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an engineering education perspective

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Building technology entrepreneurship capabilities: An engineering education perspective

Kari Kleine, Ferran Giones, Mauricio Camargo, Silke Tegtmeier

Abstract

Although technology entrepreneurship has received increased attention in the near past, the link between entrepreneurship education and the transfer and commercialization of technology has not equally explored. In this study, we apply an inductive approach to investigate two cases of science and technology entrepreneurship education (STEE), we use documents and interviews to build each of the cases. Our findings suggest that open and problem-based pedagogical approaches are more applied in STEE related courses compared to regular engineering courses. Additionally, STEE benefits greatly from taking place in a practical context with access to support structures that assist in developing technical and business aspects of start-ups. The findings hold implications for research, educational programs, policy makers and entrepreneurs.

Keywords: science and technology entrepreneurship education, problem-based pedagogical approaches, practical context, interview and document analysis, engineering

1. Introduction

Much has been discussed on the changing role of universities in society, in particular when examining the contribution of universities to the economic growth and societal development (Audretsch 2012). The transition from universities as research centers to universities as innovation drivers has left many co-existing models in place (Schmitz et al. 2016), making it difficult to identify and articulate valid response mechanisms to new societal challenges.

The demand to respond to societal challenges contrasts with the research-focused nature of most universities that has traditionally left the role of technology innovation and entrepreneurship to other agents. Thus, the function of science and technology commercialization has often required the activation of specific actors such as Technology Transfer Offices (TTOs) linked to the government, universities, or research centers (Fitzgerald and Cunningham 2015). Prior research has identified the existent constraints to activate academic engagement, highlighting the distance between science and

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technology research activities with industry related innovation and entrepreneurship initiatives (Perkmann et al. 2013).

An alternative path to respond to the divergence between the new demands imposed by the societal challenges and the existing science and technology development focus of universities is to transform the educational programs being offered. Instead of aiming to modify consolidated structures through directed interventions, such as entrepreneurship incentives for established researchers, the efforts would be focused on building the student's skills and capabilities for technology entrepreneurship and innovation.

To study this alternative path, we explore the case of two European universities. Prior research has observed, compared to the USA, that in the European context there have been additional challenges and difficulties for successful academic entrepreneurship in the form of university spin- offs (Fini et al. 2016). Therefore, the exploration of alternative paths or mechanisms to promote technology entrepreneurship and innovation could be particularly relevant. We identified the engineering programs of two universities based in France and Denmark as two particularly suitable cases that serve the purpose of illustrating responses to the demand of activating science and technology education with a focus on science-based entrepreneurial activity.

The two cases of science and technology entrepreneurship education (STEE) share common elements, for instance there are similarities on the overall design, content, pedagogical methods, learning environment, and intended learning outcomes. Nevertheless, each program has specific characteristics in relation to those categories and unique features in driving STEE. A comparative analysis of the two cases provides insights on potential guidelines to structure programs that foster technology entrepreneurship through education and training.

Both programs, one at Lorraine University (UL) in France and the other at the University of Southern Denmark (SDU), were developed as a response to a strong demand in their region for professionals with an entrepreneurial mindset and engineering capacities. The regional actors see the universities as a collaborative partner for research and education in the field of science and technology. The strong connection with the region's industry becomes an influencing factor on the design and implementation of the specific approach to STEE.

The overall theme for the pedagogical model at UL and SDU is organized around the student-subject-project triangle. Supporting problem-based learning is the preferred approach. In more detail, the DSMI model (acronym for *Den Syddanske Model for Igeniøruddlannelser*) used at SDU requires that students work on problems proposed by companies in the region during their studies, introducing company visits and participation of company employees as guest lectures as part of the regular course activities.

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The development of attitudes towards entrepreneurial behavior is also activated through internal projects. For instance, as part of a master program, engineering students enroll in a business venturing course (the course receives different names in each institution), where either researchers or company representatives pitch their ongoing projects to the students. Those projects build then the basis for the ongoing course or semester focus. The course offers a safe environment to apply technology commercialization practices through a real case exercise; although the learning outcomes of the course are focused on analyzing and applying methods, the real-life outcomes have been the creation of student-lead start-ups in the region.

A significant catalyzer of the technology entrepreneurship education for both programs has been the creation of a specific learning environment and communities of knowledge and practice related to it. In the case of UL it has been the creation of the Lorraine Fab Living Lab, and at SDU the Innovation Lab facility. These communities in their innovation spaces become a centerpiece of the training programs as they have different properties compared to other engineering or research labs. Instead of replicating industry labs at a smaller scale, they are a tangible representation of the often-abstract entrepreneurship process. The intense use of these facilities in the educational programs aims to modify the self-efficacy perception of the students regarding the entrepreneurial behavior (Piperopoulos and Dimov 2014).

Taking this context into account we aim to investigate the phenomenon of STEE in these two engineering programs. This enables us to provide answers to the following questions: How is entrepreneurship education being introduced in engineering programs? What specific considerations are being taken into account and what are characteristics of current programs?

The key findings of our work are threefold: Firstly, the two educational programs show that a pedagogic approach that emphasizes interactive teaching and problem-based learning is mostly applied in STEE related courses. The respective program coordinators perceive that to be essential in involving the students and in motivating them to be proactive. Self-directed learning plays a fundamental role to complete the students' knowledge and skills by taking initiatives, based in curiosity, definition of learning goals and the identification of resources to achieve these goals. Secondly, creating a context where theoretical knowledge can be applied in a "real world" setting is crucial to achieve specific learning outcomes. These "real world" collaborative projects serve as a staging ground where the specific knowledge acquired in scientific modules finds practical sense and feeds the emergence and improvement of new concepts. At the same time, within those projects, students learn to manage the complexity of dealing with compromises between technical implications, human resources and business aspects. Thirdly, it is important to provide the students with self-directed access to communities of knowledge and practice and innovation spaces. The

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collaboration with such incubational infrastructures allows students to demystify the difficulties and challenges of taking entrepreneurial risk and enhances their motivation to pursue own start-ups. This happens through an increased awareness of methods, tools and competences that enables them to overcome challenges, which they otherwise would perceive to be beyond their capabilities.

Following this introduction, we will provide a reference framework for science and technology entrepreneurship education. This includes the reasoning for the research questions that guide our work. Then we describe the method we pursued. As the aim is to provide illustrative examples that can be used as a guide to propose alternative paths to activate technology entrepreneurship, we will then present findings related to the two cases we have investigated. To finish, a discussion section that includes implications for research and practice is proposed previous to our concluding remarks.

2. Reference framework

The debate on the role of universities in the generation of innovation and entrepreneurial activity remains an active subject of discussion. The concept of an entrepreneurial university with the mission of "creating, disseminating and applying knowledge for economic and social development" (Schmitz et al. 2016, p. 17) signifies the evolution of the role of universities in society. Furthermore, this debate is now moving towards the idea that in an entrepreneurial society the university mission will also be to "contribute and provide leadership for creating entrepreneurial thinking, actions, institutions, and entrepreneurship capital" (Audretsch 2012, p. 314).

The broader and extended expectations on the universities' contribution to innovation and entrepreneurship has been responded to with the introduction of new educational programs and entrepreneurial activities in the academic setting (Anne Støren 2014; Kuratko 2005). There has been a diversity of approaches in both the introduction and delivery of entrepreneurship education programs, and in the activation of entrepreneurial activities. While entrepreneurship education approaches range from teaching about what entrepreneurs do, to actually helping students learn how to think and behave as entrepreneurs (Neck and Greene 2011); entrepreneurial activity in universities has been promoted with a diversity of initiatives such as support mechanisms to knowledge and technology transfer using TTOs (Fitzgerald and Cunningham 2015), or the introduction of academic entrepreneurship programs (Meoli and Vismara 2016; Perkmann et al. 2013).

The disconnection between the entrepreneurship education and the entrepreneurial activities in the academic setting is particularly relevant in the science and technology fields. Although entrepreneurship and innovation courses have gradually moved beyond business management programs, we still know little on the impact that specific pedagogic approaches might have on science and technology students (Nabi et al. 2016). With notable exceptions (see Souitaris et al. 2007), we

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know much more about the impact of different approaches on business or management students (see Piperopoulos and Dimov 2014) than of those pursuing engineering or other technical studies. Similarly, research on academic entrepreneurship and technology transfer activities has often overlooked the participation of students, and their training, in the innovation and entrepreneurship activities (Siegel and Wright 2015), focusing instead on the involvement of faculty members and their efforts to disseminate knowledge and new technologies to the society.

We aim to address this research gap by exploring how universities have introduced entrepreneurship education programs in science and technology fields, focusing in how they balance the duality between scientific knowledge and entrepreneurial education. We review recent research findings on entrepreneurial education to complete the theoretical framework that guides the analysis of a selection of engineering educational programs.

2.1 Advances in entrepreneurship education

The field of entrepreneurship education has matured and gained legitimacy in the last decade and it has also gained centrality in the curriculum in education programs across disciplines, as envisioned by Katz (2008). Although there is a diversity of pedagogical approaches and program designs labelled under entrepreneurship education, the maturity in the field has also made visible preferred approaches that would fit better with recent years' research insights. Two dominant characteristics of these programs are the focus on learning to behave like an entrepreneur (Neck and Greene 2011) and the use of action-based learning approaches (Rasmussen and Sørheim 2006).

As entrepreneurship education programs have progressively abandoned their attachment to the business plan as the core element in their curriculum (Honig 2004), a shift in the expected learning outcomes has also occurred. Learning about entrepreneurship or the characteristics of entrepreneurs has become a marginal part of modern courses, instead it is now more common to dedicate time to achieve learning outcomes related to developing skills and competences related to entrepreneurial thinking and decision-making (Neck and Greene 2011). The evolution in the content of the program also reflects the progress in entrepreneurship research; Thrane et al. (2016) describe how the entrepreneur-opportunity nexus reconceptualization (Davidsson 2015) impacts the present and future educational programs. Thrane and colleagues argue that educational programs should aim to follow an entrepreneurial learning process, focusing on the building blocks of entrepreneurial identity, opportunity creation, and the activation of the new venture (Thrane et al. 2016).

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The second interrelated aspect is the introduction of action-based learning approaches. Thus, we have seen a migration from passive to active entrepreneurship education programs. The traditional teaching, with a passive involvement of students, was suitable for knowledge learning outcomes related to studying what entrepreneurs do. To achieve learning outcomes related to thinking and behaving like entrepreneurs, the activation of the students becomes a central aspect of the educational program (Rasmussen and Sørheim 2006). Again, such changes in the pedagogical approach go hand in hand with research insights on entrepreneurs' behaviours, habits and heuristics (Aldrich and Yang 2014). The active-learning approaches have opened also the door to the introduction of specific contexts for entrepreneurial learning. As observed also in research, context has an influence on the activation of entrepreneurial behaviour (Autio et al. 2014). Therefore, it is not surprising that specific learning contexts provide a more or less favourable environment for entrepreneurial learning; in fact, recent research is already exploring how specific spaces (such as "maker" spaces) might impact entrepreneurs' actions and decisions (Mortara and Parisot 2017, 2016).

As entrepreneurship education keeps being transferred to new fields, new questions and challenges emerge. A potential concern is to ensure that the best practices in entrepreneurship education are visible enough when educators aim to adapt existing programs to a new context or field. We aim to explore the specific challenge that science and technology engineering program coordinators face when they aim to bring entrepreneurship into their curriculum. How is entrepreneurship education being introduced in engineering programs? What specific considerations are being taken into account and what are characteristics of current programs? To answer these research questions we study two cases of engineering programs that educate science and technology entrepreneurs.

3. Method

We identified two engineering educations that focus on science and technology entrepreneurship within their curriculum. One program is the "Master Sc. in Engineering – Innovation and Business" at the University of Southern Denmark and the other one is the "Master Sc. Global Design – Management of Innovation and Design for Industry" at the French Université de Lorraine.

As our research questions aimed to provide answers to specific characteristics of educational programs that have not been investigated regarding STEE prior to this study, we considered it to be appropriate to use a document analysis and interviews with program coordinators as research method. Since these programs have not been analysed before and we intended to make an in-depth analysis of them (addressing mainly the "how" and "why"), we assumed that an inductive qualitative research method is appropriate (Edmondson and McManus 2007; Eisenhardt 1989). We therefore focused on a

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methodological approach that enabled us to identify the specifics of the educational programs and their STEE related courses such as general content, job profiles, competences and applied pedagogical approaches in detail. Further, we intended to identify key characteristics of the programs that foster science and technology entrepreneurship education and to investigate commonalities and differences of the two cases.

We proceeded as follows: first, we analysed the official documents of the two faculties that describe the programmes and teaching approaches in detail. This includes curricula, syllabi and documents on teaching models of the respective universities. We identified major concepts related to STEE in the documents and sorted the available material accordingly. This produced the following categories: pedagogical approach, learning processes, program objectives, job profiles, core competences, knowledge, skills, courses and content.

As the documents cannot tell us in detail how these categories apply in practice, we triangulated the identified content with semi-structured interviews of the program coordinators of both programmes (see appendix 1 for the interview guide). The interviews revolved around the major themes previously described and were organized accordingly: introduction and framing, job profiles, pedagogical approach and learning processes, program objectives and learning outcomes, program structure, program content, teaching staff and assets. In total, the interview guide contained 32 open- ended questions. Open-ended questions find suitable application in exploratory research as recommended by Edmondson and McManus (2007). The audio-recorded interviews, which lasted 58 and 59 minutes, were transcribed and content-analysed by an iterative approach of inductive category building as well. This allowed a triangulation of the data gathered in the document analysis and allowed to simplify focal categories to the following: general content, job profiles, competences and pedagogical approaches.

Although the documents and the interviews provided us with large amounts of data on the two educational programs, we are currently in the process of establishing other units of analysis in investigating this context by interviewing current students and teaching staff of both programs. This will allow a more in-depth understanding of the program specifics in relation to STEE and will serve to evaluate current findings in the future. Other focal groups are alumni that have gained professional experience or launched a start-up after completing their education at one of the two programs.

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4. Cases

This chapter will give a brief introduction to the context of the two educational programs at their respective universities before identifying commonalities and differences in relation to STEE. We conclude this chapter by providing an overview over the key findings, which serves as the basis for the subsequent parts of this study.

4.1 University of Southern Denmark: Master Sc. in Engineering – Innovation and Business

The University of Southern Denmark (SDU) is a multi-campus university with approximately 30 000 students and 2 000 researchers. The educational program "M. Sc. in Engineering – Innovation and Business" (hereafter named IB) is located at campus Sønderborg in Southern Denmark and is taught in the English language. The hosting section is SDU Technology Entrepreneurship and Innovation which is part of the Faculty of Engineering. Courses contain usually 15 – 25 students and the 2-year master education consists of 120 points according to the European Credit Transfer and Accumulation System (ECTS). A specific characteristic of the program is the high degree of internationality and the interdisciplinary nature of study collaboration as the students have completed an engineering degree in different disciplines in various countries on bachelor level prior to being admitted to the master program. Courses focus in general on either business or engineering aspects or a mixture of both. In line with local industry and the general research focus of the technical institute, there is an emphasis on Mechatronics in the engineering courses that are part of the education. The program has been the starting point of several student driven technology-based start-ups in recent years since it provides substantial support to start-ups through various incubators. Although this is not defined as a success criterion in evaluating the educational program, it serves as an additional incentive for investigating this education and its context.

4.2 Université de Lorraine: Master Sc. Global Design – Management of Innovation and Design for Industry

The University of Lorraine is likewise a multi-campus university with approximately 52 000 students and 3 800 researchers. The educational program "M. Sc. Global Design" has a specialty named MIDI ("Management of Innovation and Design for Industry"), is located at campus Nancy in Eastern France and is taught in the French language. The hosting department is the ENSGSI, "Ecole Nationale Superièure en Genie des Systèmes et de l'Innovation", which is part of the Engineering College. In average courses of 25 – 30 students, the 2-year master education consists of 120 ECTS.

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Similar to the IB education at SDU, there exists a high degree of internationality and as the students have completed engineering degrees in different disciplines in various countries on bachelor level prior to being admitted to the master program, study collaborations are often of a very interdisciplinary nature. In general, there is a course emphasis on business, design or engineering aspects or a mixture of them, which corresponds to local industry and the general research focus of the ERPI research laboratory (Research Team on Innovation Processes), which is an industrial engineering lab focusing on innovation. The MIDI program produces several student start-ups every year and provides substantial support to start-ups through various incubators.

4.3 Case commonalities and differences in relation to STEE

In line with the semi-structured interview guide there has been a strong focus on STEE related aspects of the educational programs. The following will investigate both commonalities and differences in the program cases. Corresponding to the primary focus of this study and as the analysis of documents and interviews delivered large amounts of content for the categories "general content", "job profiles", "competences" and "pedagogical approaches", they have been summarized in a table format. Other significant findings will be described in text form before the key findings are synthesized in graphics which will conclude this chapter.

In describing the general purpose of their respective education, the IB program coordinator stated the following: "*The basic idea was always to create growth in the region by having more start-ups, […] we also just educate engineers for the industry, but with the kind of an entrepreneurial mindset more or less, so they can go into companies and still be the creative employees who then benefit the organization*." The general focus on educating both entrepreneurs and employees for various tasks in industry was similarly mentioned by the MIDI program coordinator. Another similarity that both interviewees emphasized when introducing their programs was a strong focus on innovation and the implications thereof. The MIDI program coordinator said, "*By definition innovation processes are complex processes, you are dealing with multiple stakeholders; every stakeholder is autonomous, having different goals individually*". This statement is reflected in the description of competences of graduating students which follows subsequently.

Table 1 provides a comprehensive summary of the findings for specific core categories of the two educational programs. The table includes findings that resemble commonalities in both programs and differences that are listed separately for each program. It clearly shows many similarities and the interdisciplinary nature of the two approaches to science and technology entrepreneurship education.

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Table 1: Summary of empirical findings.

<table>
<tr><th></th><th>University of Southern Denmark: M. Sc. in Engineering – Innovation and Business</th><th>Université de Lorraine: Master Design Global – Management of Innovation and Design for Industry</th></tr>
<tr><td rowspan="2">General content</td><td colspan="2">- Holistic view on innovation
- Ideation and creativity
- Product development processes and prototyping
- Business models and market specifics
- Innovation as a contextual and complex phenomenon
- Real-life cases as the basis for semester projects with the objective of creating innovation</td></tr>
<tr><td>- Operations and manufacturing processes
- Internship in the form of an in-company period or an entrepreneurial training course</td><td>- Holistic view on technology systems in taking technology, competences and stakeholders into account
- Personal development
- Methodologies and tools for innovation
- Usability studies</td></tr>
<tr><td rowspan="2">Job profiles</td><td colspan="2">- Entrepreneurs
- Project managers
- Industrial engineers
- Innovation managers</td></tr>
<tr><td>- Consultants (primarily within IT)</td><td>- Product manager</td></tr>
<tr><td rowspan="2">Competences</td><td colspan="2">- Project management abilities
- Creating or adapting products
- Managing multi-disciplinary resources and implications
- Reflecting on the context of technologies and companies
- Integrating technical, managerial and human dimensions</td></tr>
<tr><td>- Starting up new businesses based on technical products
- Creating value propositions for existing or new markets and stimulating innovations in a given context
- Identifying entrepreneurial opportunities
- Group and team related dynamics
- Knowledge sharing across disciplines
- Taking responsibility for decisions and results</td><td>- Product development
- Design, launch and management of innovation projects in a practical context
- Design and operationalization of processes within a practical context
- Self-directed learning
- Flexibility and adaptability
- Creativity and an ability to manage creative processes</td></tr>
<tr><td rowspan="2">Pedagogical approach</td><td>- Open and interactive learning
- Active involvement of students through exercises, project work, etc.
- Dialogue-based teaching</td><td>- Self-directed learning
- Problem-based learning
- Learn to learn</td></tr>
<tr><td colspan="2">- Involvement in projects with “real-life” context
- Input from multi-disciplinary sources
- Offering advice for entrepreneurs through collaboration with external partners (both on a business and a technology level)</td></tr>
</table>

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According to the program coordinators there is no specific teaching staff utilized in STEE related courses. Rather lecturers are typically researchers of related fields and although the pedagogical model defines a certain approach, the lecturers are free to apply it according to their preferences. At both universities training programs are available that facilitate tools and methods to apply open and problem-based teaching that engages students to participate actively and relate knowledge to practical contexts.

Students are in principal free to pursue start-ups during their studies. While the IB program coordinator mentioned there is nonetheless a conflict of interest and a time management issue if they decide to launch a venture during the studies, the MIDI program coordinator stated that students in their program are encouraged to engage in start-ups should they desire to do so.

4.4 Key findings in relation to science and technology entrepreneurship education

Based on table 1 and the emphasis of the program coordinators, there are three key findings that will receive more attention in the following and simultaneously build the foundation for the contribution of this research.

4.4.1 Pedagogic approach in STEE related courses

A pedagogic approach that encourages interactive learning, active involvement of students and self-directed learning is more applied in STEE related courses compared to pure engineering courses and is of special importance according to the interviewees. In explaining why self-directed learning is important, the MIDI program coordinator stated, "*There is one philosophy behind our pedagogy; that is learn to learn. And as you´re able to address your self-directed strategy, so you are more able to be adaptive*. […] *You must be able to learn new things, because every single day new tools, new approaches are available, so you have to be able to learn.*" The interactive teaching approach can be put into practice in different ways. According to the IB program coordinator, "*You can do this interactive teaching in many, many ways, it is just that you understand, how can you create exercises, how can you use, for example online systems to facilitate a learning process, whatever you can use in order to make the students think and reflect, instead of just lecturing like feeding the students*." Figure 1 includes the pedagogical approach as a dimension and illustrates the key finding that active involvement of students is higher in technology entrepreneurship related courses than in pure engineering courses or practical engineering exercises.

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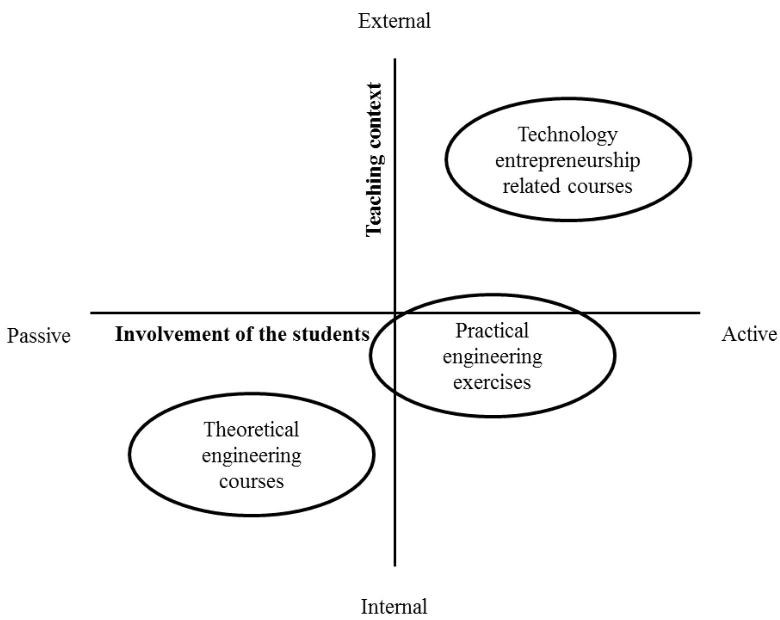
4.4.2 Context is of high importance in STEE related courses

Both program coordinators stressed the importance of "real-life" projects where theoretical knowledge finds application in a complex context in order to achieve specific learning outcomes. In describing some general but important learnings, the IB program coordinator explained, "*These general things are the softer things, how you interact with your group for example, if you work in a team later on, how do you deal with complexity, how do you take responsibility for your work, how do you organize your work and all these kind of things are things that you learn because you work in groups and you work on real-life projects and I think they are very important for the life afterwards*." The importance of real projects was also emphasized by the MIDI program coordinator when stating, "*There is interesting thinking, we´re working on an entrepreneurial project or more enterprise linked project so the students along the courses they have a project linked with a company, could be a start-up, could be an already existing company, but they have to create a new product, new services, new business model, so the fact that they interact with real companies, I guess let´s allow them to have a better understanding on the priorities of an entrepreneur and the dynamics in this entrepreneurial process. So participating in real projects is an important fact*." The teaching context is primarily internal in both theoretical and practical engineering courses. In contrast, technology entrepreneurship related courses are occurring in a much more external context as figure 1 illustrates.

Figure 1: Teaching context and pedagogical approach in the form of student involvement in different courses.



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4.4.3 The importance of access to communities of knowledge and related physical spaces

Both interviewees stated that access to communities of knowledge is critical in building STEE capabilities like creativity, prototyping skills and the ability to solve complex issues in specific contexts. Furthermore, physical spaces facilitate access to those communities through common use of machinery, joined projects or workshops or a stimulating collaboration environment. When asked about support structures for students that pursue a start-up, the IB program coordinator stated the following: "*We collaborate with different external organizations, public organizations or incubators where there is the possibility to get support or getting a mentor. So there is access, we kind of tell them about the possibilities.* […] *And in this network or in this incubator environment there are other companies that are also technical. So you get kind of access to a network through these incubators so there you could get your technical sparring basically*." Using suitable physical spaces like Fablabs or SDU´s Innovation Lab and connected communities enables students to solve issues they perceive to be beyond their capabilities. The MIDI program coordinator stressed especially the importance of communities of knowledge and practice: „*Space matters, it´s important, having machines is important, but it´s not the most important thing for me. For me the most important is having communities of people working in those spaces.* […] *The same space is shared by communities and as far as we have problems, sometimes we go through these communities, because you know the competences are not the same.* […] *So next we are sharing competences and helping each other. For me that is the secret.* […] *So this crosslinking of communities is so important!*" While the educational program at SDU involves mainly one external partner in offering additional advice for student entrepreneurs, the MIDI program utilizes three different communities that the students gain access to. Both programs offer laboratories for product development, access to machinery, etc. in similar extent, although the MIDI program has access to larger relevant infrastructures.

Figure 2 compares the IB program at SDU and the MIDI program at UL regarding the dimensions of involvement of incubators and laboratories as well as the overall ratio of courses with a strong relation to STEE. In the MIDI program the ratio of STEE related courses in the context of all courses is approximately 30%. For the IB program the ratio is at least 30% and can reach up to 60%, depending on electives chosen by the students.

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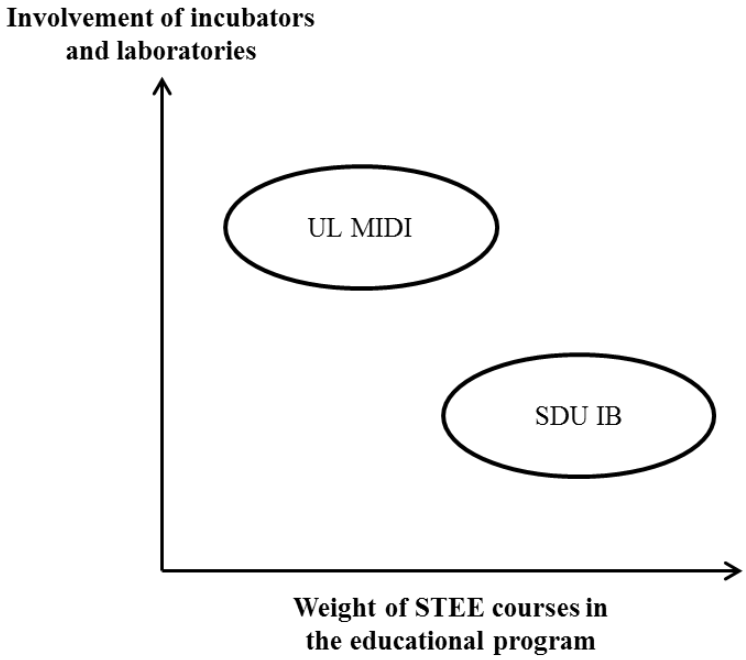
Figure 2: Comparison of the MIDI and the IB programs regarding involvement of incubators and laboratories in educational activities and the weight of STEE related courses in the educational programs.



5. Discussion and implications

The development of entrepreneurial education has been accompanied by the introduction of entrepreneurship training in a diversity of programs and scientific fields. The evolution of entrepreneurship education research has brought evidence to the adequacy of action-based approaches where the student takes a central role in driving the learning process (Rasmussen and Sørheim 2006). As a result, this is now considered as the first option design for new entrepreneurship courses. Our research findings suggest that as entrepreneurship education has been transposed to new education and training fields, such as engineering programs, there have been unexpected consequences for both the overall education program design and the students learning outcomes.

First, the introduction of action-based approaches, popular now in entrepreneurship but not so much in other science and technology fields, generates often a shock for the students. Engineering education programs still have a substantial number of courses that rely on passive engagement of the students, following a more traditional teaching model, where exercises or computer simulations are the closest that the student gets to reality. Action-based approaches favour the introduction of active learning activities that can occur in the classroom context, but also outside of the university boundaries; this puts the student in situations of high uncertainty, often without a clear final output in mind besides engaging with an iterative process to unlock the potential product-market fit of a new technology.

Second, the introduction of action-based training for entrepreneurship competences requires a

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supportive and collaborative environment. It is a different approach and in some cases, it requires a transition process, similar to the process of activating entrepreneurial cognition aspects (Gregoire et al. 2009). The students benefit from interactions with internal and external actors that help them to build self-efficacy perception on the entrepreneurial behaviour (Piperopoulos and Dimov 2014). An unexpected finding from the cases studied is the low degree of control that the faculty kept on the type and content of the interactions that the students had with internal and external stakeholders in their entrepreneurial activities. These generated unexpected results through the activation of unpredictable ideas, in a smaller scale, but we could argue that this is a process that resembles the construction of entrepreneurial social capital (Stam et al. 2014) in the context of an educational program.

Lastly, the interaction with individual but also groups of stakeholders is activated in specific contexts, helping the technology entrepreneurship students overcome thresholds in their learning process. Entrepreneurship researchers have been more and more interested in exploring contexts, from incubators and innovation labs to the more recent fab labs or similar experimentation spaces (Aernoudt 2004; Mortara and Parisot 2017; Moultrie et al. 2007). We observed that the education programs for technology entrepreneurship naturally bring in aspects such as structured design approaches and tools, prototyping, and other techniques that are common in engineering but not in business or management courses. The tangible and evidence-based approach to problem solving in the engineering programs enrich the transposition of action-based entrepreneurship training by further accelerating and making visible the learning and progress of the students. This is a promising contribution of technology entrepreneurship programs in science and technology to the overall entrepreneurship education research.

The findings of our study are built upon a small selection of cases as we narrowed our focus on two programs in Europe. Therefore, further research efforts to generate findings from other programs and other locations would enrich and complement the here presented insights. Additionally, other units of analysis (other actors) and their perspectives, e.g. alumni and teaching staff, should be emphasized in future studies. This would offer to the researchers a more comprehensive understanding of the impact and effect of specific approaches and contexts. Future research should also investigate the meaning of incubational infrastructures in the academic setting and characteristics and details of physical spaces and related communities of knowledge and practice in this regard. Another avenue for future work is the impact assessment of STEE through various measures that go beyond the reductionist measure of the number of technology start-ups

6. Conclusion

As universities take additional functions in their contribution to society, new challenges emerge. There

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is an increasing societal demand to universities, they should not only produce and disseminate new knowledge, but also generate entrepreneurial capital (Audretsch 2012). This demand introduces a novel challenge in the academic setting, where innovation and entrepreneurship are only starting to progressively permeate and transform the academic logics (Schmitz et al. 2016). Our study on how engineering education programmes are introducing science and technology entrepreneurship education is an illustration of this transformation.

The cases of two engineering masters in Europe suggest that the integration of science and entrepreneurship education benefits from a combination of pedagogical approaches. Our cases show that the education design focus shifts from the "what" to the "how" students learn. The STEE aims to build on the technical knowledge and skills of the students to then activate entrepreneurship competences. Therefore, the application of science and technical knowledge is done through the entrepreneurial behaviour, introducing a new source of uncertainty to students. This new source of uncertainty requires action-based learning, as the experiences that the students collect will be the driver of their learning. As learning becomes experiential, the context gains weight; our findings show how physical spaces become enablers of intense learning experiences, in particular if they are embedded in communities of practice. To sum up, the introduction of entrepreneurship education implies an overall revision of the teaching model of the engineering master degree; it is a revision that increases the weight on the use of external contexts and action-based learning, requiring a higher tolerance for uncertainty to both students and teachers.

The popularization of entrepreneurship education programs in universities is a global phenomenon. But the generation of high impact science and technology entrepreneurship remains an elusive goal. Policy makers have struggled to find the adequate mechanisms that could convert academic researchers into successful science-based entrepreneurs (Siegel and Wright 2015). Our findings support the idea that students can cover this gap, becoming science and technology entrepreneurs that bridge the new technological developments with application markets. As a result, STEE initiatives could render to policy makers part of the much sought-after impacts. However, STEE initiatives require (1) to introduce action-based pedagogical approaches that put the student in the centre and build on continued student to student and student-teacher interaction, (2) access to physical spaces (as learning setting) that enable individual experimentation of entrepreneurial activities and tasks with the involvement of external communities of practice.

Since science and technology entrepreneurship holds the potential of having a substantial contribution to society, policy efforts that support interdisciplinary education of science students to acquire, even if only partially, an entrepreneurial identity should have a direct effect on the generation of entrepreneurial capital in society.

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Appendix A: Semi-structured interview guide

- Introduction & framing
    - *In two sentences, how do you describe your educational program?*
    - *What are the general objectives of your educational program? Amount of start-ups as a success criterion?*
    - *What is your understanding of the term(s) "Science and Technology Entrepreneurship Education"? What is STEE? What is it not?*
    - *In general, how do you define the learning outcomes of STEE?*
    - *Are there any STEE related requirements for the students admitted to your educational program?*

- Job profiles
    - *Which job profiles are relevant for your educational program?*
    - *What are specific learning outcomes of STEE related courses that are relevant for those job profiles?*
    - *Which core competences are graduates supposed to possess at the end of the education in order to qualify for those job profiles?*
    - *Any other insights into knowledge and skills that graduates are supposed to possess?*

- Pedagogical approach
    - *Which pedagogical approach is being used/recommended in STEE related courses? Why?*
    - *Which teaching model(s) is pursued? Why?*
    - *How is that teaching model communicated and implemented? Are there any instructions on specific activities that are designed to implement that teaching model?*
    - *What could be the best and most appropriate pedagogies in STEE? Why?*

- Program structure
    - *How is the program structured? What is the underlying reasoning?*
    - *Structure wise: How to balance theoretical knowledge and practice-based knowledge in STEE?*
    - *Is there a specific learning process? How does the program structure correspond to it?*

- Program content
    - *Which content is communicated in STEE related courses? Why?*
    - *Which stages of entrepreneurship play a role in the educational program?*
    - *Are there any activities/courses that aim at identifying entrepreneurial opportunities? Are there any attempts to get the students "out into the real world"?*
    - *How does the education support the intentions & abilities to start-up a business after the educational program?* (investigate separately for intentions and abilities)
    - *Are there any specific activities that challenge students to pursue an actual start-up already during their studies? How is this supported through the program (structure,*

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activities, mentors, etc.)? Is it desired that students work on the education and their start-up in parallel? How do you deal with this conflict?
- *Content wise: How to balance theoretical knowledge and practice-based knowledge in STEE?*

- Teaching staff
  - *Is there specific teaching staff for STEE related courses? If yes, which one? Why?*
  - *Do you use mentorship? Technical or entrepreneurial?*

- Assets, etc.
  - *Which physical spaces/environments/assets are used in your educational program? Other labs, etc.?*
  - *What is the impact of those spaces/environments/assets? How does it affect entrepreneurial mindset, self-efficacy, etc.?*
  - *Do incubators/accelerators play a role in your STEE related courses? How about funding/investment contacts? Is there any financial support for creating technical prototypes?*
  - *What are resource implications for universities attempting to develop interdisciplinary STEE?*

- Conclusion
  - *What is the weight of STEE related courses in your educational program?*
  - *What are strengths and weaknesses of your program in relation to STEE?*
  - *What is the future meaning of STEE for your educational program?*
  - *What are the most important things in STEE in your opinion?*