The International Journal of Management Education 22 (2024) 101029

Contents lists available at ScienceDirect

The International Journal of Management Education

journal homepage: www.elsevier.com/locate/ijme

Rethinking entrepreneurship and management education for engineering students: The appropriateness of design thinking

Imran M. Ilyas [a,*], Juha Kansikas [b], Alain Fayolle [c,d]

[a] *Jönköping International Business School, Jönköping University, Gjuterigatan 5 Box 1026, Jönköping, SE55111, Sweden*
[b] *Jyväskylä University School of Business and Economics, Mattilanniemi 2, Building Agora, Jyväskylä, 40014, Finland*
[c] *IDRAC Business School, 47 rue du Sergent Michel Berthet, 69009 Lyon, France*
[d] *Turku School of Economics, University of Turku, Rehtorinpellonkatu 3, 20500, Turku, Finland*

A R T I C L E I N F O

Keywords:
Educational needs
Science and technology entrepreneurship education
Design thinking
Teaching model
Lean methodology

A B S T R A C T

The study argues that the educational needs of engineering students for entrepreneurship and managerial education are specific and evolving over time toward a set of skills and knowledge needed in digital and dynamic world. Existing research largely ignored the distinct and evolving nature of these educational needs and their implications for entrepreneurship and managerial education of engineering students. Using design thinking and teaching model literature, we proposed teaching model framework and derived propositions from conceptual arguments to address these educational needs effectively. The proposed conceptual teaching model framework elaborates on the incorporation of cognitive acts of design in various aspects at ontological, didactical, and contextual levels. The framework views education as a process of co-construction, centered on students, where the role of the teacher is similar to that of a coach. Students work in teams and practice the cognitive acts of design that lead to the development of interpersonal, entrepreneurial, and managerial skills. For this purpose, open-ended questioning, real-life customer problems, design thinking methodology, and lean methodology are proposed as effective content and pedagogies to promote the entrepreneurial behaviors required in the current industrial scenario.

1. Introduction

As technology-based new ventures (e.g., SpaceX) are becoming more prominent, the focus of education for engineering students has shifted to the commercialization of technology using entrepreneurial ventures (Levie, 2014; Siegel & Wright, 2015; Mosey, 2016). Previous research in the domain of managerial education of engineering students has largely focused on technology commercialization with less emphasis on entrepreneurship education (Barr et al., 2009; Phan et al., 2009). Recently, some scholars (Fayolle et al., 2021; Lamine et al., 2021) have focused on science, technology, and engineering entrepreneurship education (STEE), which is defined as a "*subdomain of entrepreneurship education and training focusing on students or individuals engaged in engineering, technology and science-based studies or professional careers*" (Fayolle et al., 2021, p. 278). In previous research, different issues related to STEE have been explored, including curricular aspects, teaching frameworks, knowledge transfer, and the role of technology transfer offices (Bolzani et al., 2021; Duval-Couetil et al., 2021; Qureshi & Mian, 2021; Snihur et al., 2021). However, STEE needs to be examined

* Corresponding author.
E-mail addresses: imran.ilyas@ju.se (I.M. Ilyas), juha.kansikas@jyu.fi (J. Kansikas), ajc.fayolle@gmail.com (A. Fayolle).

https://doi.org/10.1016/j.ijme.2024.101029
Received 2 February 2024; Received in revised form 13 June 2024; Accepted 16 July 2024
Available online 20 July 2024
1472-8117/

further (Linton & Xu, 2021) particularly in relation to educational needs of engineering students and central concepts in engineering such as and design thinking and their implications for teaching models for STEE (Fayolle et al., 2021; Lynch et al., 2021)

Regarding the educational needs of engineering students and their impact on STEE, there is a gap in the literature which can be described as follows: "*it seems important to design and do research focusing on the background and profile of target audiences, taking into consideration student/participant differences notably in terms of learning styles*" (Fayolle et al., 2021, p. 285). Engineering students, defined as STEM-related (science, technology, engineering, and mathematics) students enrolled in universities and other higher education institutes (Stenard, 2021), have distinct educational needs regarding entrepreneurship education (e.g., learning style needs, need for entrepreneurial skills) due to their psychology, characteristics of work-related tasks, and motives to engage in entrepreneurship education (Fayolle et al., 2021; Felder & Silverman, 1988; Shekhar & Huang-Saad, 2021; Verzat et al., 2009). Furthermore, these needs are evolving over time due to the increasing use of online digital technologies in entrepreneurship education (Chen et al., 2021; Secundo et al., 2021), disruptive industry trends, new work practices, and new forms of partnerships between industry and universities (Lamine et al., 2021; Phan et al., 2009). For example, with the advent of digital technologies, engineers should learn how to effectively engage in teamwork using online channels. It is important to study the learning styles and needs of engineering students for STEE, as engineering students have an active role in contributing to entrepreneurial activity and ecosystems of innovations (Elliott et al., 2020). It is emphasized further as scholars found differences between engineering and business students and recommended for tailoring teaching approach in following words: "*the findings also reveal the need for didactic approaches in EE (entrepreneurship education) to be tailored to the specific needs of distinct groups of students*" (Maresch et al., 2016, p. 177).

Furthermore, there is a call for further research on teaching models for STEE: "*based on the framework proposed by Fayolle and Gailly (2008) distinguishing two levels of instruction, ontological and didactical, and that include five operational dimensions. A series of research questions have been raised in relation to this framework (Fayolle, 2013) and can be seen as starting points for future research in the field of STEE*" (Fayolle et al., 2021, p. 285). Thus, there is a need for research that can elaborate on different aspects of teaching models for STEE to address the educational needs of engineering students.

As the needs of engineering students include developing human, entrepreneurial, and managerial skills, STEE tends to incorporate such teaching models and pedagogies that can help in developing these skills (Phan et al., 2009; Snihur et al., 2021; Verzat et al., 2009). Recent research in entrepreneurship education emphasized the incorporation of design thinking to stimulate the development of skills such as opportunity recognition, decision-making in highly uncertain situations, risk taking, communication, and interpersonal skills (Garbuio et al., 2018; Lynch et al., 2021). Additionally, since design thinking which involves use of designers' tool kit to imagine and create entrepreneurial solution to a customer need (Garbuio et al., 2018), originates from engineering and is considered a central activity in this field (Dym et al., 2005; Simon, 1996), it is considered a suitable paradigm upon which we can build a teaching model and related pedagogies for STEE that are capable of addressing different educational needs of engineering students. So, the research question of this study is as follows: How can the educational needs of STEE students be addressed with a teaching model framework based on design thinking?

To answer this question, we elaborated on the different educational needs of engineering students for STEE, such as learning style needs, the need for human relation competences, entrepreneurial skills, and managerial skills. Additionally, we explain how these needs are evolving over time due to the advent of new technologies, industry trends, working practices, and partnerships between universities and industry. To address these educational needs of engineering students, we proposed a conceptual teaching model framework based on design thinking and teaching model literature that could be suitable for entrepreneurship education of science and engineering students. The teaching model is derived from the Fayolle and Gailly (2008) and Fayolle (2013) frameworks and consists of three levels: ontological, didactical, and contextual. At the ontological level, dimensions related to the educator's conceptions, philosophical paradigm, and theoretical basis of design-based STEE are discussed. The didactical level is related to the operational dimensions of the teaching model (Béchard & Grégoire, 2005; Fayolle & Gailly, 2008). The didactical level in our proposed framework discusses the objectives, content, pedagogies, and evaluation techniques in relation to the requirements of design-based STEE. Finally, contextual factors are included in the teaching model framework for their relevance in the design of educational settings (Kleine et al., 2019; Welter & Gartner, 2016). Furthermore, propositions are derived from conceptual arguments in literature.

The study contributes in multiple ways. First, it discusses the needs of engineering students for entrepreneurial and managerial education based on their psychology, work-related tasks, and motives to engage in entrepreneurship education (Fayolle et al., 2021; Felder & Silverman, 1988; Snihur et al., 2021; Verzat et al., 2009). Additionally, the educational needs of engineering students are evolving over time toward a set of skills required to operate in a digital and dynamic world (Lamine et al., 2021). Second, it develops propositions and elaborates a teaching model framework for STEE based on design thinking to address the educational needs of engineering students (Fayolle et al., 2021; Lamine et al., 2021; Lynch et al., 2021; Maresch et al., 2016; Mosey, 2016; Siegel & Wright, 2015). Finally, future research directions related to different dimensions of the teaching model are elaborated.

2. Educational needs of engineering students

As engineering students have different backgrounds and are being prepared for specific types of tasks, they have specific learning needs. Based on previous research (Chandler & Jansen, 1992; Fayolle et al., 2021; Felder & Silverman, 1988; Jonassen et al., 2006; Linton & Xu, 2021; Lynch et al., 2021; Markham et al., 2000; Passow & Passow, 2017; Phan et al., 2009; Snihur et al., 2021; Verzat et al., 2009), there are different types of educational needs for engineering students regarding STEE, including learning style needs, need for human relation competences, entrepreneurial skills, and managerial skills for technology commercialization. Furthermore, these needs are evolving over time in the emerging digital era (Lamine et al., 2021; Lynch et al., 2021). For example, communication is shifting over time to digital channels and platforms. Future science and technology entrepreneurs need to master these new modes of communication to interact with relevant stakeholders efficiently and succeed. In the following sections, these needs are discussed in detail.

2.1. Learning style needs

The learning style model "*classifies students according to where they fit on a number of scales pertaining to the ways they receive and process information*" (Felder & Silverman, 1988, p. 674). According to this model, the educational needs of engineering students are different from those of other students due to their distinctive psychology and consequent learning styles (Felder & Brent, 2003). The distinctive psychology of engineering students leads them to preferentially focus on different types of information and their propensity to operate on perceived information in different ways. According to the learning style model (Felder & Silverman, 1988), engineering students preferentially perceive sensory information that is collected from the outside world rather than internal abstract information. Furthermore, sensory information that is collected through visual channels (i.e., pictures, demonstrations and so forth) is preferred over others. While organizing the information, engineering students are more efficient in inductive approaches, where facts and observations are given, and underlying principles are inferred from them. In terms of processing the information, engineering students prefer to process it more actively through physical activity and discussion. Finally, engineering students tend to learn in large jumps (global perspectives) to understand the big picture and then try to solve the problem (Felder & Brent, 2003; Felder & Silverman, 1988).

While the needs of engineering students are distinctive, the teaching style of engineering professors is often based on traditional lecture methods and is not tailored to match the common learning styles of students (Fayolle et al., 2021; Felder & Silverman, 1988; Snihur et al., 2021; Verzat et al., 2009). Although the traditional lecture is an efficient technique for delivering large quantities of analytical information and insightful knowledge, it does not take into account individual differences and learning styles. This lack of attention to individual differences makes the lecture technique less applicable for STEE (Fayolle et al., 2021). Therefore, there is a need for a teaching model that uses sensory and visual information, involves tasks in which students can learn from inductive facts while considering the full picture, and allows activities that involve demonstrating and performing tasks.

2.2. Need for human relation competences

Human relation competences are defined as "*the ability to work with, understand, and motivate other people both individually and in groups*" (Chandler & Jansen, 1992, p. 225). They include teamwork, networking, communication skills, leadership skills, and interpersonal skills. Engineering students are prepared to perform technical tasks in organizations and there is more focus on delivering a large amount of knowledge and technical hard skills. However, in modern organizations, much of the work is completed through teamwork, and most engineering-related tasks are done cooperatively. In this emerging scenario, the value of human relation competences (e.g., interpersonal and communication skills) is increasing over technical skills in performing job tasks (Felder et al., 2000; Passow & Passow, 2017; Verzat et al., 2009). Consequently, along with technical expertise, corporations and employers frequently rate communication skills, teamwork capabilities, interpersonal skills, and networking skills as the top desirable skills for new engineering graduates (Felder et al., 2002; Lynch et al., 2021; Roman, 2006). Thus, it is one of the basic needs of engineering students to develop these skills to proceed successfully in their career.

Furthermore, these skills are evolving over time with the advent of new technologies and shifts in working conditions in organizations (Lamine et al., 2021). For example, digital technologies enable new channels and platforms where professionals can virtually interact with team members and customers. In these virtual platforms, informal interaction and body language have limited space. However, meetings can be organized with more convenience involving participants worldwide. To perform adequately, STEE students need to learn communication and interaction in these virtual settings. However, those involved in engineering education predominantly emphasize delivering technical knowledge and skills with little or no emphasis on how to act in digital settings. Consequently, there exists an imbalance between what industry demands and what educational institutions provide in terms of the right proportion of human relation competences (Dym et al., 2005; Eskandari et al., 2007; Jonassen et al., 2006). To reduce this difference, there is a need to change what is being taught and how it is taught in engineering institutions (Lynch et al., 2021). Previous research illustrated that teamwork and interactive classrooms promote students' soft skills (Verzat et al., 2009) and there is a need for such teaching models that enhance teamwork, networking, interaction, and communication among STEE students.

2.3. Entrepreneurial knowledge and skills

Entrepreneurial skill refers to "*the drive to see the venture through to fruition, and the ability to recognize opportunity*" (Chandler & Jansen, 1992, p. 232). In other words, it includes the ability to recognize opportunities and create new ventures to exploit those opportunities. Furthermore, entrepreneurial skills also involve creating new entrepreneurial opportunities, risk taking, proactiveness while facing uncertain circumstances, and solving problems in an innovative way (Bolton & Lane, 2012). The need for developing entrepreneurial skills in engineering students has remained high. However, over the last two decades, following the new trends, this need has emerged as crucial and vital for the managerial education of engineering students, as many technology-based new ventures are disrupting existing industries with their innovative technologies and new business models (Mosey, 2016; Phan et al., 2009). Furthermore, the need for entrepreneurial skills is evolving with the advent of new trends such as incubators, technology accelerators, crowdfunding, and ecosystems (Lamine et al., 2021). For example, ecosystems which are network of interdependent organizations linked to or operating around a focal firm or a platform (Adner, 2017) offer new opportunities for new venture creation. Engineering students can recognize these opportunities and conceive new products and services to address unmet needs by becoming part of these ecosystems. Furthermore, student entrepreneurs can launch a crowdfunding campaign to gather seed money. Additionally, engineering students can use incubators and technology accelerators to successfully create new ventures (Merguei, 2022; Wright et al., 2017). Apart from creating new ventures from scratch, existing employees of large companies could also act entrepreneurially inside these large companies. For example, Gmail was founded inside Google when its employees acted entrepreneurially inside the company. This phenomenon is called corporate entrepreneurship and it could be regarded as an emerging phenomenon as more and more large companies tend to act entrepreneurially to stay competitive (Finkle, 2012). Previous research found that the entrepreneurial skills of engineering students could be developed through increased exposure to creativity, critical thinking, designing, and initiative taking (DeTienne & Chandler, 2004; Kirby, 2004; Kwapisz et al., 2021; Verzat et al., 2009).

However, engineering education widely relies on teaching models based on traditional lectures and other approaches such as problem-based learning and project-based learning (Guerra, 2017; Mann et al., 2021; Lehmann et al., 2008; Kolmos et al., 2006) that largely focus on individuals' learning and development of critical thinking skills while emphasize less on promoting students' creativity and developing skills to work on actual solution such as journey mapping, prototyping, and experimentation (Lynch et al., 2021). To create and develop engineering students' entrepreneurial skills, new teaching models, pedagogies and content are needed that can complement existing teaching approach and develop skills in students related to working on actual solution based on creative ideas generated in uncertain and dynamic situations (Honig, 2004; Linton & Xu, 2021; Shepherd, 2004). This approach allows students to make risky decisions and act in uncertain situations through interaction with multiple actors (e.g., customers) using designer's tools.

2.4. Managerial skills for technology commercialization

Evidence has been found that graduate engineers and scientists with research-based degrees are often expected to exhibit the skills required to perform various managerial tasks in organizations (Markham et al., 2000). This set of skills is mostly concerned with project management, product development, assessing the commercial viability of new high-tech products, new product launch in markets, cost consciousness, and other business and management-related knowledge and skills (Arias et al., 2018; Markham et al., 2000). Engineering students in many cases have little or no training for these skills. Analytical tools and traditional teaching styles can help in delivering a large body of knowledge for the managerial education of engineers (Glen et al., 2014). However, this knowledge has limited applicability for developing such skills that can enable students to translate and shift the learning from one scenario to another. Furthermore, the need for managerial skills is evolving over time as new managerial skills are needed. For example, the competence of modifying existing business models and developing new ones can help managers successfully run organizations. STEE students need to learn how to develop and implement innovative business models to be able to compete in the current competitive and global context (Snihur et al., 2021). So, there is a need to emphasize teaching models that can complement the existing analytical and traditional teaching methods to deliver important knowledge as well as develop the skills necessary for managing organizations and technology commercialization. In this regard, teaching models based on design thinking have good potential (Glen et al., 2014).

In sum, the educational needs of engineering students are different and are evolving, with a greater emphasis on entrepreneurial learning, creativity, and learning by doing in the emerging digital world. Managerial education for engineering students (i.e., STEE) needs to pursue teaching models and pedagogies that are suitable for developing these skills. In this regard, design thinking is proven to be efficient and suitable for developing entrepreneurial and interpersonal skills (Daniel, 2016; Garbuio et al., 2018; Neck & Greene, 2011; Nielsen & Stovang, 2015), as it develops cognitive abilities necessary to think and act with an entrepreneurial mindset (Dong et al., 2016). Additionally, design thinking is considered to be strongly associated with engineers (Dym et al., 2005; Simon, 1996). Therefore, a design perspective is suitable for teaching models that can cope with the needs of engineering students (Linton & Xu, 2021; Lynch et al., 2021). In the next section, we discuss design thinking and its implications for addressing the specific needs of engineering students.

3. Design thinking as an appropriate way to educate engineering students

3.1. Design thinking

Design is widely considered to be the central activity of engineering (Simon, 1996), and engineering graduates are distinguished for their ability to design effective solutions in accordance with particular social needs. However, the role of design in engineering education in general and engineering management education in particular remains largely underdeveloped (Dym et al., 2005; Lynch et al., 2021). To advance the discussion, we first need to understand the main idea of design thinking. In previous literature, design thinking is defined as "*the cognition, processes, and tools designers use to imagine a desired future, informs the process and skills needed to spot and develop opportunities*" (Garbuio et al., 2018, p. 42). In design thinking, the problems and solutions coevolve in the process of producing novel but feasible solutions (de Figueiredo, 2021; Glen et al., 2015; Maher, 2000; Wiltschnig et al., 2013) using multiple step approach consisting of empathize, define, ideate, prototype, and test phases (Brown, 2008). Instead of following a linear sequence in which problem definition leads to the enumeration and selection of solutions, in design thinking, the problem frame can be modified depending on the emergence and progression of the solution over time (Dorst & Cross, 2001). Consequently, design thinking requires mastering a set of cognitive acts that helps to adjust in changing situations by reformulating the problem and subsequent solutions (Dong et al., 2016; Garbuio et al., 2018).

The research in design thinking identified four fundamental cognitive acts: framing, analogical reasoning, abductive reasoning, and mental simulations (Visser, 2006, 2009). The cognitive act of framing is a process of producing schema by drawing associations between the situation, assumptions, and precedence (Garbuio et al., 2018; Schön, 1983). In simple words, framing involves perceiving reality from a certain standpoint or angle. To propose a creative solution, individuals should be able to view the problematic situation from a novel standpoint or frame (Dorst, 2011). Teaching models based on design thinking emphasize developing a mindset that can enable engineering students to perceive problematic situations from a unique standpoint or frame to find creative solutions. For example, STEE students could frame lockdowns during covid-19 crisis as an entrepreneurial opportunity to develop and commercialize digital technologies.

Analogical reasoning is the cognitive act of identifying and transferring relevant knowledge from one situation to another based on similarities between the two situations (Holyoak & Thagard, 1995). Human cognition spontaneously performs analogical reasoning (Hofstadter, 2001). For STEE, analogical reasoning helps students to act in uncertain situations with creative solutions by developing similarities between the current problem and past cases. For instance, in the case of covid-19 crisis, STEE students could explore and develop novel solutions by identifying and transferring relevant knowledge from similar situations in history (e.g., Spanish flu in certain regions of the World where it had significant influences).

Another important cognitive act related to design thinking is called abductive reasoning, in which individuals propose a hypothesis to explain certain unusual phenomena based on limited observations and data (Peirce, 1998). Unlike deductive or inductive reasoning, the hypothesis in abductive reasoning may or may not be logically or empirically true (Garbuio et al., 2018). This mindset helps entrepreneurs to make logic of the proposed solution in high-risk and uncertain situations where data and past experiences are not available to make completely rational decisions. In the example of covid-19 crisis, students with design thinking-based education would try to propose hypotheses to explain unprecedent situation created by pandemic based on ongoing observations and data as the pandemic was emerging instead of waiting for its end.

Finally, mental simulation is the cognitive act that involves predicting the outcome of a certain strategic choice (e.g., opportunity, business model) by imagining the operational aspects in the absence of data or previous experience (Markham et al., 2000). Since it involves assessing the feasibility and potential of a strategic option in terms of its outcome and emotional attachment, mental simulation is considered a key cognitive act for entrepreneurs (Gaglio, 2004; Garbuio et al., 2018). In the example of covid-19 crisis, students who master the cognitive act of mental simulation would propose a solution and its operational aspects to solve the ongoing situation based on their intuition and imagination instead of waiting for the complete data and facts. Teaching models based on design thinking emphasize developing these four cognitive acts for engineering students that help them to develop an entrepreneurial mindset to better cope with their distinct and evolving needs. In the Table 1 below, we summarize the cognitive acts in design thinking with examples related to the uncertain situation of covid-19 crisis.

Students practice cognitive acts in design thinking during the five-step process consisting of empathize, define, ideate, prototype, and test (Brown, 2008). The design thinking process starts with customer need and trying to understand the customer by empathizing with their situation by stepping in their shoes. It is followed by define phase, where based on all data and observations, students try to narrow down and define what aspects they will focus on depending on where the customer need actually resides. In the phase of ideation, several alternative ideas are generated as possible solutions to the problem. Afterwards, best ideas are chosen and basic prototypes are developed with initial features that could solve the customer need. Finally, in testing phase, experimentation is conducted where prototypes are tested with the real users to evaluate whether they solve the customer need. Also, feedback is taken from users based on these tests and used in the process. This process continues in cycles until final product is developed.

Previous research has discussed the implications of other approaches such as problem-based learning for entrepreneurship and management education of engineering students (Guerra, 2017; Mann et al., 2021; Lehmann et al., 2008; Kolmos et al., 2006). Although there is no consensus about the formal definition of problem-based learning, in this approach, students are given a problem, and they are supposed to come up with creative solutions in collaboration with their team (Jonassen et al., 2006; Taylor & Miflin, 2008). Problem-based learning is founded on four learning principles: constructive, self-directed, collaborative, and contextual learning (Dolmans et al., 2005). The principle of constructive learning emphasizes enabling students to create meaning and build personal interpretations of the given problems. Students learn by defining the problem and proposing a solution based on personal interpretations. Educators and teachers can stimulate constructive learning with their students, using approaches based on open-ended problems, discussion, note-taking, and elaboration. The second principle emphasizes learning as a self-directed process in which learners are given freedom to plan and monitor the way they want to tackle a problem. This emphasis helps motivate students and

Table 1
Cognitive acts in design thinking.

Cognitive act in design	Description	Example
Framing	Perceiving reality from a certain standpoint or angle.	Framing lockdowns during covid-19 crisis as an opportunity to develop digital technologies.
Analogical reasoning	Identifying and transferring relevant knowledge from one situation to another based on similarities between the two situations.	During covid-19 crisis, exploring and developing novel solutions by identifying and transferring relevant knowledge from similar situations in history (e.g., Spanish flu).
Abductive reasoning	Proposing hypotheses to explain certain unusual phenomena based on limited observations and data.	Providing explanation to unprecedent situation created by covid-19 pandemic based on emerging signs and observations instead of waiting for its end.
Mental simulation	Predicting the outcome of a certain strategic choice (e.g., opportunity, business model) by imagining the operational aspects in the absence of data or previous experience.	In case of covid-19 crisis, proposing a solution and its operational aspects to solve the ongoing situation based on the intuition and imagination.

eventually turns the process into lifelong learning (Dolmans et al., 2005). The motives of students are an important source of entrepreneurial behavior, as they affect both entrepreneurial intentions and participation in entrepreneurship education (Hassan et al., 2021). The third principle argues that effective learning requires social interaction and should take place in team and other collaborative arrangements. The last principle argues that learning takes place in a context or situation and that the effectiveness of the process can be improved by exposing students to problems from multiple perspectives to stimulate the transfer of knowledge from one context to another (Dolmans et al., 2005).

The two approaches of problem-based learning and design thinking have some similarities. For example, both approaches are student centric where students work on customer problems while teachers guide them in this process. Furthermore, both approaches use teamwork during the learning process and students learn through interaction with their team members while trying to find solution for a certain problem. However, the design thinking approach differentiates from problem-based learning in several aspects. First, in problem-based learning the emphasis is on the problem and its various dimensions whereas design thinking places significant emphasis on users or customers and how they perceive the problem. For effective science, technology, and engineering entrepreneurship education (STEE), it is a significant first step to learn what are different needs of the users and design thinking approach is particularly helpful in this regard. Second, design thinking follows a multi-step process where students are encouraged to empathize with users and develop solutions based on user needs. During this process, students learn several skills such as teamwork, developing prototypes, experimentation, and how to incorporate user feedback. However, problem-based learning uses self-directed process where student learn by trying to solve abstract problems. Finally, at the end of the process, design thinking approach leads to actual physical product as a solution to customer needs while problem-based learning leads to abstract solution. We have summarized the two approaches in the Table 2 below.

Based on the comparison, we argue that design thinking is distinctive approach that is suitable for STEE due to its implications for creating new products for actual customer needs while empathizing with how they perceive it. Existing research related to management and entrepreneurship education of engineering students has studied approaches such as problem-based learning (Guerra, 2017; Mann et al., 2021; Lehmann et al., 2008; Kolmos et al., 2006). However, there is a gap in existing research regarding the implications of design thinking for STEE (Lynch et al., 2021).

3.2. *The role of design thinking in STEE*

The relevance of design thinking in entrepreneurship education is increasing with the popularity of lean startup approaches that emphasize opportunity creation as a cognitive skill (Garbuio et al., 2018). Consequently, scholars are increasingly calling for the use of design-based teaching models in entrepreneurship education (Garbuio et al., 2018; Glen et al., 2014; Lynch et al., 2021; van Burg & Romme, 2014). In the case of STEE, design thinking becomes relevant because it is considered a central activity distinctively associated with engineering (Dym et al., 2005; Simon, 1996). Design thinking can be incorporated with the managerial education of engineers to complement instead of replacing the analytical tools and teaching methods generally used for equipping students with cognitive skills and technical methods to deal with routine tasks of organizations (Garbuio et al., 2018; Glen et al., 2014). However, these analytical tools and methods are unable to develop interpersonal and entrepreneurial skills that are required in the current industrial scenario characterized by uncertainty, ill-defined problems, scarce or ambiguous information, and unclear mean–end relationships (Garbuio et al., 2018).

Design thinking addresses these gaps by identifying specific cognitive acts and structures required to generate productive outcomes in uncertain, open-ended, ambiguous, and unstructured situations (Garbuio et al., 2018; de Figueiredo, 2021). So, design thinking can help to meet the needs of engineering students in multiple ways. First, it takes into account the distinct psychology of engineering students by emphasizing tools and procedures, including user centricity, journey mapping, prototyping, and experimentation. Second, it helps to develop interpersonal and communication skills by allowing students to work in teams (Dym et al., 2005). Third, design thinking develops entrepreneurial skills by enabling students to empathize with customers, anticipate customer needs beforehand, take risks by promoting an iterative loop of divergent–convergent thinking, and develop new solutions (Fixson & Rao, 2014; Fixson & Read, 2012). As a consequence of incorporating design thinking in STEE, the learning process follows a different trajectory. Thus, there is a need for teaching models and pedagogies that can connect the learning process associated with design thinking to the objectives translated from the distinct and evolving needs of engineering students.

Table 2
Design thinking vs Problem based learning.

Key dimensions	Design thinking	Problem based learning
Main theme	Use of designers' tool kit to imagine and create entrepreneurial solution to fulfill a customer need.	Come up with a solution in collaboration with the team for a problem.
Focus area	Customer needs and preferences	Problem and its dimensions
Process	Empathize, define, ideate, prototype, and test.	Constructive, self-directed, collaborative, and contextual learning.
Outcome	Customer understanding and insights about their needs and preferences, creative ideas to find possible solution, visualizations of solution, prototypes, and solution in the form of actual product or service.	Better understanding of the problem and solution to the problem.

4. Teaching model for design-based STEE

As distinct and evolving needs of engineering students can be addressed appropriately with STEE based on design thinking, this section discusses and elaborates the teaching model for such education. The concept of the teaching model was originally developed in education science (Anderson, 1995), but it was used for the first time in entrepreneurship education by Béchard and Grégoire (2005) and Fayolle and Gailly (2008). They proposed and illustrated different teaching models in entrepreneurship education. Béchard and Grégoire (2005, p. 107) defined a teaching model as "*the representation of certain type of setting designed to deal with a pedagogical situation in function of particular goals and objectives, that integrates a theoretical framework justifying this design and giving it an exemplary character.*" In other words, a teaching model serves as a connection between the conceptions that scholars and educators have about teaching and their actual teaching behavior. Scholars have focused on ontological and didactical levels to integrate the main aspects of teaching models for entrepreneurship education (Fayolle, 2013; Fayolle & Gailly, 2008). While in some studies, the role of context is also discussed in the teaching model for entrepreneurship education (Béchard & Grégoire, 2007), in the case of STEE based on design thinking, the educational settings and the context play key roles (Lynch et al., 2021). Consequently, we discuss the ontological, didactical, and contextual levels for defining the teaching model for STEE based on design thinking. The proposed teaching model is discussed in detail in later sections of the paper. Table 3 provides summary of different dimensions of proposed teaching model for STEE.

4.1. Ontological level

The ontological level consists of the dimensions related to the educators' basic assumptions about the world, education, and entrepreneurship (Béchard & Grégoire, 2005). The ontological level of a teaching model for STEE based on design thinking can be seen as composed of three main dimensions: philosophical paradigm, theoretical basis, and educator's conceptions. The philosophical paradigm of the proposed teaching model can be founded on constructionism and an interactionist stance with a strong emphasis on experiential learning (Kolb, 1984), problem-solving approaches, and design thinking. Therefore, reality is influencing and being influenced by human agency simultaneously, and education is a process of co-construction. Second, the theoretical basis of the proposed teaching model can be traced back to psychology and design thinking in particular. The human agency influences reality by creating opportunities through design thinking. The last dimension is related to the educator's conceptions about teaching, students, the teacher's role, and the knowledge to be taught. In our proposed teaching model, teaching is mainly concerned with coaching students to think and act like an entrepreneur. Additionally, students are informed agents who want to learn the knowledge and skills required for managerial positions in the industry (i.e., communication and interpersonal skills), for new venture creation (i.e., opportunity creation), and for the commercialization of technology (i.e., project management and new product development). The teacher is a coach who helps students design solutions by providing advice and necessary knowledge or skills in several feedback loops. Finally, educators teach about how to create opportunity (i.e., minimum viable product) by using data about industry, real-life problems, and new technologies. Thus, our first proposition will be formulated as follows.

Proposition 1. *Engineering students need ontologically teaching models in entrepreneurship and management education that combine experiential, constructivist and interactive commercialization-related competencies with technological knowledge.*

Table 3
Teaching model for design-based science, technology, and engineering entrepreneurship education (STEE).

Ontology	Didactical					Context
	Objectives	Audience	Content	Pedagogy	Evaluation	
Philosophical paradigm: Constructionism Theoretical basis: Design thinking Educator's conceptions and role: 1) Teacher is a coach 2) Students are informed agents 3) Students are taught about entrepreneurship	Meeting the needs of engineering students 1) Learning style needs 2) Human relation competences 3) Entrepreneurial knowledge and skills 4) Managerial skills for technology commercialization Practicing cognitive acts of design	Engineering students 1) Undergraduate students 2) Graduate students 3) Industry professionals, executives, entrepreneurs	Specific emphasis on problems 1) Real life customer needs 2) Industry data 3) Practice based & industry journals	Design thinking methodology 1) Empathy map 2) How might we statement 3) User journey mapping 4) story boarding 5) Feedback grid Lean Methodology 1) Lean canvas 2) Business model canvas	Continuous assessment to see the progress in the development of skills related to educational needs and practicing cognitive acts of design. 1) Identification of customer need 2) Progress in development of solution (e.g., business model canvas or prototype) 2) Presentations 3) Written reports 4) Teamwork	Studio spaces for teamwork Social interaction with entrepreneurs to tackle real life customer needs Entrepreneurial culture in university Educational institutes and their management

4.2. Didactical level

The didactical level is related to the dimensions required for the operationalization of ontological conceptions (Béchard & Grégoire, 2005; Fayolle, 2013; Fayolle & Gailly, 2008). Considering the nature of design thinking and STEE, the didactical level of the proposed model consists of objectives, content, pedagogies, and evaluation.

4.2.1. Objectives

In general, the main objective of entrepreneurship education varies from developing the interest of students in entrepreneurship through providing knowledge, skills and shaping intentions to starting and sustaining a successful entrepreneurial venture over time to achieve personal and socio-economic goals in the long term (Costin et al., 2021; Nabi et al., 2017). Additionally, the objectives of entrepreneurship education should be connected to the needs of students (Fayolle & Gailly, 2008). As discussed in the previous sections, STEE students have educational needs that significantly influence the objectives of the entire education process directed to these students. Consequently, STEE based on design thinking has four main objectives. First, STEE is directed to provide knowledge and skills using pedagogies that take into account the psychological and learning needs of engineering students (Felder & Silverman, 1988). Second, STEE based on design thinking is intended to develop human relation skills (i.e., communication and interpersonal skills) that are necessary to successfully manage the everyday tasks in organizational settings that are often performed in teams (Verzat et al., 2009). The third main objective of such education is to shape entrepreneurial intentions and develop entrepreneurial skills for engineering students. These types of skill may include risk taking, managing in highly uncertain scenarios, creating/identifying opportunities, and developing new technology ventures (Linton & Xu, 2021; Mosey, 2016). Finally, STEE has as a key objective the development of managerial skills associated with commercialization of the technology, including project management, product development, cost consciousness, and assessing the commercial viability of new high-tech products (Markham et al., 2000).

Another set of objectives is related to practicing and mastering a set of cognitive acts that helps to adjust in changing situations by reformulating the problem and subsequent solutions (Garbuio et al., 2018). As described previously, there are four fundamental cognitive acts in design thinking, including framing, analogical reasoning, abductive reasoning, and mental simulations (Visser, 2006, 2009). STEE based on design thinking uses pedagogies and content that help students perform cognitive acts quite frequently. In sum, STEE based on design thinking has as a central objective of developing and reshaping the knowledge, skills, and attitude of engineering students in traditional engineering and technical areas as well as in managerial and entrepreneurial dimensions.

Proposition 2. *Didactically, objectives of engineering student entrepreneurship and management pedagogical solutions in teaching need to be based on personal student goal setting and goal achievement and thus on gathering a pool of skills on problem solving and new business development.*

4.2.2. Content

The content depends on the objectives and audience of the course (Fayolle, 2013; Fayolle & Gailly, 2008). For STEE based on design thinking, the audience is engineering students at different levels (e.g., undergraduate, graduate, and executive), and the objectives are to address their needs for human relation, entrepreneurial and managerial skills. As we discussed previously, the adaptation of design thinking in STEE seems to be an efficient and appropriate way to address the evolving needs of engineering students in the current world. The content of these courses should suit the nature of design thinking and related pedagogies. In design thinking, there is a fundamental emphasis on solving the customer need, and less attention is given to theoretical aspects of the phenomenon (Garbuio et al., 2018). Consequently, design thinking starts with the understanding and empathizing with customers' preferences, and the content of the teaching model emphasizes finding solutions to customer needs using visuals, prototyping and experimentation (Dym et al., 2005). These real-life customer needs can be found through discussion with possible consumers, entrepreneurs, industry professionals, and representatives from regional ecosystems.

Furthermore, practice-based and industry journals can provide useful content for such courses because they emphasize tackling the issues faced by entrepreneurs. Finally, content that promotes sketching, graphical representation, experiments, and games is more effective in developing the required knowledge and skills for engineering students due to their particular psychology and learning needs (Dym et al., 2005). For example, STEE students can develop skills to tackle uncertainty through games and statistical courses (e.g., determining probability of an outcome). In sum, the STEE teaching model stimulates pragmatic purposes more than theoretical purposes.

Proposition 3. *The content of entrepreneurship and management education, related to the STEE teaching model, needs to be pragmatic and serve both business and technology expertise accumulation among engineering students.*

4.2.3. Pedagogies

Pedagogies, or teaching methods, are means to achieve objectives by delivering the content designed for a certain audience. Thus, pedagogies depend on objectives, audience, and content (Fayolle, 2013; Fayolle & Gailly, 2008). STEE based on design thinking could be implemented in class using pedagogies such as design thinking methodology and lean methodology. These pedagogical approaches are likely to fulfill student needs (Lamine et al., 2021). In the following, we have discussed both pedagogies in detail.

4.2.3.1. Design thinking methodology. We can implement design thinking approach in the class using various tools and methods that designers use while developing design-based solutions in multiple step approach consisting of empathize, define, ideate, prototype, and test phases (Brown, 2008; Carlgren et al., 2016; Schumacher & Mayer, 2018). During the empathy phase, students try to understand customer needs and preferences by empathizing with them based on what they think, say, do, and feel. For this purpose, students could practice empathy map that is a tool used by designers for sitting in shoes of customers (Fernández & Martínez, 2020). In the define phase, students could use tools such as point of view statement and how might we statement to narrow down and define what aspects of the customer need that would be focused on depending on where the customer need actually resides. Afterwards ideation phase begins where several alternative ideas are generated as possible solutions to the customer need. Brainstorming could be used to uncover and explore new angles and avenues and possible solutions. Furthermore, customer or user journey mapping could be used to visualize the process that user goes through while fulfilling their needs (Rosenbaum et al., 2017). In the phase of prototyping, best ideas are chosen and basic prototypes are developed with initial features that could solve the customer need. Students could develop physical prototype or sketch the possible solution using tools such as story boarding where how the solution will work is sketched using multiple points in the story. It helps to shift from static image of solution to multiple visuals to develop ideas about how the solution will work in an actual situation. Finally, in testing phase, experimentation is conducted where prototypes are tested with the real users to evaluate whether they solve the customer need. Also, feedback is taken from users based on these tests and used in the process. For this purpose, tools such as feedback grid could be used to have elaborated feedback from users. This process continues in cycles until the final product is developed (Carlgren et al., 2016; Schumacher & Mayer, 2018).

Design thinking methodology is helpful for several reasons for STEE. First, students practice cognitive acts in design thinking while performing the five steps process (Garbuio et al., 2018). During empathizing and define phase, students practice the cognitive acts of framing and analogical reasoning by trying to understand customer needs from a standpoint (i.e., user shoes) and by defining the customer need based on similarities between the current situation and their past experiences. Moreover, during ideation, prototyping, and testing phases, students practice the cognitive acts of abductive reasoning and mental simulation by proposing several ideas, developing prototypes, and testing the possible solutions to customer needs. Second, designers' tools such as empathy map, user journey mapping, story boarding, and feedback grid are visual tools that suit well to educational needs of engineering students who receive the information favorably from visual means. Third, design thinking methodology is highly human centric where students work in teams and try to develop solutions for customers after interacting with them again and again. During this process, students get numerous opportunities to develop their human relation skills. Finally, design thinking process starts from customer needs and ends with viable product or service thus helps to develop entrepreneurial skills in engineering students.

4.2.3.2. Lean methodology. Another pedagogy that could be helpful in our proposed teaching model is lean methodology. The pedagogy of lean start-up stems from quality management and engineering and is built on the management discourse of design thinking (Blank, 2013; Garbuio et al., 2018; Ries, 2011). In lean methodology, students are encouraged to follow a hypothesis-driven approach to the assessment of opportunity and the development of new products for a specific customer (Paço et al., 2016). It focuses on starting with a business idea that can be translated into a verifiable hypothesis for new products, often called the "minimum viable product." The minimum viable product begins with a prototype composed of basic features, and it develops over time depending on the needs and feedback of the customers. The lean methodology emphasizes designing, experimenting, and obtaining feedback from customers for the next development iteration instead of following a predefined business plan. Thus, it follows design thinking for developing entrepreneurial skills in students (Garbuio et al., 2018).

The lean methodology is often used by educators with the help of two graphical tools: the lean canvas and the business model canvas (Harms, 2015). The lean canvas allows visualization of the different aspects of a start-up with the help of a chart consisting of 9 boxes, each covering a specific area (i.e., customer segments, unique value proposition, channels to connect different actors, cost structure, revenue streams, unfair advantage, problem, solution, and key metrics) (Maurya, 2012). In lean canvas, students are encouraged to develop hypotheses about solving the needs of customers with value proposition or minimum viable product. Additionally, students can prioritize different aspects of the solution or start-up by using the lean canvas tool. Similarly, another graphical tool used by educators in lean methodology is known as the business model canvas (Snihur et al., 2021; Harms, 2015). However, instead of focusing on the minimum viable product, it focuses on setting up a new business model and students are asked to develop a business model for a business idea rather than starting with a business plan (Garbuio et al., 2018). Students develop a business model using a business model canvas that comprises 9 building blocks, each covering the specific area of the business model of the firm (Osterwalder & Pigneur, 2010). The business model canvas was built to change the way people design, test, and build strategies. It can be used to propose solutions for both new and existing ventures (Jackson et al., 2015).

The lean methodology and visual tools of the lean canvas and business model canvas can help in design thinking-based STEE in a number of ways. First, they provide a set of transferable skills and techniques for new venture creation, such as identifying customer needs and proposing value proposition. Second, students learn and master a toolkit in graphical form (i.e., business model canvas and lean canvas) that can be used for developing new business models and other vital aspects in the process of new venture creation. Third, it enhances the students' capabilities for problem solving to find creative solutions. Fourth, students can follow an iteration for optimal outcomes. Fifth, it encourages the students to experiment and take action to learn. Sixth, students can master the art of coming up with innovative and creative solutions with repeated use of the tool (Jackson et al., 2015; Neck & Greene, 2011). Seventh, the graphical representation and its encouragement for engaging in prototyping and experimentation make it more suitable for engineering students as they learn more with pictures and practical engagement (Felder & Silverman, 1988). Finally, these tools encourage students to be involved in in-depth collaborative work for devising the new business model or proposing a lean start-up (Garbuio et al., 2018; Johansson-Sköldberg et al., 2013).

Thus, related to the pedagogical solutions of the STEE teaching model, the following proposition is suggested.

Proposition 4. *The pedagogies of the STEE teaching model, namely, design thinking methodology and lean methodology, increase experiential learning and pragmatic marketing orientation on business model designs among engineering students.*

4.2.4. Assessment

In entrepreneurship education, the assessment generally depends on the objectives (Fayolle & Gailly, 2008). In the case of design thinking-based STEE, students can be assessed in terms of whether they have developed the required level of interpersonal, entrepreneurial, and managerial skills. Additionally, students are assessed in terms of the extent to which they have mastered the four cognitive acts in design thinking. These skills can be assessed by evaluating their capabilities to work effectively in teams, create/identify and evaluate a new opportunity by analyzing the customer needs in particular cases, develop creative solutions to tackle highly uncertain situations (i.e., prototype, minimum viable product; new business model), engage in group discussions to improve the proposed solution based on feedback (i.e., customer feedback), develop knowledge of important terminologies and concepts related to commercial feasibility (i.e., opportunity cost, depreciation, etc.), writing insightful reports, presenting the final results diligently, and so forth. The second dimension of the assessment process is related to how it is conducted. Since the learning process in design thinking-based education is different from traditional approaches in engineering education, the approaches used to assess students are also different (Dym et al., 2005). In design-based education, continuous assessment is necessary with certain milestones (Garbuio et al., 2018). Hence, students are evaluated in terms of their progress in the assigned tasks, for example, how well they are able to develop a new business model while using the business model canvas in the lean methodology. Similarly, students could be assessed for instance whether they have developed feasible prototype. We have summarized the assessment related aspects in the proposed teaching model in Table 4.

Related to the assessment of STEE teaching model courses, the following proposition is formulated.

Proposition 5. *Assessment objectives, measurement scales, and grading are course specific when developing entrepreneurship and management education with the STEE teaching model for engineering students, and thus, they need to be tailored uniquely for each course.*

5. Contextual factors

Context is always considered an important aspect of entrepreneurship (Welter, 2011; Welter & Gartner, 2016; Zahra & Wright, 2011). In entrepreneurship education, contextual factors are important, as they contribute to the design, shape, and construction of educational settings. Additionally, in design-based learning, context is an important part because learning is always associated with a specific context or situation (Dolmans et al., 2005). To argue further, we need to define context. In entrepreneurship research, context refers to "*circumstances, conditions, situations, or environments that are external to the respective phenomenon and enable or constrain it*" (Welter, 2011). Context has four main dimensions: spatial, temporal, institutional, and social (Zahra & Wright, 2011).

Regarding STEE (Fayolle et al., 2021), the context is relevant in four dimensions, including the spaces required for the educational process, social network of the university, entrepreneurial culture in the university, and role of educational institution in incorporating design-based teaching model in the curriculum. First, design thinking requires students to think and develop their ideas to perform various individual and team-based tasks. These tasks may include brainstorming, proposals for minimum viable products, group discussions, prototyping and so forth. Traditional classrooms are not effective for such tasks, so design-based STEE requires the reconfiguration of spaces. For this purpose, the concept of design studios is adopted from the fields of art, architecture and industrial design. Design studios are dedicated spaces with artifacts and flexible settings to accommodate individuals and small groups to engage in creative work (Barry & Meisiek, 2015; Doorley & Witthoft, 2011). The studio settings facilitate the practice of the cognitive acts of design thinking required for developing an entrepreneurial mindset and performing innovative activities (Fixson et al., 2015; Garbuio et al., 2018). These design studios may have artifacts that need space to be placed in the right location at the right time. For example, prototyping tools in learning spaces can improve the learning process, especially in STEE (Garbuio et al., 2018). Additionally, students can reconfigure these spaces as their projects and ideas evolve over time (Barry & Meisiek, 2015; Doorley & Witthoft, 2011; Fixson

Table 4
Assessment criteria and tools.

Key dimensions	Description
Objectives	Educational needs:
	Progress in fulfilling the educational needs and developing skills such as entrepreneurial skills.
	Cognitive acts of design:
	Practicing cognitive acts of design (i.e., framing, analogical reasoning, abductive reasoning, and mental simulation).
Starting point	Progress in understanding customer needs
Performance in using tools to develop actual solution.	Design thinking methodology:
	Performance in development of tools such as empathy map, how might we statement, user journey mapping, story boarding for prototyping, feedback grid for consumer feedback.
	Lean methodology:
	Performance in development of business model canvas or lean canvas.
Assessment tools	Continuous assessment on how they progress
	Mid term and end of project presentations
	Written reports
	Performance in teamwork

et al., 2015). Consequently, in design-based STEE, spaces need to be reconfigurable from classrooms to studios where students can work in teams (Doorley & Witthoft, 2011). In a more advanced form, these design studios may work as places for experimenting with the commercialization of new technologies. In most universities, incubators, technology transfer offices, and startup accelerators function as platforms or spaces to develop students' ideas and propose minimum viable products for the purpose of commercialization with or without new venture creation. In these forms, spaces not only provide students with the opportunity to think but also provide support, such as advice on practical aspects of the new venture creation (Levie, 2014; Mian et al., 2016; Phan et al., 2009).

Second, the relationships or social network of the university also influence the learning in design-based STEE, as multiple university networks offer diverse ecosystems for entrepreneurship education events and new idea creation (Maritz et al., 2022; Nicotra et al., 2021). This network consists of the connections of the university with multiple groups, such as inventors, venture capitalists, incumbents, new firms, and other stakeholders, who influence the emergence, survival, and growth of new firms (Zahra & Wright, 2011). Social networks can provide access to real-life problems and the analysis of industry data. This access can help STEE students practice and master the cognitive acts of design in the most meaningful and relevant way. For example, students can analyze the progress of different ventures by using lean canvas and business model canvas. Furthermore, on a more advanced level toward developing a technology venture, the social network of the university and other relevant actors is also important because it can provide access to the acute resources required for technology-based ventures. These resources may include access to support industries and infrastructure that would otherwise not be available. As network of professional bodies are important stakeholders in the university network, so their views, feedback, and suggestions could serve as a source to develop and improve the content and pedagogies in proposed teaching model.

Third, the culture in the university can influence the development of an entrepreneurial mindset (Zahra & Wright, 2011). In the context of universities, if activities related to entrepreneurship, new venture creation, and technology commercialization are viewed with high prestige; they encourage students to engage in learning and developing skills necessary for working as entrepreneurs in terms of educational conceptions and learning contexts (Aadland & Aaboen, 2020). Additionally, an entrepreneurship-friendly culture facilitates the learning process in STEE by introducing supportive policies and necessary resources. Finally, another relevant aspect of context is educational institutes such as universities and business schools. These educational institutes could facilitate the integration of the design-based teaching into the curriculum of programs where engineering students are enrolled for entrepreneurship and management education. They could incorporate design-based teaching model for STEE in step-by-step approach. First, adopting in courses which are focused on entrepreneurship and then incorporating it in other management education related courses to address different educational needs of engineering students for entrepreneurship and management education. Students could be motivated by using content and pedagogies that could relate their existing knowledge and interests to learning objectives of the course. Thus, the following proposition related to the context of the STEE teaching model is generated.

Proposition 6. *Contextually, entrepreneurship and management education course development related to the STEE teaching model needs to consider the requirements of space, social capital, and university culture and resource access when creating course designs for entrepreneurship and technology interaction.*

6. Discussion and conclusion

The study discusses the educational needs of engineering students for managerial and entrepreneurship education. Based on existing literature, it is argued that engineering students have particular psychology, work-related tasks, and motives to join entrepreneurship education. As a result, the educational needs of engineering students for STEE are different. Additionally, it is argued that the educational needs of engineering students for STEE are evolving over time due to the advent of new technologies, changes in work practices, and new partnerships between industry and universities. To address the distinct and evolving educational needs of engineering students, a teaching model is proposed for STEE based on design thinking. The proposed teaching model is derived from Fayolle and Gailly's (2008) and Fayolle's (2013) frameworks and elaborated on ontological, didactical, and contextual dimensions for effective STEE. For different dimensions of the teaching model, propositions are derived, and future research directions are proposed to extend the research on STEE.

This study contributes in multiple ways and creates ideas for future research. First, it discusses the needs of engineering students for entrepreneurial and managerial education (Fayolle et al., 2021; Lamine et al., 2021; Linton & Xu, 2021; Lynch et al., 2021). Previous studies discussed some of the needs, but they did not take into account the distinct and emerging trends in these needs. This study argues that the needs of engineering students for managerial education are unique due to their particular psychology, emphasis on technical or hard skills compared to soft skills, work-related tasks, and motives to engage in entrepreneurship education. Based on the existing literature (Chandler & Jansen, 1992; Felder & Silverman, 1988; Jonassen et al., 2006; Markham et al., 2000; Passow & Passow, 2017), it is argued that the educational needs of engineering students for STEE could be categorized as learning style needs, needs for human relation competences, entrepreneurial skills, and managerial skills for technology commercialization. Furthermore, it is argued that these needs are evolving over time in the emerging digital era (Lamine et al., 2021; Lynch et al., 2021; Snihur et al., 2021). With the advent of new technologies, the nature of the workplace and dynamics of communication and interaction with teammates, customers, and other work-related aspects are changing. Online digital platforms offer new forms of communication between stakeholders and allow technology entrepreneurs to commercialize their technologies using digital channels. Future technology entrepreneurs need to learn the communication, teamwork, and commercialization of new technologies using these digital channels and online platforms. Moreover, the need for entrepreneurial skills is evolving as technology entrepreneurs can develop new ventures using incubators, technology accelerators, crowdfunding, and ecosystems (Merguei, 2022). Future technology entrepreneurs need to learn these skills such as how to collect seed money using crowd funding campaigns. Similarly, they can improve the growth of new ventures by incorporating themselves into ecosystems that provide necessary resources and knowhow. Finally, the need for managerial skills in STEE students is evolving over time as new managerial skills are needed in current market dynamics. Customer preferences, emerging institutional conditions, and new technologies are changing market conditions. For successful management and commercialization of technologies, future technology entrepreneurs and managers need to develop new competences. For example,

Table 5
Propositions and suggestions for further research.

Proposition	References	Future research suggestions
Proposition 1. Engineering students need ontologically teaching models in entrepreneurship and management education that combine experiential, constructivist and interactive commercialization-related competencies with technological knowledge.	Kolb (1984); Béchard and Grégoire (2005)	What are the ontological choices that need to be decided in designing experiential, constructivist and interactive entrepreneurship and management education? What are the similarities and differences ontologically between experiential learning, constructivism, and interactive learning? What are the commercialization-related competencies and technological knowledge in entrepreneurship and management education? How do these decisions related to the three above questions influence on engineering student entrepreneurship and management education?
Proposition 2. Didactically, objectives of the engineering student entrepreneurship and management pedagogical solutions in teaching need to be based on personal student goal setting and goal achievement and, thus, on gathering a pool of skills on problem solving and new business development.	Nabi et al. (2017); Fayolle and Gailly (2008); Felder and Silverman (1998); Mosey (2016); Markham et al. (2000).	What are the design processes for entrepreneurship and management education courses for engineering students that reflect students' personal goal setting and goal achievement? What are the didactical solutions needed in personal study plans? What are the pool of skills that combine both technological studies and new business development in entrepreneurship and management education?
Proposition 3. The content of the entrepreneurship and management education, related to the STEE teaching model, needs to be pragmatic and serve both business and technology expertise accumulation among engineering students.	Garbuio et al. (2018); Dym et al. (2005); Dillon (1984).	What is the type of collaboration and social capital with companies and other stakeholders that will ensure business and technology expertise accumulation in the STEE model? What are the types of course designs needed for pragmatic purposes based on the STEE model? How do they need to be elaborated and taught? What is the expertise accumulation at the STEE model? How will it take place?
Proposition 4. The pedagogies of the STEE teaching model, namely, design thinking methodology and lean methodology, increase experiential learning and pragmatic marketing orientation on business model designs among engineering students.	Paco et al. (2016); Garbuio et al. (2018); Neck and Greene (2011); Jackson et al. (2015); Taylor and Miflin (2008); Dolmans et al. (2005); Felder and Silverman (2005); Felder and Brent (2005).	How do teachers need to design lean methodology, problem-based learning, and project-based learning courses to achieve experiential and pragmatic purposes of the STEE model for engineering students? What are the types of experiential learning and pragmatic marketing-orientation typical for engineering students and for the STEE model? How do teachers organize business model teaching related to the three pedagogies of STEE model?
Proposition 5. Assessment objectives, measurement scales, and grading are course specific when developing entrepreneurship and management education with the STEE-teaching model for engineering students, and thus, they need to be tailored uniquely for each course.	Fayolle and Gailly (2008); Dym et al. (2005); Garbuio et al. (2018).	What does it mean ontologically, didactically and contextually, when STEE-model courses are assessed and graded uniquely for each course? What are the relationships between course content and course assessment in STEE-model based entrepreneurship and management education? How does the assessment of the courses support learning and increase the expertise of engineering students in the STEE-model?
Proposition 6. Contextually, entrepreneurship and management education course development related to the STEE teaching model needs to consider requirements of space, social capital, and university culture and resource access when creating course designs for entrepreneurship and technology interaction.	Zahra and Wright (2011); Barry and Meisiek (2015); Doorley and Witthoft (2011); Levie (2014); Mian et al. (2016); Phan et al. (2009).	What are the types of space-related solutions that fit for the STEE-model based teaching for engineering students? How can universities support STEE-model teaching and increase the development of entrepreneurial ecosystems around them? What are the types of resources that will support STEE-model teaching? How does university culture prevent or support entrepreneurship and technology interaction locally, nationally, and internationally?

STEE students need to learn how to develop and implement innovative business models to be able to compete in the current competitive and global context (Snihur et al., 2021). In short, the study discussed in detail the educational needs of engineering students and how these needs are evolving over time. These findings provide important insight for research on STEE and entrepreneurship education in general, as they identify and elaborate on student differences due to their educational needs (Fayolle et al., 2021).

Second, the study contributes by proposing and elaborating the teaching model for STEE based on design thinking to address the needs of engineering students (Fayolle et al., 2021; Lamine et al., 2021; Maresch et al., 2016; Mosey, 2016; Siegel & Wright, 2015). Thus, it addresses the call for research on the topic. Unlike the traditional lecture, the proposed teaching model emphasizes that educational settings for engineering students could be student-centered and based on constructivism, where the role of the teacher is similar to that of a mentor. In these educational settings, the objectives are to meet the educational needs of engineering students for STEE, including learning style needs, human relation competences, entrepreneurial skills, and managerial skills for technology commercialization. Additionally, students are inspired to practice cognitive acts of design (e.g., framing, analogical reasoning, abductive reasoning, and mental simulations) that help them to adjust to changing situations by reformulating the problem and subsequent solutions (Garbuio et al., 2018). Regarding the content and pedagogy, students can be given real-life problems and games to develop creative solutions using methods such as lean canvas, business model canvas, problem-based learning, and project-based learning. This type of content and pedagogies are particularly useful, as they use graphical representations and demonstrations that suit the psychology of engineering students. Additionally, they help the students to practice cognitive acts of design that can lead to the development of human relation competences, entrepreneurial skills for new venture creation, and managerial skills for technology commercialization. In the proposed teaching model, students are assessed based on their progress in assigned projects, teamwork, and knowledge and skills related to tasks. Furthermore, the proposed teaching model takes into account the role of contextual factors such as spaces, social networks, and entrepreneurial culture in the teaching model approach (Nabi et al., 2017). It is argued that the proposed teaching model delivers required results effectively if the learning spaces are tailored for work in small teams (i.e., studios instead of classroom halls). Additionally, the entrepreneurial culture in universities and social networks of universities facilitate learning in design-based STEE. Finally, the study contributes by developing propositions for each dimension of the teaching model and highlighting future research directions for STEE. The insights and propositions on each dimension of the teaching model will help researchers understand and build upon future research efforts in STEE (Fayolle et al., 2021). The propositions and suggestions for future research directions are presented in Table 5.

There are a number of practical implications for educators, trainers, and teachers in the field of technology management. First, educators can take into account the educational needs of engineering students while designing and delivering a course. In other words, educators should give importance to the psychological differences of students and how they receive and process information. Additionally, STEE education process should emphasize on developing human relation competences, entrepreneurial skills, and managerial skills among students. Second, educators can use the proposed teaching model to develop courses that can enhance particular cognitive acts related to design thinking in engineering students required for technology entrepreneurship. Finally, educators can more often use those pedagogies and content that suit the distinct psychology and needs of engineering students. For example, educators can use pedagogies that emphasize graphical tools (e.g., lean canvas, business model canvas, story boarding).

This study has some limitations, and future research may focus on these areas. First, the current study is based on theoretical arguments and proposed teaching model and propositions are conceptual, while no empirical data is used from the field. Future research may examine case studies or other empirical settings (e.g., quantitative data) to analyze and test the proposed teaching models and elaborate in more details about its implications for STEE. Second, our study focuses on overall teaching model for STEE with limited focus on specific areas. Future studies may analyze impact of specific dimensions of proposed teaching model on outcomes of STEE. For example, researchers could analyze the effect of studio learning on entrepreneurial intentions in design-based STEE.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Imran M. Ilyas: Writing – review & editing, Writing – original draft, Conceptualization, Project administration, Visualization. **Juha Kansikas:** Project administration, Visualization, Writing – review & editing. **Alain Fayolle:** Supervision, Writing – review & editing.

Data availability

No data was used for the research described in the article.

References

Aadland, T., & Aaboen, L. (2020). An entrepreneurship education taxonomy based on authenticity. *European Journal of Engineering Education, 45*(5), 711–728. https://doi.org/10.1080/03043797.2020.1732305

Adner, R. (2017). Ecosystem as structure: An actionable construct for strategy. *Journal of Management, 43*, 39–58. https://doi.org/10.1177/0149206316678451

Anderson, L. W. (1995). *International Encyclopedia of teaching and teacher education*. Oxford: Pergamon Press.

Arias, E., Barba-Sánchez, V., Carrión, C., & Casado, R. (2018). Enhancing entrepreneurship education in a master's degree in computer engineering: A project-based learning approach. *Administrative Sciences, 8*(4), 58. https://doi.org/10.3390/admsci8040058

Barr, S. H., Baker, T. E. D., Markham, S. K., & Kingon, A. I. (2009). Bridging the valley of death: Lessons learned from 14 years of commercialization of technology education. *The Academy of Management Learning and Education, 8*(3), 370–388. https://doi.org/10.5465/amle.2009.44287937

Barry, D., & Meisiek, S. (2015). Discovering the business studio. *Journal of Management Education, 39*(1), 153–175. https://doi.org/10.1177/1052562914532801

Béchard, J. P., & Grégoire, D. (2005). Understanding teaching models in entrepreneurship for higher education. In P. Kyro, & C. Carrier (Eds.), *The dynamics of learning entrepreneurship in a cross-cultural university context* (pp. 104–134). Tampere: University of Tampere Research Center for Vocational and Professional Center.

Béchard, J. P., & Grégoire, D. (2007). Archetypes of pedagogical innovation for entrepreneurship education: Model and illustrations. In A. Fayolle (Ed.), *Handbook of research in entrepreneurship education* (pp. 261–284). Cheltenham, UK: Edward Elgar Publishing.

Blank, S. (2013). Why the lean start-up changes everything. *Harvard Business Review, 91*(5), 63–72.

Bolton, D. L., & Lane, M. D. (2012). Individual entrepreneurial orientation: Development of a measurement instrument. *Education + Training, 54*(2/3), 219–233. https://doi.org/10.1108/00400911211210314

Bolzani, D., Munari, F., Rasmussen, E., & Toschi, L. (2021). Technology transfer offices as providers of science and technology entrepreneurship education. *The Journal of Technology Transfer, 46*(2), 335–365. https://doi.org/10.1007/s10961-020-09788-4

Brown, T. (2008). Design thinking. *Harvard Business Review, 86*(6), 84–92.

Carlgren, L., Rauth, I., & Elmquist, M. (2016). Framing design thinking: The concept in idea and enactment. *Creativity and Innovation Management, 25*, 38–57. https://doi.org/10.1111/caim.12153

Chandler, G. N., & Jansen, E. (1992). The founder's self-assessed competence and venture performance. *Journal of Business Venturing, 7*(3), 223–236. https://doi.org/10.1016/0883-9026(92)90028

Chen, L., Ifenthaler, D., & Yau, J. Y.-K. (2021). Online and blended entrepreneurship education: A systematic review of applied educational technologies. *Entrepreneurship Education, 4*(2), 191–232. https://doi.org/10.1007/s41959-021-00047-7

Costin, Y., O'Brien, M. P., & Hynes, B. (2021). Entrepreneurial education: Maker or breaker in developing students' entrepreneurial confidence, aptitude and self-efficacy? *Industry and Higher Education, 36*(3), 267–278. https://doi.org/10.1177/09504222211040662

Daniel, A. D. (2016). Fostering an entrepreneurial mindset by using a design thinking approach in entrepreneurship education. *Industry and Higher Education, 30*(3), 215–223. https://doi.org/10.1177/0950422216653195

de Figueiredo, M. D. (2021). Design is cool, but . . . A critical appraisal of design thinking in management education. *International Journal of Management in Education, 19*(1), Article 100429. https://doi:10.1016/j.ijme.2020.100429.

DeTienne, D. R., & Chandler, G. N. (2004). Opportunity identification and its role in the entrepreneurial classroom: A pedagogical approach and empirical test. *The Academy of Management Learning and Education, 3*(3), 242–257. https://doi.org/10.5465/amle.2004.14242103

Dillon, J. T. (1984). The classification of research questions. *Review of Educational Research, 54*(3), 327–361. https://doi.org/10.3102/00346543054003327

Dolmans, D. H., De Grave, W., Wolfhagen, I. H., & van der Vleuten, C. P. (2005). Problem-based learning: Future challenges for educational practice and research. *Medical Education, 39*(7), 732–741. https://doi.org/10.1111/j.1365-2929.2005.02205.x

Dong, A., Garbuio, M., & Lovallo, D. (2016). Generative sensing: A design perspective on the microfoundations of sensing capabilities. *California Management Review, 58*(4), 97–117. https://doi.org/10.1525/cmr.2016.58.4.97

Doorley, S., & Witthoft, S. (2011). *Make space: How to set the stage for creative collaboration*. Hoboken, NJ: John Wiley & Sons.

Dorst, K. (2011). The core of 'design thinking' and its application. *Design Studies, 32*(6), 521–532. https://doi.org/10.1016/j.destud.2011.07.006

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies, 22*(5), 425–437. https://doi.org/10.1016/s0142-694x(01)00009-6

Duval-Couetil, N., Ladisch, M., & Yi, S. (2021). Addressing academic researcher priorities through science and technology entrepreneurship education. *The Journal of Technology Transfer, 46*(2), 288–318. https://doi.org/10.1007/s10961-020-09787-5

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

Elliott, C., Mavriplis, C., & Anis, H. (2020). An entrepreneurship education and peer mentoring program for women in STEM: Mentors' experiences and perceptions of entrepreneurial self-efficacy and intent. *The International Entrepreneurship and Management Journal, 16*(1), 43–67. https://doi.org/10.1007/s11365-019-00624-2

Eskandari, H., Sala-Diakanda, S., Furterer, S., Rabelo, L., Crumpton-Young, L., & Williams, K. (2007). Enhancing the undergraduate industrial engineering curriculum: Defining desired characteristics and emerging topics. *Education & Training, 49*(1), 45–55. https://doi.org/10.1108/00400910710729875

Fayolle, A. (2013). Personal views on the future of entrepreneurship education. *Entrepreneurship & Regional Development, 25*(7–8), 692–701. https://doi.org/10.1080/08985626.2013.821318

Fayolle, A., & Gailly, B. (2008). From craft to science: Teaching models and learning processes in entrepreneurship education. *Journal of European Industrial Training, 32*(7), 569–593. https://doi.org/10.1108/03090590810899838

Fayolle, A., Lamine, W., Mian, S., & Phan, P. (2021). Effective models of science, technology and engineering entrepreneurship education: Current and future research. *The Journal of Technology Transfer, 46*(2), 277–287. https://doi.org/10.1007/s10961-020-09789-3

Felder, R. M., & Brent, R. (2003). Designing and teaching courses to satisfy the ABET engineering criteria. *Journal of Engineering Education, 92*(1), 7–25. https://doi.org/10.1002/j.2168-9830.2003.tb00734.x

Felder, R. M., Felder, G. N., & Dietz, E. J. (2002). The effects of personality type on engineering student performance and attitudes. *Journal of Engineering Education, 91*(1), 3–17. https://doi.org/10.1002/j.2168-9830.2002.tb00667.x

Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7), 674–681.

Felder, R. M., Woods, D. R., Stice, J. E., & Rugarcia, A. (2000). The future of engineering education: Part 2. Teaching methods that work. *Chemical Engineering Education, 34*(1), 26–39.

Fernández, B. F., & Martínez, A. L. (2020). The challenge of teaching consumer insights to nonmarketing students as a minor in undergraduate studies: Empathy maps as a didactic resource. *Journal for Advancement of Marketing Education, 28*(2), 14–24.

Finkle, T. A. (2012). Corporate entrepreneurship and innovation in silicon valley: The case of Google, inc. *Entrepreneurship Theory and Practice, 36*, 863–884. https://doi.org/10.1111/j.1540-6520.2010.00434.x

Fixson, S. K., & Rao, J. (2014). Learning emergent strategies through design thinking. *Design Management Review, 25*(1), 46–53. https://doi.org/10.1111/drev.10271

Fixson, S. K., & Read, J. M. (2012). Creating innovation leaders: Why we need to blend business and design education. *Design Management Review, 23*(4), 4–12. https://doi.org/10.1111/j.1948-7169.2012.00207.x

Fixson, S. K., Seidel, V. P., & Bailey, J. (2015). Creating space for innovation: The role of a "design zone" within a business school. In V. L. Crittenden, K. Esper, N. Karst, & R. Slegers (Eds.), *Evolving entrepreneurial education: Innovation in the babson classroom* (pp. 217–234). Bingley, UK: Emerald Publishing.

Gaglio, C. M. (2004). The role of mental simulations and counterfactual thinking in the opportunity identification process. *Entrepreneurship Theory and Practice, 28*(6), 533–552. https://doi.org/10.1111/j.1540-6520.2004.00063.x

Garbuio, M., Dong, A., Lin, N., Tschang, T., & Lovallo, D. (2018). Demystifying the genius of entrepreneurship: How design cognition can help create the next generation of entrepreneurs. *The Academy of Management Learning and Education, 17*(1), 41–61. https://doi.org/10.5465/amle.2016.0040

Glen, R., Suciu, C., & Baughn, C. (2014). The need for design thinking in business schools. *The Academy of Management Learning and Education, 13*(4), 653–667. https://doi.org/10.5465/amle.2012.0308

Glen, R., Suciu, C., Baughn, C. C., & Anson, R. (2015). Teaching design thinking in business schools. *International Journal of Management in Education, 13*(2), 182–192. https://doi.org/10.1016/j.ijme.2015.05.001

Guerra, A. (2017). Integration of sustainability in engineering education: Why is PBL and answer? *International Journal of Sustainability in Higher Education, 18*(3), 436–454. https://doi.org/10.1108/IJSHE-02-2016-0022

Harms, R. (2015). Self-regulated learning, team learning and project performance in entrepreneurship education: Learning in a lean startup environment. *Technological Forecasting and Social Change, 100*, 21–28. https://doi.org/10.1016/j.techfore.2015.02.007

Hassan, A., Anwar, I., Saleem, I., Islam, K. M. B., & Hussain, S. A. (2021). Individual entrepreneurial orientation, entrepreneurship education and entrepreneurial intention: The mediating role of entrepreneurial motivations. *Industry and Higher Education, 35*(4), 403–418. https://doi.org/10.1177/09504222211007051

Hofstadter, D. R. (2001). Analogy as the core of cognition. In D. Gentner, K. J. Holyoak, & B. N. Kokinov (Eds.), *The analogical mind: Perspectives from cognitive science* (pp. 499–538). Cambridge, MA: MIT Press.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps: Analogy in creative thought*. Cambridge, MA: MIT Press.

Honig, B. (2004). Entrepreneurship education: Toward a model of contingency-based business planning. *The Academy of Management Learning and Education, 3*(3), 258–273. https://doi.org/10.5465/amle.2004.14242112

Jackson, W. T., Scott, D. J., & Schwagler, N. (2015). Using the business model canvas as a methods approach to teaching entrepreneurial finance. *Journal of Entrepreneurship Education, 18*(2), 99–111.

Johansson-Sköldberg, U., Woodilla, J., & Çetinkaya, M. (2013). Design thinking: Past, present and possible futures. *Creativity and Innovation Management, 22*(2), 121–146. https://doi.org/10.1111/caim.12023

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139–151. https://doi.org/10.1002/j.2168-9830.2006.tb00885.x

Kirby, D. A. (2004). Entrepreneurship education: Can business schools meet the challenge? *Education and Training, 46*(8/9), 510–519. https://doi.org/10.1108/00400910410569632

Kleine, K., Giones, F., & Tegtmeier, S. (2019). The learning process in technology entrepreneurship education—insights from an engineering degree. *Journal of Small Business Management, 57*, 94–110. https://doi.org/10.1111/jsbm.12514

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice-Hall.

Kolmos, A., Flemming, K. F., & Lone, K. (2006). The aalborg model-problem-based and project-organized learning. In A. Kolmos, K. F. Flemming, & K. Lone (Eds.), *The aalborg PBL model -progress, diversity and challenges* (pp. 9–18). Aalborg: Aalborg University Press.

Kwapisz, A., Schell, W. J., Aytes, K., & Bryant, S. (2021). Entrepreneurial action and intention: The role of entrepreneurial mindset, emotional intelligence, and grit. *Entrepreneurship Education and Pedagogy, 5*(3), 375–405. https://doi.org/10.1177/2515127421992521

Lamine, W., Mian, S., Fayolle, A., & Linton, J. D. (2021). Educating scientists and engineers for technology entrepreneurship in the emerging digital era. *Technological Forecasting and Social Change, 164*, Article 120552. https://doi.org/10.1016/j.techfore.2020.120552

Lehmann, M., Christensen, P., Du, X., & Thrane, M. (2008). Problem-oriented and project-based learning (POPBL) as an innovative learning strategy for sustainable development in engineering education. *European Journal of Engineering Education, 33*(3), 283–295. https://doi.org/10.1080/03043790802088566

Levie, J. (2014). The university is the classroom: Teaching and learning technology commercialization at a technological university. *The Journal of Technology Transfer, 39*(5), 793–808. https://doi.org/10.1007/s10961-014-9342-2

Linton, J. D., & Xu, W. (2021). Research on science and technological entrepreneurship education: What needs to happen next? *The Journal of Technology Transfer, 46*(2), 393–406. https://doi.org/10.1007/s10961-020-09786-6

Lynch, M., Kamovich, U., Longva, K. K., & Steinert, M. (2021). Combining technology and entrepreneurial education through design thinking: Students' reflections on the learning process. *Technological Forecasting and Social Change, 164*, Article 119689. https://doi.org/10.1016/j.techfore.2019.06.015

Maher, M. L. (2000). A model of co-evolutionary design. *Engineering with Computers, 16*(3–4), 195–208. https://doi.org/10.1007/pl00013714

Mann, L., Chang, R., Chandrasekaran, S., Coddington, A., Daniel, S., Cook, E., Crossin, E., Cosson, B., Turner, J., Mazzurco, A., Dohaney, J., O'Hanlon, T., Pickering, J., Walker, S., Maclean, F., & Smith, T. D. (2021). From problem-based learning to practice-based education: A framework for shaping future engineers. *European Journal of Engineering Education, 46*(1), 27–47. https://doi.org/10.1080/03043797.2019.1708867

Maresch, D., Harms, R., Kailer, N., & Wimmer-Wurm, B. (2016). The impact of entrepreneurship education on the entrepreneurial intention of students in science and engineering versus business studies university programs. *Technological Forecasting and Social Change, 104*, 172–179. https://doi.org/10.1016/j.techfore.2015.11.006

Maritz, A., Nguyen, Q., & Ivanov, S. (2022). Student entrepreneurship ecosystems at Australian higher education institutions. *Journal of Small Business and Enterprise Development, 29*(6), 940–957. https://doi.org/10.1108/jsbed-11-2021-0466

Markham, S. K., Baumer, D. L., Aiman-Smith, L., Kingon, A. I., & Zapata, M. (2000). An algorithm for high technology engineering and management education. *Journal of Engineering Education, 89*(2), 209–218. https://doi.org/10.1002/j.2168-9830.2000.tb00515.x

Maurya, A. (2012). *Running lean: Iterate from plan A to a plan that works*. Sebastopol, CA: O'Reilly Media.

Merguei, N. (2022). Venturing out: Designing effective pre-acceleration programs. *Technovation, 116*, Article 102500. https://doi.org/10.1016/j.technovation.2022.102500

Mian, S., Lamine, W., & Fayolle, A. (2016). Technology business incubation: An overview of the state of knowledge. *Technovation, 50–51*, 1–12. https://doi.org/10.1016/j.technovation.2016.02.005

Mosey, S. (2016). Teaching and research opportunities in technology entrepreneurship. *Technovation, 57–58*, 43–44. https://doi.org/10.1016/j.technovation.2016.08.006

Nabi, G., Liñán, F., Fayolle, A., Krueger, N., & Walmsley, A. (2017). The impact of entrepreneurship education in higher education: A systematic review and research agenda. *The Academy of Management Learning and Education, 16*(2), 277–299. https://doi.org/10.5465/amle.2015.0026

Neck, H. M., & Greene, P. G. (2011). Entrepreneurship education: Known worlds and new frontiers. *Journal of Small Business Management, 49*(1), 55–70. https://doi.org/10.1111/j.1540-627x.2010.00314.x

Nicotra, M., Del Giudice, M., & Romano, M. (2021). Fulfilling university third mission: Towards an ecosystemic strategy of entrepreneurship education. *Studies in Higher Education, 46*(5), 1000–1010. https://doi.org/10.1080/03075079.2021.1896806

Nielsen, S. L., & Stovang, P. (2015). DesUni: University entrepreneurship education through design thinking. *Education + Training, 57*(8/9), 977–991. https://doi.org/10.1108/et-09-2014-0121

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: A handbook for visionaries, game changers, and challengers*. Chichester, UK: John Wiley & Sons.

Paço, A., Ferreira, J., & Raposo, M. (2016). Development of entrepreneurship education programmes for HEI students: The lean start-up approach. *Journal of Entrepreneurship Education, 19*(2), 39–52.

Passow, H. J., & Passow, C. H. (2017). What competencies should undergraduate engineering programs emphasize? A systematic review. *Journal of Engineering Education, 106*(3), 475–526. https://doi.org/10.1002/jee.20171

Peirce, C. S. (1998). *The essential peirce: Selected philosophical writings, 1893-1913*. Bloomington, Indiana: Indiana University Press.

Phan, P. H., Siegel, D. S., & Wright, M. (2009). New developments in technology management education: Background issues, program initiatives, and a research agenda. *The Academy of Management Learning and Education, 8*(3), 324–336. https://doi.org/10.5465/amle.2009.44287934

Qureshi, S., & Mian, S. (2021). Transfer of entrepreneurship education best practices from business schools to engineering and technology institutions: Evidence from Pakistan. *The Journal of Technology Transfer, 46*(2), 366–392. https://doi.org/10.1007/s10961-020-09793-7

Ries, E. (2011). *The lean startup: How today's entrepreneurs use continuous innovation to create radically successful businesses*. New York, NY: Random House LLC.

Roman, H. T. (2006). The undeniable link between engineering and technology education. *Tech Directions, 66*(4), 16–19.

Rosenbaum, M. S., Otalora, M. L., & Ramírez, G. C. (2017). How to create a realistic customer journey map. *Business Horizons, 60*(1), 143–150. https://doi.org/10.1016/j.bushor.2016.09.010

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York, NY: Basic Books.

Schumacher, T., & Mayer, S. (2018). Preparing managers for turbulent contexts: Teaching the principles of design thinking. *Journal of Management Education, 42*(4), 496–523. https://doi.org/10.1177/1052562917754235

Secundo, G., Mele, G., Vecchio, P. D., Elia, G., Margherita, A., & Ndou, V. (2021). Threat or opportunity? A case study of digital-enabled redesign of entrepreneurship education in the COVID-19 emergency. *Technological Forecasting and Social Change, 166*, Article 120565. https://doi.org/10.1016/j.techfore.2020.120565

Shekhar, P., & Huang-Saad, A. (2021). Examining engineering students' participation in entrepreneurship education programs: Implications for practice. *International Journal of STEM Education, 8*(40), 1–15. https://doi.org/10.1186/s40594-021-00298-9

Shepherd, D. A. (2004). Educating entrepreneurship students about emotion and learning from failure. *The Academy of Management Learning and Education, 3*(3), 274–287. https://doi.org/10.5465/amle.2004.14242217

Siegel, D. S., & Wright, M. (2015). Academic entrepreneurship: Time for a rethink? *British Journal of Management, 26*(4), 582–595. https://doi.org/10.1111/1467-8551.12116

Simon, H. A. (1996). *The sciences of the artificial*. Cambridge, MA: MIT Press.

Snihur, Y., Lamine, W., & Wright, M. (2021). Educating engineers to develop new business models: Exploiting entrepreneurial opportunities in technology-based firms. *Technological Forecasting and Social Change, 164*, Article 119518. https://doi.org/10.1016/j.techfore.2018.11.011

Stenard, B. S. (2021). Interdisciplinary skills for STEAM entrepreneurship education. *Entrepreneurship Education and Pedagogy*, 1–28. https://doi.org/10.1177/25151274211029204

Taylor, D., & Miflin, B. (2008). Problem-based learning: Where are we now? *Medical Teacher, 30*(8), 742–763. https://doi.org/10.1080/01421590802217199

van Burg, E., & Romme, A. G. L. (2014). Creating the future together: Toward a framework for research synthesis in entrepreneurship. *Entrepreneurship Theory and Practice, 38*(2), 369–397. https://doi.org/10.1111/etap.12092

Verzat, C., Byrne, J., & Fayolle, A. (2009). Tangling with spaghetti: Pedagogical lessons from games. *The Academy of Management Learning and Education, 8*(3), 356–369. https://doi.org/10.5465/amle.2009.44287936

Visser, W. (2006). *The cognitive artifacts of designing*. Mahwah, NJ: Lawrence Erlbaum Associates.

Visser, W. (2009). Design: One, but in different forms. *Design Studies, 30*(3), 187–223. https://doi.org/10.1016/j.destud.2008.11.004

Welter, F. (2011). Contextualizing entrepreneurship—conceptual challenges and ways forward. *Entrepreneurship Theory and Practice, 35*(1), 165–184. https://doi.org/10.1111/j.1540-6520.2010.00427.x

Welter, F., & Gartner, B. (2016). *A research agenda for entrepreneurship and context*. Incorporated, Cheltenham, UK: Edward Elgar Publishing.

Wiltschnig, S., Christensen, B. T., & Ball, L. J. (2013). Collaborative problem–solution co-evolution in creative design. *Design Studies, 34*(5), 515–542. https://doi.org/10.1016/j.destud.2013.01.002

Wright, M., Siegel, D. S., & Mustar, P. (2017). An emerging ecosystem for student start-ups. *The Journal of Technology Transfer, 42*(4), 909–922. https://doi.org/10.1007/s10961-017-9558-z

Zahra, S. A., & Wright, M. (2011). Entrepreneurship's next act. *Academy of Management Perspectives, 25*(4), 67–83. https://doi.org/10.5465/amp.2010.0149