Technological Forecasting & Social Change xxx (xxxx) xxxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

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

Combining technology and entrepreneurial education through design thinking: Students' reflections on the learning process

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ARTICLE INFO

Keywords:
Technology and entrepreneurship education
Design thinking
Corporate entrepreneurship
Tangential skills

ABSTRACT

There has been a growing call to educate scientists and engineers in entrepreneurship. However, how entrepreneurship should be taught to these students is a question that scholars and practitioners are still intrigued with. Design thinking has been put forward as a pedagogy that could be particularly suitable when introducing entrepreneurship to science and engineering students. Empirical evidence to support this claim are scarce. This study therefore seeks to enhance our understanding of this issue through an exploratory case study of students' reflections during and after participation in a course that uses design thinking to teach entrepreneurial skills through a technologically challenging case. The findings indicate that the course constituted a major challenge for the students, but also an opportunity for developing both tangential skills and knowledge about the commercialization of technology. Further, there is evidence of transformational learning as students began to apply design thinking in real-life beyond the context of the course.

1. Introduction

In a volatile and rapidly changing world, students within science and engineering need to have advanced technological skills that meet the demands of our knowledge-based economy. However, scientific and technological skills alone are no longer enough to prosper as an employee in the 21st century (King, 2012; Litzinger et al., 2011). Scientists and engineers cannot solely rely on their technological knowledge but will also be expected to have skills in areas such as problem solving, creative thinking, written and oral communication and teamwork (Jonassen et al., 2006; Passow and Passow, 2017). It is also critical for them to understand how technology can be brought successfully to the market through commercialization (Barr et al., 2009; Bilán et al., 2005). Nevertheless, there have been indications that science and engineering students are not acquiring these skills in their education to the extent that they should (Jonassen et al., 2006; Male, 2010). Design thinking has been proposed as one way of teaching an entrepreneurial mind-set to students (Daniel, 2016; Neck and Greene, 2011; Nielsen and Stovang, 2015) and may represent a way of filling this skill deficiency. Design thinking has gained popularity within entrepreneurship education over recent decades (Huq and Gilbert, 2017; Lahn and Erikson, 2016). Yet, there is limited insight into how students perceive design thinking as a teaching method. Hence, through an exploratory case study, this paper aims to address the following research question: *How do students reflect upon their learning process of design thinking in education that combines entrepreneurship and technology?*

In order to bridge the gap between science and engineering education and the skills that employees of the 21st century need, there has been a growing call from industry bodies to educate science and engineering students in entrepreneurship (e.g., European Society for Engineering Education, 2012, 2017). Introducing entrepreneurship to these areas of study has accordingly been given increasing attention both in practice and research (Duval-Couetil et al., 2012; Mitchell, 2007; Vest, 2005). With the rapid growth of the new area of engineering entrepreneurship education, there has also been a growing call for research and assessment of education within the field (Bilán et al., 2005; Täks et al., 2014). This is also an issue within the broader field of entrepreneurship education, where scholars are discussing how to teach entrepreneurship and which outcomes to expect from different teaching methods (Fayolle, 2013, 2018; Neck and Greene, 2011; Pittaway and Cope, 2007a).

This study takes a closer look at one teaching method, namely design thinking, that could be suitable for introducing entrepreneurship to science and engineering students. The context of the study is an

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https://doi.org/10.1016/j.techfore.2019.06.015
Received 30 January 2018; Received in revised form 14 June 2019; Accepted 24 June 2019

interdisciplinary master's level course in corporate entrepreneurship. Corporate entrepreneurship is defined by the objectives of not only seeing opportunities for starting new ventures, but also of investigating opportunities for renewal or innovation within existing companies (Sharma and Chrisman, 1999). In the course, students were asked to find new entrepreneurial opportunities for a technological service. This required students to grasp both an understanding of the technology, its capacities and limitations, while at the same time searching for entrepreneurial opportunities. By analysing students' reflections during and after the course, we aim to contribute to a better understanding of the value of design thinking as a teaching method for entrepreneurship in general, and especially in a technological setting. As our research is exploratory in nature, it does not seek to categorically prove or disprove whether design thinking works as a pedagogy, but rather to guide the future direction of research on the topic.

The paper is structured as follows. First, we discuss entrepreneurship education and how design thinking has been introduced as a teaching method for entrepreneurship. We continue by describing the methodology used in the case study, before the findings are presented. The paper concludes with a discussion of the findings, our conclusions and the implications of our work for future research on design thinking in entrepreneurship education in general and engineering entrepreneurship education in particular.

2. Literature review

An enhanced understanding of the role that entrepreneurship can have in economic growth and job creation, has resulted in a substantial increase in entrepreneurship courses and programs in higher education institutions worldwide (Katz, 2003; Kuratko, 2005; Pittaway and Cope, 2007a). With the increase, a multitude of teaching approaches within entrepreneurship education has emerged, ranging from traditional courses that teach students about entrepreneurship, to process-oriented courses focusing on business plan development, to more action-oriented courses introducing for example, effectual entrepreneurship, learn start-up or design-based learning (Garbuioet al., 2018; Neck and Greene, 2011; Pittaway and Edwards, 2012). While some have argued strongly that entrepreneurship education should strive to be actionable, others have suggested a more processual approach where learning about, for and through entrepreneurship (Hannon, 2005; Jamieson, 1984) are not mutually exclusive, but are rather complementary pedagogies that can be present in the same course (Blenker et al., 2011; Thrane et al., 2016).

It is generally agreed that it is valuable to have elements of active and practice-based pedagogies in entrepreneurship education courses (Hägg, 2017; Neck and Greene, 2011; Rasmussen and Sørheim, 2006). The action orientation is often different to what the students are used to in other courses and thereby pushes them out of their comfort zones (Sidhu and Deletraz, 2015). Being outside one's comfort zone releases the potential of personal growth and development (Dweck, 2008) and can thereby lead to deeper learning (Marton and Säljö, 1976) and perspective transformation (Mezirow, 1991). As Mezirow (1991) describes, educators need to be facilitators of learning environments that promote transformation through critical reflection on assumptions and beliefs. The strong bias towards action orientation therefore needs to be counterbalanced with reflective thinking to avoid cognitive overload among entrepreneurship students (Hägg, 2017). Applied purposefully, action-oriented pedagogies are expected to prepare students for the real world (Neck and Greene, 2011). After all, in the words of Neck and Greene (2011, p. 55), “entrepreneurship is complex, chaotic, and lacks any notion of linearity”, and entrepreneurship educators accordingly have the responsibility to deliver courses that develop the skills that students need to excel in highly uncertain and ambiguous environments.

Science and engineering students also need these skills as employees in the 21st century job market. While their education provides them with strong technological knowledge, they will also be expected to be skilled in areas such as problem solving, creative thinking, communication, teamwork and commercialization (Bilán et al., 2005; Barr et al., 2009; Jonassen et al., 2006; Passow and Passow, 2017). However, there have been claims that science and engineering education is not providing enough opportunities to acquire these skills in its present form (Jonassen et al., 2006; Male, 2010). Entrepreneurship has been introduced as a way of enhancing the development of such skills in these areas of study (Duval-Couetil et al., 2012; Mitchell, 2007; Vest, 2005). The commercialization aspect has especially received increasing attention, as universities are becoming preoccupied with providing education programs that contribute to the establishment of new ventures or the creation of new business entities within existing companies through corporate entrepreneurship (Barr et al., 2009). The literature on the impact of entrepreneurship education on science and engineering students is limited (Huang-Saad et al., 2018). Although, there are contributions to this literature; for example, Duval-Couetil et al. (2012), who established that technology and venturing self-efficacy, ability to evaluate business ideas and risk tolerance is significantly higher for engineering students with entrepreneurship education than for those without. Further, Bilán et al. (2005) studied an engineering entrepreneurship course and found a significantly higher score for creativity, ability to generate business ideas and presentation skills in students after having taken the course. Maresch et al. (2016) compare business and engineering students, and find that although both have increased entrepreneurial intention after entrepreneurship education, the effect is less for engineering students than business students. They accordingly suggest that the pedagogy of entrepreneurship education should be adapted to fit engineering students better and that a design approach could be a means to do so.

Design thinking is a form of teaching that aims at generating new ideas and exploring alternative solutions, instead of picking between existing alternatives (Beckman and Barry, 2007). Multiple models of design thinking have emerged over the years as design thinking has spread from the design community to a variety of other fields (Dorst, 2011). In this paper, design thinking is portrayed in line with Brown (2008) as a series of five steps: empathize, define, ideate, prototype and test. Design thinking has been regarded as an efficient approach for tackling highly ambiguous situations and unveiling unanticipated problems very early (Fixson and Rao, 2014), and several scholars have argued for its value in management education (Dunne and Martin, 2006; Garbuio et al., 2018), in entrepreneurship education (Daniel, 2016; Garbuio et al., 2018; Neck et al., 2014; Nielsen and Stovang, 2015) and social entrepreneurship education (Kickul et al., 2018). Garbuio et al. (2018) state that students tend to easily handle well-defined processes that require analytical reasoning to reach a single answer with significant guidance from instructors. They argue that design cognition provides a way to introduce students to complex, ill-defined entrepreneurial problems with unclear means-end relationships, and thereby prepare them for what they will meet as graduates. Further, Penaluna and Penaluna (2019) argue that design thinking can be particularly relevant when introducing entrepreneurship education to study programs outside business schools, while Ranger and Mantzavinou (2018) highlight the opportunities it provides for non-traditional engagement with industry partners.

There has been an increased interest in understanding the processes and outcomes that take place when design thinking is used as a teaching approach. As a novel teaching method, the literature on design thinking in business education is still in its infancy. However, there have been studies conducted in other contexts that suggest that design thinking has the potential for making students in secondary education more agentic, inspired, interested in learning and developing themselves, helping them to master new skills and apply their talents responsibly (Carroll et al., 2010; Wagner, 2014). Nevertheless, the same studies indicated that there were also challenges in terms of collaborative learning and time pressure. In an entrepreneurship education context, Daniel (2016) carried out a comparative case study of design thinking

and business planning, and found that students in the design thinking course felt more motivated and content with their performance. Students were however less positive in terms of the activities in the course, the assessment methods and found the course too easy. As the study is based on students' programme evaluation through the university quality assurance system, there is less insight into why this was the case, and the study thereby highlights why using standardized evaluation surveys can be problematic when aiming to understand students' perspectives. Lahn and Erikson (2016) are also advocates for a design-based approach in entrepreneurship education and argue through a thematic analysis of master theses that entrepreneurship education through design appears to strengthen systematic self-reflection and learning, compared to master students that participated in start-up internships. Finally, Huq and Gilbert (2017) emphasize how design thinking can create a learning environment with humour and fewer barriers between students and teachers, empowering the students and thereby contributing to enhanced student satisfaction and learning outcomes.

Although empirical insights on design thinking are emerging within management education, its acceptance among students and teachers may still be questioned (Nielsen and Stovang, 2015). Much is still not well understood and there is a call for further research on student satisfaction and learning outcomes of design-led entrepreneurship pedagogy (Huq and Gilbert, 2017) and how it works in different contexts (Nielsen and Stovang, 2015). Thus, despite a growing interest in using design thinking in entrepreneurship education, there is still a need to explore in-depth how students perceive design thinking. This is the point of departure for this paper, which explores design thinking in a context that combines entrepreneurship education with the commercialization of technology through corporate entrepreneurship.

3. Research design

3.1. Research approach

The study applied a case study methodology (Yin, 2009, 2011) and was conducted at a Norwegian university during a master's level course in Corporate Entrepreneurship in 2015. The course had an intensive format and lasted five weeks. The data collection took place both during the course and after. The limited prior literature on design thinking in an entrepreneurship education setting guided our research design in the explorative case study. Hence, we based our data collection on the principle of triangulation, applying multiple sources of evidence in order to search for converging findings from different sources and thereby strengthen validity (Yin, 2009). The primary source of data was weekly reflective diaries written during the course and reflection essays handed in by the students after course completion. This was supplemented with secondary data, observations, and an interview with the teacher in order to better understand the context of the course.

3.2. Case description

The master's levels course in Corporate Entrepreneurship was run at a Norwegian business school. The intensive format of the course meant that the students were expected to spend the same number of working hours over five weeks that they would otherwise do during a whole semester. The course aimed to provide students with tools and methods in tackling complex problems at the corporate level. The learning outcomes of the course as published in the course catalogue are described in Table 1 below.

The teaching approach in the course relied on several practices substantiated by actionable theory (Neck et al., 2014) and were based on the design thinking process model described by Brown (2008) as a series of five steps: empathize, define, ideate, prototype, and test. The theory behind the course was largely kept hidden from students, as discussed in Kamovich and Longva (2016), with the course instead emphasising the practical activities of searching and exploring for entrepreneurial opportunities. In an interview, the course teacher emphasized that in his opinion students learned best by *doing design thinking*, rather than learning *about design thinking*. Unlike more conventional university courses where students obtain static knowledge about existing theories and models focusing on “what is” and “what has been”, this course required students to be active participants in creating their knowledge with a focus on “what might be” (Dunne and Martin, 2006; Nielsen and Stovang, 2015). The course teacher is a serial entrepreneur with a background from Stanford Graduate School of Business, where he was introduced to design thinking. Besides having a theoretical understanding of the design thinking concept, he also actively applied it in a social enterprise that spun out of the Hasso Plattner Institute of Design at Stanford University (commonly referred to as the d.school). He had taught design thinking within higher education for the 5 years prior to this course. In the course, the teacher was supported by a team of four teaching assistants, who all had previously taken several courses where design thinking had been used as a teaching method.

The students were from several different masters' programmes and had mixed backgrounds, including finance, military, computer science, hospitality, literature, public relations, law and an electrician. In the course, the students were divided into four teams and introduced to four different “real-life” problems prepared by a company. The company is a provider of ground station and earth observation services for polar orbiting satellites with its head office in Norway. The company's services are highly technical in nature and were outside the normal subject matter taught to students. The company agreed to partner with the course in order to create and explore opportunities for the applicability of their remote sensing technology. The technology served as a basis for formulating the initial problems in the areas of the company's interest. The problems varied from predicting macro-economic trends or benefiting commercial organizations to helping commodity or equity traders to make better investment decisions using remote sensing images. The initial problems the students were to tackle were perceived as ill-defined from the outset of the course; thus, mimicking a real-world situation where opportunities and the directions of projects are vague and uncertain. The students were introduced to an existing company's problem instead of working on their own, as this was a setting that many students would be meeting in the work place. However, the problem was ill-defined and needed to be re-defined by the students.

The course was divided into five thematic time blocks, each dedicated to one step in the design thinking process as described by Brown (2008). Despite such partition, the non-linearity and iterative nature of the process was emphasized, encouraging students to freely navigate between the steps. At times, the student groups were interrupted and forced to move onto a different step. In interviews with the teacher, he commented that he actively managed this and pushed student groups that had become stuck or stagnated on a single step to move onto a different thematic block. Design thinking is iterative in nature and implies going forth and back between the five steps in the design thinking process. The feedback loops and shifts that occur foster learning and assist students to make headway towards a solution for the problem space (Nielsen and Stovang, 2015).

Since each stage in the design thinking process has its own logic and requires its own concrete tools, the course employed different activities to introduce a number of tools and methods to support each step. For example, to increase students' aptitude for empathy, several exercises were used to teach them the value of observation. Another exercise introduced them to conducting in-depth interviews. The students paired up and started interviewing each other. They were asked to avoid closed-ended questions, ask for details, ask ‘why?’ questions at least five times, elicit stories and emotions, and take notes. Tools and methods such as a user journey map and process blueprint, prototyping, and

Table 1
Learning outcomes described in the course catalogue.

Knowledge and comprehension	• Knowledge of the design thinking methodology, and how it can be applied in a corporate environment to develop innovative solutions. • Comprehension of cutting-edge innovation topics such as crowdsourcing and human-centred design. • Understanding of how corporate culture is developed and how it can be gradually and purposefully changed towards a more entrepreneurial mind-set.
Skills competence	• Students should gain the necessary skills to inject any corporate environment with creative, innovative, and entrepreneurial solutions. • Students should be able to serve as successful, creative change agents in business organizations of all types.

storytelling were also used. Unlike the DesUni model (Nielsen and Stovang, 2015) that allows for business-oriented tools and methods, this course did not employ any such tools.

Hence, from an ontological point of view, the course adheres to the "creation" approach in the entrepreneurship literature debate about the nature of opportunities. The creation approach emphasizes experimentation and the ability to learn from it (Alvarez and Barney, 2007), and students are accordingly required to exercise creativity, mental flexibility, as well as the willingness and ability to fail and learn from it (Garbuio et al., 2018). Thus, instead of assuming that opportunities already exist in the environment, design thinking focuses on making new ideas and opportunities emerge through deliberate practices (Nielsen and Stovang, 2015). In this article, given the corporate venture focus of the course with its ill-defined problems tackled by the students, the research took place in the context of entrepreneurial opportunity creation and relied on the design thinking process model by Brown (2008). Corresponding practical activities were used to master each step in the process and help students understand the underlying logic behind each activity. It is important to emphasize that this particular course uses a design thinking approach that has been adapted from design schools to management education. The approach has accordingly been criticized for oversimplifying design thinking (Dorst, 2011; Vinsel, 2018). While reviewing this debate is beyond the scope of this paper, it is important to bear in mind that the findings presented in the remainder of the paper stem from a particular view of the design thinking concept.

None of the authors were involved in teaching the course, although two of the authors observed much of the course. One of these authors acted as a teacher assistant for one of the groups. This involved meeting with the group to discuss the teams' progress once or twice a week. This contributed to a better understanding of how the students experienced the course.

3.3. Data collection

Since our research objective was to understand the students' perceptions of the experience of participating in a course that combines entrepreneurship and technology through design thinking, the primary source of data was weekly student reflective diaries and student reflection essays. The use of student reflections as a justifiable data source in entrepreneurship education has previously been established (Heinonen, 2007; Pittaway and Cope, 2007b). Students were assessed based on a reflection essay after the course, although there were no structured learning activities on reflection during the course. Six of the students in the course agreed to write weekly reflection diaries. These were handed in at the end of each of the five weeks that the course lasted, which resulted in 79 pages of written material. The reflection diaries were not a formal part of the course and were collected specifically for this research. The diaries were guided by questions addressing the students' own perceptions of learning for each week and reflections on the application of design thinking.

The second source of written reflections were the reflection essays handed in by the students two weeks after course completion as part of their formal course assessment. While two weeks after the course is a relatively short time, we consider it balances the need for reflection with the need for the course content and highlights of the course to be relatively fresh in students' minds. From the 28 students participating in the course, 27 students gave us access to their individual reflection essays. This resulted in 229 pages of written material. Five open-ended questions were used to guide students' personal reflections. The questions revolved around the following themes: (i) Value behind the design thinking process; (ii) Major learning take-aways; (iii) Major challenges during the process; (iv) The application of design thinking in the future; (v) Distinction between design thinking and student's previous way of thinking.

In addition to the written student reflections, the data were supplemented with access to course materials, course descriptions, observations of teaching, observation of group work, as well as an interview with the lecturer in order to better understand the course specifics and the context.

3.4. Data analysis

Recognizing that qualitative analysis is cyclical art, we carried out first and a second cycle coding as suggested by Saldaña (2012). The coding process is illustrated in Fig. 1. The first cycle started with a descriptive coding strategy where the authors attempted to keep an open mind and summarize passages of qualitative data in basic topics using single words or short phrases. Two authors coded essays individually, while one author coded the reflection diaries. After coding five common essays, the coding in three of them was compared, revealing a high similarity in the use of codes. This resulted in an initial list of codes, which were used for the remainder of the essays and diaries. This cross-check of the initial essays allowed us to give sharper definitions, discuss equivocal cases, and do respective reliability checks, which led to the formulation of a common understanding around each code and its fit to the blocks of data (Miles et al., 2014). New codes were discussed and added to the list as they emerged. To aid our process of coding and analysis, we used the computer-based qualitative analysis program NVivo (version 11).

After the first cycle initial coding, we advanced to second cycle coding. With the initial codes from the first cycle coding in mind, we applied focused coding when re-coding the material in the second cycle. The objective of focused coding is to look for recurrent patterns and conceptual similarity among codes (Saldaña, 2012). While coding is a highly iterative process where it is necessary to revise and refine categories and themes throughout the analysis process, the main features of the process can be described as: 1) developing categories from the recoded material, and 2) structuring the categories to arrive at broader themes.

4. Findings

The coding of the data took us from 26 codes and 11 sub-codes in the first cycle coding, to four main themes developed from 12 categories in the second cycle coding. The main themes we arrived at are depicted in Fig. 2 along with the associated categories, and the findings from these are further described in the section below.

4.1. Being challenged

One of the themes that emerged first during our coding and re-

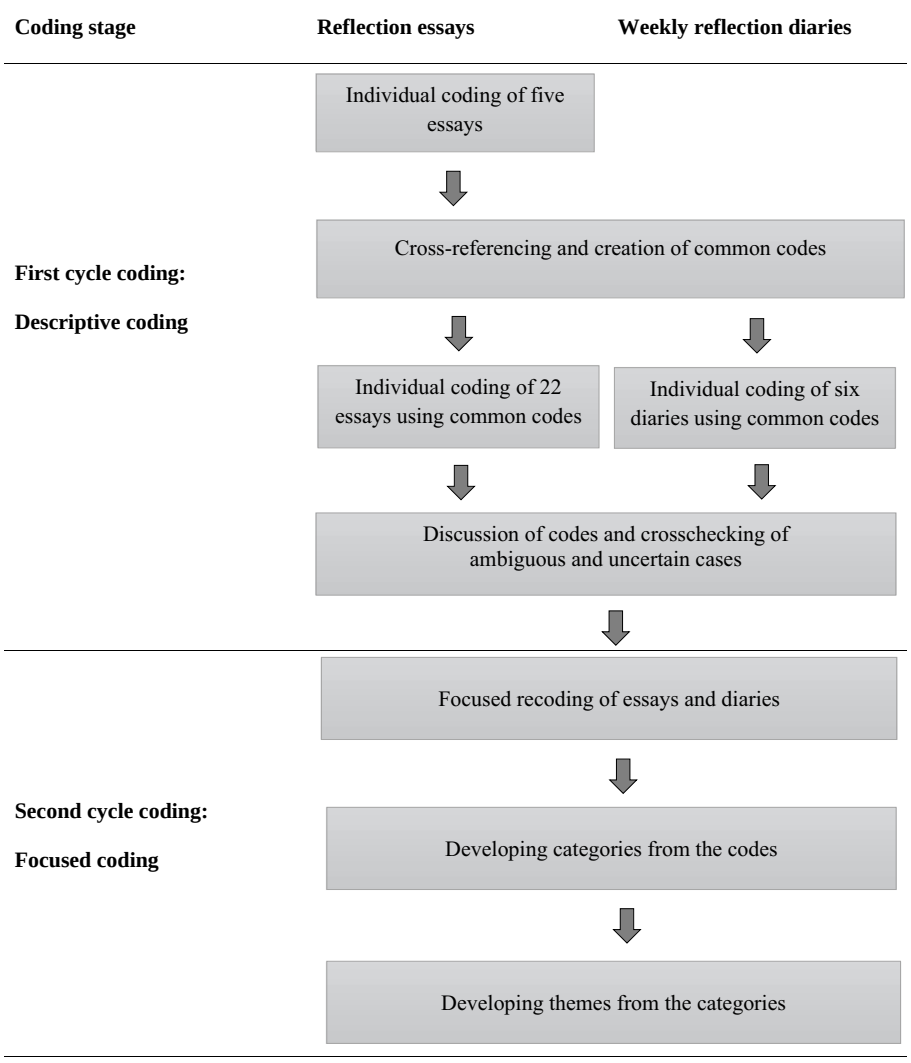

Fig. 1. Stages in the coding process.

coding was how challenging the students found the course. The combination of task complexity in terms of technical and financial knowledge, working in new and rather large teams with a flat structure, and being under time pressure, appears to have caused some frustration in the beginning of the course. One student said, *"I felt powerless, and the chaos led to physical stress, with mouth ulcers and a sore neck as results, to name a few."* However, the same student said that over time, he became more comfortable, and in the end, he felt it was an overall positive learning experience. Hence, students also describe the course as a developmental experience that has had a fundamental impact. In one of the essays, a student writes, *"Yes it is challenging, and yes it is hard work - but all in all, you get to use your creative side, go out of your comfort zone and try new things."*

4.1.1. Task complexity

The design challenge was highly technical and represented a substantial challenge for many students. Their ability to grasp two different sectors (satellite services and financial services industry) and attempt to search for profitable intersections in these proved to be a challenge for many. In one of the essays, a student writes *"one of our main challenges was as simple as knowing how we could utilize the technology [the Company] had to solve our task. The reason why we had this challenge was because we did not have knowledge within the group on how the technology worked. As a result of this, we did use a lot of time to understand the capacity of the technology."* The students found the complexity of the task in terms of technology and industry knowledge challenging at the beginning of the course. However, following the development in the learning diaries and reflections in the essays, it appears that most students eventually came to terms with the challenge after the first couple of weeks *"Even though the complexity of the assignment at first exceeded what I really thought could be possible, at the end, I had learned so much, and the team came up with several ideas for [The Company]"*. This seems to support the idea that design thinking could be valuable when training students to understand technology, its opportunities and its limitations, while at the same time having them search for commercial opportunities. The reflections suggest that the learning pushed them to the limit of their technical understanding, but that at the end of the course they felt they had come to grips with the technical element of the challenge.

4.1.2. Team dynamics

Teamwork and collaboration among the team was clearly a significant challenge for many students. Many referred to conflicts or difficulties within the team in their reflections. While they were accustomed to group work, the size of the groups was larger than normal, interdisciplinary and composed of students with whom they had not worked before. As stated by one student in the learning diaries: *"My group had members with different nationalities and many strong personalities. This affected the interaction increasingly throughout the process. Overall, I think you learn more about the challenges of working in a team*

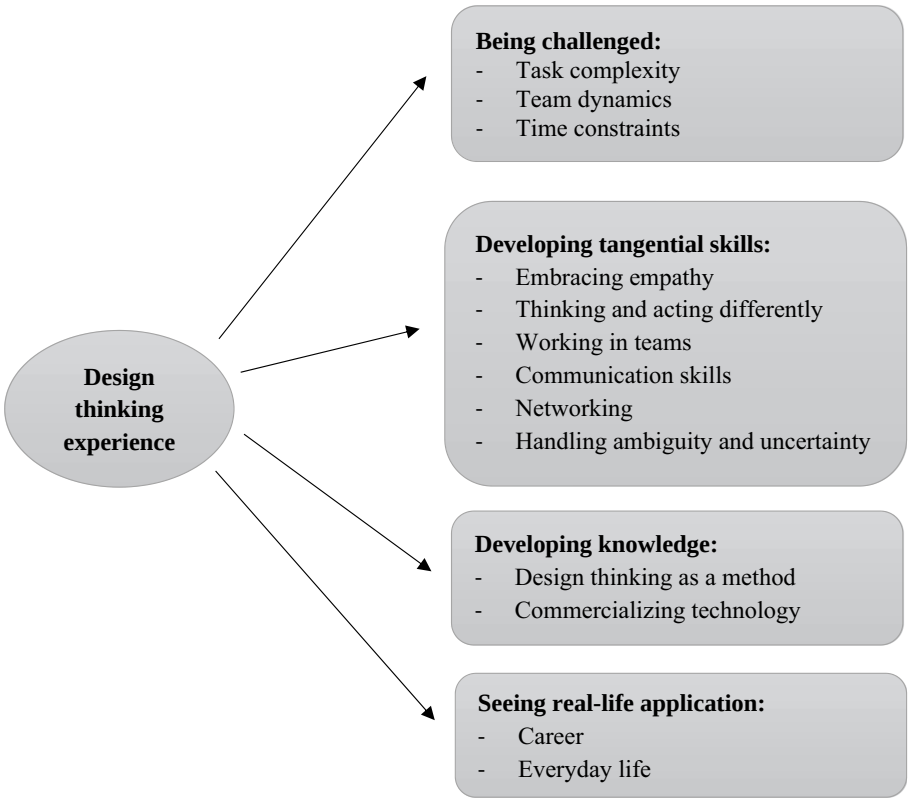

Fig. 2. Main themes with associated categories.

without a strong leader, than the design thinking method in itself. The group was quite divided at the end of the course and worked a lot to keep communication constructive." Although teams did not experience critical meltdowns, the communication posed a challenge for many *"…we mainly worked individually, communicating through social media, and it became more 'I' than 'team'"*. The lack of leadership was emphasized among many of students, as most teams had a flat structure and many were waiting for a leader to emerge. There were also indications of power struggles. The students saw the lack of leadership as frustrating and at times distracting from the overall design challenge. *"Whenever I used to do a group-work in the past, there used to be a power hierarchy and structure in the group. I always had a specific task to do and I did that. Usually the teachers corrected what they thought wasn't good enough. This time it was quite different though. There was no structure at all and no interference from the teacher"*. While it might be tempting to say the teachers should have stepped in and resolved the teamwork and leadership issues, it seems like this was a key opportunity for learning to take place. One student put it succinctly and summarised the team challenges by saying the course *"demonstrates the challenges of implementing design thinking in [a] working environment and at the same time has shown how it works and which kind of challenges it brings"*.

4.1.3. Time constraints

Another aspect that students reported as challenging was the time pressure due to the intensity of the design challenge. Several emphasized that time pressure was a major challenge, especially in combination with the complexity of the technology and working in a new team. A student states, "*I think that for a task like this, we need more time. We just had five weeks on this challenge… If it is an easy challenge, you maybe not need that much time, but if the challenge is more complex, I definitely think that time is important. Concerning this [the Company] challenge, I felt we just had started when we were finished*". However, many students also saw the potential for learning time management through the induced time limits and one student writes in the final learning diary week "*The fact that the design thinking process has time limit indicates that there is a need to manage the time and get things done quicker than we have been doing. We need to push the prototype out to the market as soon as possible because the empathy drawn on the prototype is as important as the first empathy phase. We had been hearing this a lot in the theory, but the need was much more evident when we actually did it."* Hence, while the time constraints were a factor that really challenged the students, it was a learning opportunity where students could feel a sense of achievement in mastering the challenge despite the demanding time limits.

4.2. Developing tangential skills

As presented above, the challenges that the students met were demanding, but also a foundation for learning. There were many reflections on this in the data, but the main categories turned out to be embracing empathy, thinking and acting differently, working in teams, communication skills, networking and handling ambiguity and uncertainty.

4.2.1. Embracing empathy

Throughout the essays and diaries, there are compelling indications that learning about and practising the empathy skillset was a central feature of the course. When discussing empathy, several students coupled it with their take-aways. For example, *"… I really think that any business, or person for that matter, is lost without empathy to either customers or other people, may they be co-workers, employees, friends or just random people. The importance of being able to put yourself in the shoes of another person and trying to see things from her perspective, is priceless"*. Another highlighted: *"Looking back, I cannot really see how I did not make the connection at once. Now, it is so clear, so obvious; the key to making powerful innovations is understanding and addressing human needs."* The students' reflections illustrate that going through the design thinking process enabled them to embrace a human centred focus and its importance in the entrepreneurial process and other areas.

4.2.2. Thinking and acting differently

Another issue that emerged was how the students contrasted the design thinking process with traditional university education. For example, *"it was quite challenging to get rid of the scientific way of working with a problem and open up for creativity with no theoretical rules on how to solve this assignment"*. Several highlighted the dominance of the scientific method in previous education and that it was challenging to leave the idea of following strict rules for a predefined problem. Instead, they were allowed to define the problem area themselves and discover what the actual issues were, which made them question the limitations of traditional education. It was also experienced as a change of perspective to focus on creating value in the real world instead of focusing on academic measures. A student states, *"This was a really valuable experience for me, because it seemed like no one cared about their own grades; all they cared about was what value we could provide to [the Company]."* In terms of impact, one student writes in the learning diaries *"The insight for me this week is that design thinking process is really worth it. I really believe that it won't be exaggerating if I said this course is a life changing experience for me. It has changed the way I think and the way I look [at the world]."* Overall, the data from students paint the course in the light of having been a developmental experience for the most of them that has changed the way they see the world.

4.2.3. Working in teams

While many emphasized that working in teams was a major challenge, this is also highlighted as a learning opportunity to develop teamwork skills. Some teams worked quite well, and one student describes in the reflection diaries how this surprised her when she was the one holding the final presentation, and everyone stayed until late to help practice. She states *"This was an extremely unique experience for me, as I have always felt alone on presentations prior to this challenge, but now I really felt that I had the whole team in my back. They were amazing."* Many students describe how positive team experiences will guide how they work in teams in the future. Others had a more challenging time and reflected more on how they would do things differently in the future. One student describes *"Well I've become better at remaining calm and constructive in a very challenging team. Further, I believe it was confirmed that those who talk the loudest is not necessarily those who say the wisest things. If we as a group had made use of everyone's' knowledge, we would have come much further, and the solution would have been better."* The students were accordingly reflecting on their experiences, good and bad, and thinking about how they would focus on team dynamics in future studies and careers.

4.2.4. Communication skills

Several emphasized that they had developed their communication skills when communication took place within the team. In the reflection diaries, one student describes communication in the ideation process *"I learnt that communicating a lot in the group and adding up to people's idea can lead to ideas that would have otherwise been quite elusive. Sometimes, to me, it felt like I knew nothing about certain things. Then we did an ideation session where one of us had an idea and we all built up to that idea. In the process, new and supplementary ideas began to flow in dramatically."* However, communication skills were also challenged when aspiring to reach informants, doing interviews, as well as during the final presentation for the company. Students reported that they had trained and developed their enquiry skills. Many emphasized the challenge of gaining in-depth information rather than superficial information. In the first week, a student writes in his diary *"I learnt some techniques of drilling down while communicating. Building up a personal touch in communication might be quite fruitful while communicating. Starting up a communication with something exciting or catchy is often better to get the interest of the other person."* Hence, both communication within the team and communication towards external actors were highlighted as important learning experiences by the students.

4.2.5. Networking

Since the design challenge required students to make contact with people that were not connected to the course, many reported that they had made use of and advanced their networking skills. It also opened their eyes to the value of a good network when searching for information. A student had the following reflections in the second week of the reflection diaries *"The main thing I learned during this week was that I can receive much more information from the different people then I can [by] search[ing] by myself."* The students did not just advance their networking skills; they also reported having extended their network with fellow students, contacts in the company, and key individuals when searching for information outside the company. A student reflects, *"No doubt this course helped me to extend my network and I'm sure that it will bring result not only in a short-term outlook like obtaining the job but also in a long-term perspective."* The course appears to have enhanced their understanding of the importance of a network, contributed to their networking skills, and extended the students' networks.

4.2.6. Handling ambiguity and uncertainty

The design challenge was intended to put the students outside of their comfort zones, and this forced them to try to cope with ambiguity and uncertainty. In the reflection diaries, one student describes the beginning of the second week this way "*In the very beginning of this week I had the only one thought in my head: "I understand that I don't understand anything". It was like a mess."* However, as the course proceeded, many students also expressed the feeling of mastery in handling ambiguity and uncertainty as they learned to live with it. One student reflected upon this in her final reflection diary week: *"What I have learned will always be helpful in a real-life setting, accepting that ambiguity and uncertainty is not bad, that feeling demotivated and stuck is sometimes what you need to open your mind to other possibilities."* Hence, it seems that this student felt more prepared for dealing with ambiguity and uncertainty in the future after experiencing the design thinking course.

4.3. Developing knowledge

The design challenge introduced students to new technologies, industries, and methods. This was emphasized as an important aspect for developing knowledge in the students' reflections. The categories that emerged as especially important during the analysis process, was knowledge of the commercialization of technology and the design thinking process itself.

4.3.1. Commercializing technology

Getting to know a large technology company along with the satellite and finance industry was highlighted as an important experience in the course. Some describe acquiring new technological and industry insight *"But the fact that these satellites are orbiting around the earth in a different speed, depending on their altitude, was new to me. I think this industry is really exciting and especially when I feel that I learn new things every week."* More importantly, many of the students also reflected on the commercial opportunities that the technology could have and saw possibilities for value creation. Students were seeing opportunities for applying the company's technology for the aviation industry, environmental organizations and the farming industry. One student stated, "*I came to know that, among others, one good potential use of satellite images was to use it in agriculture to do precision farming. Here, the satellite images can be used to determine which part of a large tract needs more nutrition and which part is doing well".* Hence, while students were acquiring technological knowledge, they were also developing insight into how to commercialize technology within a corporate setting.

4.3.2. Design thinking as a method

The students' reflections on design thinking as a method focused on the tools or steps that were used during the course, as well as the philosophy behind it. Although the level of reflection varied, a vast

majority of the students showed good comprehension of the theory behind design thinking. They were not only repeating the theory back but were also critically reflecting on the reasoning behind it and its applicability. For instance, they interpreted the method in their own way with quotes such as *"I have concluded that design thinking is a sensational method that uses the discipline of the designer's sensibility to match people's needs with what is technologically feasible and what a viable business strategy with customer's insights can convert into products or services."* However, there were also some critical reflections on the use of design thinking. Some highlighted that it was not learning the process itself that was most important, but rather the skills they developed *by* using it. Further, there were also reflections about its appropriateness for different challenges, and one student described this in relation to the complexity of the challenge *"…this week I have learned some potential flaws in the Design Thinking process, and I have realized and learned more about our own mistakes and 'shouldhaves'. For starters, the time restriction in the Design Thinking process didn't quite fit with our challenge."* However, in general, the students highlight the value of design thinking as an alternative to traditional teaching and problem solving methods. One student summarised this as *"The design thinking methodology is not a linear process where you start in one end and keep on going straight forward until you hold the finished product in your hands. You will have to go back and forward between the different stages of design thinking, and make changes to the idea and prototype."* The iterative process and the customer focus appears to have made an impression on students, and several also emphasize the focus on taking action and failing quickly as a new insight for them, as opposed to spending large amounts of time on planning before taking action.

4.4. Seeing real-life application

When discussing real-life applications in the reflection diaries and essays, students focused on how the design thinking process could be relevant for them in current jobs, future jobs, in extracurricular activities, and even in their private relationships. That students were immediately and voluntarily applying lessons learnt to their personal and professional lives stands out as an important impact of the course.

4.4.1. Career

Several of the students saw a potential for applying what they had learned in the course in their present or future careers. This concerned both the skills they had acquired, as well as the knowledge of technology, commercialization and the design thinking process. One student wrote in the final reflection diary week *"we can apply the things we have learned this week in our daily work when we read a lot of information and we have to use only the most important. We can prototype everything we want from an idea to a new product or business. After this project we have more knowledge about the process, and we could apply it for every new project or idea."* Others saw the potential of using insights from the course in their current start-up *"The innovation process is about giving the customer what they need by first defining what this actually is. This was very useful, and I will use it myself. It is apparent that you get a lot of insight if you dare to contact the right people and ask 'stupid' and clever questions."*

4.4.2. Everyday life

The students also saw potential for using what they had experienced in everyday life and some reported doing so both during and after the course. In the reflection diaries, one student writes, *"Also, the course has been quite influential for me as it has got me looking for rooms for improvement in everyday life. From idea of having a foot stand on the back of seats in public buses where passengers sitting can put their legs on, to installing a bus schedule at the airport, I've empathized and found out what problems users are facing and what could be done to comfort them using some tools of design thinking process within my mind."* One student had already used the design thinking process in discussions at a parent meeting at her daughter's school, while others emphasized their training in communication skills was valuable for personal relationships in general *"Generally, ability to listen the other persons and ask right questions can help not only in the professional environment. These skills are absolutely necessary both in marriage and in the other areas of our lives."*

5. Discussion

Reviewing the results of the students' reflections demonstrates that they have learnt both the design thinking process and acquired knowledge about how to commercialize technological opportunities. This is perhaps not surprising since knowledge of these topics was specified as a learning outcome in the course description. It is an important insight that students confirm this in their reflections, but it was also something that could be expected due to the course description.

The part that seems to have been most significant for students is real world learning, which might also be considered as a tangential benefit of participating in the class. This is demonstrated through learning what we label as tangential skills. Students report that they have embraced the concept of empathy during the process and learnt to take and understand others' perspectives. Further, they describe improvements in their communication skills, their networking skills, and their team working skills, and feel more prepared to handle ambiguity and uncertainty in the future. Finally, students state that the course experience has actually changed their perspective and taught them to think and act differently. Several describe this as a contrast to other courses in their degree, where they are used to pre-defined problems with rules to follow in order to solve them. There were no structured learning activities targeted specifically at acquiring these tangential benefits. Rather, they seem to have appeared as a result of the experience itself and the context it took place in. These tangential skills are similar to the entrepreneurial competencies described in the EntreComp framework (Bacigalupo et al., 2016) which are essential in the 21st century job market, especially for engineers and scientists who are expected to contribute to developing new and improved products and services (Duval-Couetil et al., 2012; Vest, 2005). Newly qualified engineers and scientists will not meet pre-defined problems that traditional analytical approaches to education have tended to focus on, but will face ill-structured challenges where novel solutions must be developed. Hence, the skills identified by students in this study are exactly those that industry are calling for in new graduates. Industry will require workers who are not only technically competent but have human skills. Design thinking in this context has demonstrated that it can be a fruitful training ground for teaching such skills in a technological environment and thereby introducing so called soft skills to students of hard sciences. The students' reflections provide encouraging support for the claims made by those pushing design thinking as a pedagogy for training business, engineering and science students of the future.

The tangential learning that has occurred here is consistent with results reported from other types of experiential learning in entrepreneurship education (Täks et al., 2014). This fact raises the question, are the positive results experienced from a design thinking methodology specifically related to design thinking, or are they results that are the consequence of students taking a greater cognitive ownership of their learning through active experimentation, concrete experiences, reflective observation, and abstract conceptualization as described by Kolb (1984). Our findings do not suggest that design thinking is *the* best way to teach entrepreneurship, but rather as one of the approaches that appears to support the development of entrepreneurship skills, as well as several generic skills through tangential learning. Yet, the findings suggest that this particular course enabled students to develop these skills, *while* acquiring a user- and human-centred perspective when solving commercialization problems for technology. Entrepreneurs, and scientists and engineers alike, should strive to create opportunities by understanding the perspectives and latent needs of people they are designing for (Dunne and Martin, 2006; Neck et al., 2014). Design thinking is particularly valuable to promote

this, as it places the user at the centre and encourages students to understand users' needs, acts and thoughts on a deep level (Nielsen and Stovang, 2015). We observed that some students struggled and felt uncomfortable, especially at the beginning of the process, to engage with users and stakeholders. However, towards the end of the course students appeared much more comfortable in this process of finding user needs, which suggests that they have acquired a more human-centred perspective for the technology they were working with. The student's engagement in the task appears to be consistent with them being on a “mission” as described by Amabile and Kramer (2011). Whereby the combination of an important task and time pressure combines to result in creative work. Balancing this sense of urgency so as not to be overwhelming appears to have been a delicate task that the teacher has actively managed.

Another important finding from the reflection material is the fact that the students are not only repeating theory and describing experiences, but are reflecting on underlying principles, critically evaluating the knowledge, and are seeing applicability for the learning experience beyond the course. They describe application both in their everyday life when noticing disharmonies that can form the basis for entrepreneurial opportunities (Blenker et al., 2011), as well as in their present careers and in their vision of their future careers. In the words of Marton and Säljö (1976), the students appear to have moved beyond surface learning and approached learning at a deeper cognitive level. In fact, for several of the students the learning appears to have been transformational as described by Mezirow (1991). They describe their new insights as something that has changed how they view themselves (psychological transformation), how they see the word (convictional transformation), as well as how they actually act (behavioural transformation).

Finally, the challenge aspect of the course received substantial attention in the students' reflections. Traditionally, it has been considered that the teacher's role should be to make learning as easy as possible for students in order to motivate and engage them. The students' reflections tell an alternative story. The reflections emphasize the difficulty the challenge provided to them, and nevertheless describe their motivation and engagement in the task. Hence, it appears that the students found it valuable exactly because it was challenging. By introducing them to a demanding challenge that combined a technical topic with a commercial focus, it has forced them to grow as individuals by rising to the challenge. This is an aspirational outcome for a course, suggesting that students might experience personal growth, and is demonstrated here by quotes from students saying that they will take the learning experience with them for the rest of their lives. One of the ways that we grow as individuals is by having small crises and learning to overcome them (Dweck, 2008; Erikson, 1980). However, developmental experiences do not need to be as profound as a mid-life crises or religious conversion in order to bring about developmental experiences (Krueger, 2007). The course seems to have been an example of how challenges might be used as a form of learning experience. Discussions with the teacher leading the course suggested that this sense of challenge was something he created intentionally, with an awareness that it would force students to rise to the challenge. As described by Sidhu and Deletraz (2015), the course pushes students out of their comfort zone and into the challenge zone. However, if students move too far from their comfort zone, they may end up in a panic zone, feeling overwhelmed and resulting in a negative learning experience. There were indications of this at the beginning of the course, where students described both psychological and physical stress. At the end of the course, most students appeared to have come to terms with the challenge and reported that they felt a sense of achievement. However, for educators it is important to find the right balance between challenge and mastery in such courses. Students may need a push out of the comfort zone, but there should also be a level of support to avoid the panic zone, as well as opportunities for reflection. Reflection is a key component to transform experience into knowledge and can, according to Hägg (2017), counteract cognitive overload that may arise when novice learners are introduced to complex problems. Seeing that the assessment in the course was a reflection essay, teaching reflection through structured learning activities is something that could be more emphasized in such courses in order to avoid the panic zone. The real world of entrepreneurship is demanding, as is the workplaces for scientists and engineers. Thus, pushing students out of their comfort zone in a safe educational setting can contribute to preparing them for the real world.

Hence, through the design challenge, the students have developed knowledge of the design thinking process, the commercialization of technology and have acquired tangential skills. Although, no student specifically stated having developed an entrepreneurial mind-set, there is ample evidence that this has occurred. Their ability to look for opportunities for the application of technology, and to identify which might have commercial potential comes through as themes in the above findings. An entrepreneurial mind-set is defined as the ability to rapidly sense, act, and mobilize, even under uncertain conditions (Ireland, Hitt, & Sirmon, 2003). This closely describes the process the students went through during the course, starting with unclear instructions, sensing potential opportunities, following those up with potential customers, gaining feedback and synthesising this into a coherent understanding of the commercial applications of a technology. This approach is the kind of entrepreneurial mind-set that will be required of engineers working in industry in the future. They will need to be able to sense where the commercial value lies, to quickly prototype such ideas, and work within interdisciplinary teams to generate results (Duval-Couetil et al., 2012). It is important that students practice working in such a setting. The course appears to have provided the arena to do so, and the students appear to have been engaged and to have enjoyed the opportunity to learn in this manner.

6. Conclusion

Design thinking has been suggested as a promising approach to teaching within entrepreneurship education. This study aims to add to the limited body of research on this topic by investigating how students reflect upon the experience of participating in a course that combines entrepreneurship and technology through design thinking. The data suggests that students found the course valuable and engaging. Four main findings emerged. First, the students highlighted their development of knowledge and skill as an important part of the experience. The reflections emphasized development of knowledge regarding the commercialization of technology, as well as of theoretical aspects of design thinking as a method. Further, much of the learning was tangential in nature, and was therefore based on developing generic skills such as teamwork, interpersonal communication, networking, empathy, changing ways of thinking, and gaining experience with ambiguity. Another important finding was that the students felt that much of the value stemmed from the challenge that the course represented. This might be somewhat counter intuitive, as making learning easy appears to be a more natural approach. However, students found the challenge to be of value in itself. Finally, the students appeared to have gone beyond superficial learning, as it appeared to have been deep and transformational. Students reported that they were thinking and acting differently due to things they had learned in the course and were also seeing potential for applying what they had learned in real life and their future careers.

The findings provide novel insight into students' experiences and reflections during and after participating in a course, which combines technology and entrepreneurship through design thinking. Our findings have implications for how science and engineering students can be taught about entrepreneurship in an engaging manner. While traditional entrepreneurship courses can be something that feels unfamiliar for students in these areas of study, they might feel more at home in a course with a technological context that challenges them to find commercial opportunities for the technology. Hence, students learn that

entrepreneurship is not only about starting a new venture but can also involve corporate entrepreneurship in existing companies. The design thinking method provides an opening for learning to focus on the user of the technology rather than the technology itself, and thereby implies a change of perspective for study areas that are traditionally product focused. As a result, we believe that these nuances are important for educators to keep in mind when planning entrepreneurship education courses for science and engineering students, as well as for policy makers who aim to promote entrepreneurship and the development of generic skills within these areas of study.

The study is not without limitations. First, we acknowledge the challenge of using reflection essays that were part of the students' formal course assessment. To address this limitation, the data has been supplemented with weekly learning diaries that were collected only for the purpose of research and that were not accessible to the teacher. The data collection also included observations, access to course material and an interview with the teacher. Second, critical thinking was encouraged throughout the course and also in the reflection essays. Hence, the grading was not dependent on whether students were positive or negative towards the course, but rather on their abilities to reflect on their experiences. The reflection essays were written two weeks after the course finished. While the students had the course fresh in their minds when writing the reflection essay, it would be valuable to have follow-ups in future research to see whether the course impact was temporary or lasting. Moreover, we acknowledge that the course in question is based on a particular approach to design thinking positioned within business education. As there are different approaches to teaching design thinking in higher education, empirical studies of other courses could provide other findings. Finally, this study was limited to one five-week course in a specific context. To further support the findings, it would be valuable to compare this course to other pedagogies used in entrepreneurship courses for engineering and science students.

Our study also suggests avenues for future research. First, there is a need for more studies on entrepreneurship education for science and engineering students in general, as the existing body of literature is scarce. Further, the potential for multiple case studies of entrepreneurship courses across different contexts is mentioned above, as it would allow for comparison of course characteristics, learning processes, and course outcomes. It would be valuable to understand if our findings are specific to this approach to design thinking or if they would be similar in courses applying different approaches to teaching design thinking or using other experimental learning pedagogies. Also, while our exploratory study indicates promising outcomes for this particular course, there are always opportunities for improvement. Introducing alternative assessment strategies beyond written essays and providing structured learning activities for developing reflective thinking could be some suggestions for course development. Following-up on such course changes could thereby be an opportunity for research. Moreover, the role of the teacher is a potential venue for further research. As the role of the teacher often is more a coach or a facilitator in such courses, more knowledge is needed on the teachers' perspectives and how this influence the way they are teaching. For example, how do they reflect upon challenging students to go out of their comfort zones? And are there differences in how someone from a design background and someone from a business background would teach design thinking? Finally, doing larger quantitative studies applying randomized or quasi-experimental design would enable generalization of the findings and could provide important insights into the impact of contextual factors such as culture, course duration, teachers' roles or team dynamics.

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