in [52]. While the teachers discussed how addressing digital technology from a critical and societal point of view is an opportunity, they did not feel capable of bridging between hands-on activities and more abstract discussion of computational perspectives. To fulfil the opportunities of TC, there is a need for scaffolding activities, such as in-service training, development of learning materials, and online resources [31,43,56].

TC challenged teachers’ existing competencies in relation to the subject and students’ prerequisites and needs. We identified the following challenges: the lack of shared understanding about the meaning of the societal reflection in TC, students’ varying skills and needs, and the paradox between instructional structure and freedom, and the lack of girls’ involvement. Some of the challenges are already known in research, for example, balancing between creative digital fabrication activities and formal educational structure [8,31,42,56] and the gender imbalance [31]. We argue that a crucial challenge is the lack of teachers’ competency framework that considers computing, design, and societal reflection as a whole. Current national and international frameworks understand digital competence as a capacity to use technology for other learning purposes. For example, Norwegian framework includes mere digital skills, consisting of searching and processing information from digital resources [57] and European Framework

Table 4
Teachers' perceptions of the student engagement categories in TC course.

School	Design competent	Tech-savvy	Well-schooled	Undecided	Not (yet) motivated	Total
School 1	1	3	3	12	6	25
School 2	3	2	4	4	1	14
School 3	2	3	0	5	5	15
School 4	0	1	10	10	10	31
School 5	3	1	6	30	0	40
School 6	3	3	0	4	0	10
School 7	6	2	3	5	6	22
School 8	1	2	4	6	5	18
School 9	6	2	7	2	3	20
School 10	15	3	5	5	2	30
School 11	1	2	10	10	2	25
Total	41	24	52	93	40	250
Total %	16.4	9.6	20.8	37.2	16.0	100.0

for the Digital Competence of Educators consider teachers' use of digital tools only for communication, collaboration, and professional development [58]. Hence, we call for defining subject knowledge for teachers to educate digital technologies through learning activities that utilise design process, entail computing skills, and aim for personal empowerment.

TC appealed to various types of students. With reference to the archetypical categories [6], we found that TC appealed to various types of students in Denmark. This was due to two factors: First, many schools in the Danish project made a deliberate choice to target *undecided* or *not-yet motivated* students, not only the tech-savvy, in their TC elective course. The teachers accounted for this choice by arguing that digital technology is first and foremost a democratic matter. Accordingly, schools must provide every student with an opportunity to prosper and actively engage in a digitalised society. Second, the schools adjusted content from computer science, digital fabrication, digital design, and humanities to customise a curriculum that would attract students with less prior knowledge or interest in programming and algorithms. As such, this implementation strategy of TC resonates well with the general Nordic approach, which has a strong emphasis on understanding the opportunities and risks of digitalisation from the societal reflection [34–37].

7. Conclusion

Educational researchers have warned that implementing educational reforms with purely top-down approach can lead to failure [59]. This study contributes to the previous research on making and digital fabrication by exploring how these endeavours can be implemented on a national level by engaging with teachers on a local level. Based on interviews, surveys, questionnaires, and the theme discussion with highly experienced teachers, we found both possibilities and challenges in implementing the new subject: Teachers did not yet perceive TC as a distinct and legitimate subject, TC opened up for interdisciplinary and engaging learning activities, TC challenged teachers' existing competencies in relation to the subject and students' prerequisites and needs, and TC appealed to various types of students. Taking these findings into account helps the Danish stakeholders to better understand the impacts of educational reforms from teachers' perspectives. Hopefully, these findings can be also applied in other contexts, by informing what kind of issues may emerge in this kind of initiatives.

We identify the following shortcomings in our study: Our findings derive solely from collaboration with teachers, which leaves out crucial stakeholders, such as policy-makers, parents, and students. We have not taken into consideration that many teachers will ultimately teach TC without prior experiences or any compulsory education in TC, which may exacerbate the need to better support teachers. Finally, as already stated, our study

focused on literature in making and digital fabrication, and future research should take into account other fields as well, such as Computing Education Research and Learning Sciences.

The challenges of implementing the political agenda to offer TC for all students in Denmark should be addressed merely as a general lack of research about TC. Thus, our study raises several questions: How do we draw from previous research on computing and design education to consider computing, design, and societal reflection as a combined subject? How do we develop supplementary training for pre-service and in-service teachers to support their TC teaching practices? How do we develop assessment strategies that take into account the development of computing and design skills with the capability of critically reflect technology as a whole?

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Conflict of interest

The authors declare that there is no conflict of interest in this paper.

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