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Citation for the original published paper (version of record):
Hagvall Svensson, O., Adawi, T., Lundqvist, M. et al (2020)
Entrepreneurial Engineering Pedagogy: Models, Tradeoffs and Discourses
European Journal of Engineering Education, 45(5): 691-710
http://dx.doi.org/10.1080/03043797.2019.1671811

(article starts on next page)

European Journal of Engineering Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ceee20

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To cite this article: Oskar Hagvall Svensson , Tom Adawi , Mats Lundqvist & Karen Williams Middleton (2020) Entrepreneurial engineering pedagogy: models, tradeoffs and discourses, European Journal of Engineering Education, 45:5, 691-710, DOI: 10.1080/03043797.2019.1671811

To link to this article: https://doi.org/10.1080/03043797.2019.1671811

Published online: 29 Sep 2019.

EUROPEAN JOURNAL OF ENGINEERING EDUCATION
2020, VOL. 45, NO. 5, 691–710
https://doi.org/10.1080/03043797.2019.1671811

Entrepreneurial engineering pedagogy: models, tradeoffs and discourses

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ABSTRACT

While entrepreneurship discourse is gaining traction in engineering and the number of entrepreneurship courses increase rapidly, there is a lack of study focusing on how and why engineering educators facilitate entrepreneurial experiences in their courses. Using a qualitative and inductive case-study approach, this paper explores and explicates pedagogical models for facilitating entrepreneurial experiences in engineering, and their underlying design principles. Investigating seven entrepreneurial project-based courses, three distinct pedagogical models for facilitating entrepreneurial experiences are identified. Two potentially conflicting dimensions are highlighted and argued as vital for educators to consider when implementing entrepreneurial experiences into their courses. These dimensions are: to make learning more personal, and to make learning more professional. The paper discusses how entrepreneurial engineering pedagogy is anchored in entrepreneurship education and engineering education discourse, and suggests means through which the two disparate streams of research can be integrated in order to further research on entrepreneurial engineering pedagogy.

ARTICLE HISTORY
Received 24 April 2019
Accepted 18 September 2019

KEYWORDS
Entrepreneurial engineering; entrepreneurship education; pedagogical models; entrepreneurial competence

1. Introduction

Given the growing complexity of engineering practice, increasing speed of technological change and need for innovative engineering in the face of global challenges, technical universities worldwide are under pressure to foster entrepreneurial competences among budding engineers (Byers et al. 2013). Entrepreneurial competences should be viewed as useful in any engineering career, not just for the formation of new ventures (Gibb 2002). This is the point of departure taken in this paper, which aligns well with what has been called a *broad* perspective on entrepreneurship education – enabling individuals and organisations to be creative and adaptive. This contrasts with a *narrow* perspective on entrepreneurship education – explicitly supporting start-up and small business management (Ball 1989). The European Union, a key agent in formulating policy for entrepreneurial education, has recently articulated the broad perspective on entrepreneurship education in terms of a set of entrepreneurial competences called the EntreComp-framework (Bacigalupo et al. 2016). EntreComp includes conceptualisation of competences in regard to, for example, working with opportunities (Alvarez and Barney 2010), managing uncertainty and risk (Sarasvathy 2009), and mobilising resources (Schumpeter 1942). Sense-making these competences in relation to the popular notion of the 'T-shaped' engineer (Tranquillo 2017), entrepreneurship

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and entrepreneurship education research can be viewed as providing conceptual and empirical resources to be considered when aiming to develop multi-disciplinary breadth in the engineering graduate (the horizontal bar of the T), complementing their technical knowledge and expertise (the vertical bar).

Kriewall and Mekemson (2010) argue that developing entrepreneurial competences in engineering students calls for a change in the way engineering is taught, and research shaping and evaluating this educational reform agenda has been recognised as 'a distinct field of research, which connects engineering education with entrepreneurship and innovation' (Rae and Melton 2017, 5). Burgeoning scholarship has put forth *entrepreneurial engineering pedagogy* comprised of taking-action, team projects, working with real problems, conceiving new solutions through design and collaboration with stakeholders (Creed, Suuberg, and Crawford 2002; Mäkimurto-Koivumaa and Belt 2016; Wheadon and Duval-Couetil 2017; Bosman and Fernhaber 2019). This echoes theoretical deliberations pertaining to the educational format in entrepreneurship education research (Fayolle and Gailly 2008; Neck and Greene 2011; Blenker et al. 2011), where experiential learning has been put forth as a key pedagogy for entrepreneurial competence development. Briefly, experiential learning emphasises (i) learner-controlled activities, (ii) engaging the learner's whole 'self', and (iii) using teaching and learning activities corresponding to real practices beyond the classroom (Boud 1989). Accordingly, this paper views entrepreneurial engineering pedagogy in terms of the enabling of entrepreneurial experiences in engineering curricula. In line with the ambition to develop entrepreneurial competences in all engineering graduates, entrepreneurial experiences should be integrated across the existing curriculum, rather than accessible to the small portion of students who themselves seek out elective courses or extra-curricular activities with explicit entrepreneurship focus (Streeter and Jaquette 2004).

Previous work has thoroughly highlighted that when facilitating entrepreneurial experiences, one-size does *not* fit all. Rather, entrepreneurship education need to be tailored to different contexts and learning goals (Mwasalwiba 2010; Wheadon and Duval-Couetil 2016). There is, however, limited study focusing on how engineering educators reason about instructional design choices and potential tradeoffs in entrepreneurial engineering pedagogy. This paper inductively explores *pedagogical models* engineering educators use to facilitate entrepreneurial experiences, and how these pedagogical models are motivated, including how potential tradeoffs are addressed. The discussion leverages insights from entrepreneurship education and engineering education research to provide theoretical support for the identified pedagogical models. In doing so, the aim is to offer an empirically-grounded and theoretically-informed tool to help educators to critically reflect on their own instructional design choices, germane to their own educational context, when designing courses geared towards facilitating entrepreneurial experiences.

2. Theoretical approach and research questions

As existing learning environments act as mediators for any educational reform agenda, studying classroom practice and educators' considerations has gained increasing recognition in research on educational reform (Spillane 1999; Curdt-Christiansen and Silver 2012). Goodyear (1999) describes two ways that educators can learn from other reform initiatives, such as course reforms. The first is:

> by examining the concrete objectives, actions and outcomes of another project and mapping them onto the objectives, intended actions and desired outcomes of one's own project. It is easier to do this if the mapping is close: for example, if the subject area, or educational methods, or learner profile is similar. The specific lessons learned by a project can speak directly to our experience as practitioners and innovators (p. 2).

Much of the extant empirical work on entrepreneurial engineering pedagogy is aligned with this first approach, based on a detailed description of single learning environments (e.g. Creed, Suuberg, and Crawford 2002; Soares et al. 2013). While in-depth examples of course reforms can be helpful, implementation of entrepreneurial engineering pedagogy is contextually bound and may vary substantially across specific cases (Sheppard et al. 2015; Duval-Couetil 2013). This may limit the applicability of frameworks for entrepreneurial engineering pedagogy for the individual engineering educator. Further, the first approach may obstruct proper evaluation of input-outcome relationships in impact studies on entrepreneurial engineering pedagogy. Goodyear argues that 'the extent of collective learning is limited by the lack of common theoretical frameworks within which projects can locate their goals, methods and achievements' (p. 2).

Recognising the methodological limitations of this first approach, Goodyear (1999) describes a second, more theoretically-oriented, approach:

> At some point we need also to make space for a more principled approach — for example, an approach which uses theoretical constructs as a framework for understanding educational action. *When we can see an apparently unique form of educational intervention as an instance of some broader, well-defined category, then it becomes possible for us to engage in more powerful and robust reasoning about what we are doing and what we have achieved.* All educational interventions can be seen as unique — but they can also be seen as variations on common themes (p. 2; our italics).

Such themes[1] can be understood as *pedagogical models* (Nunes and McPherson 2003).[2] The value of a pedagogical model lies in its capacity to mediate between theory and practice. It can therefore 'be used by practitioners as a framework for understanding educational action using a specific learning theory' (Nunes and McPherson 2003, 499). As such, pedagogical models act as an intermediate level between philosophical considerations pertaining to student learning (such as the nature of learning and cognition) and the concrete day-to-day teaching methods in the classroom, see Figure 1. A pedagogical model 'does not contain direct prescriptions for action, but it puts some forms of possible action into the foreground and others into the background' (Goodyear 1999, 5). Further, a pedagogical model should ideally offer examples of 'possible actions' – teaching and learning activities aligned with the model – so that it can 'speak to practice, but not trivialise what it represents' (Goodyear 1999, 1).

In relation to entrepreneurial pedagogy, Kyrö (2015) argues that going beyond posing 'what' and 'how' questions to also investigate 'why' questions – seeking an understanding of what knowledge

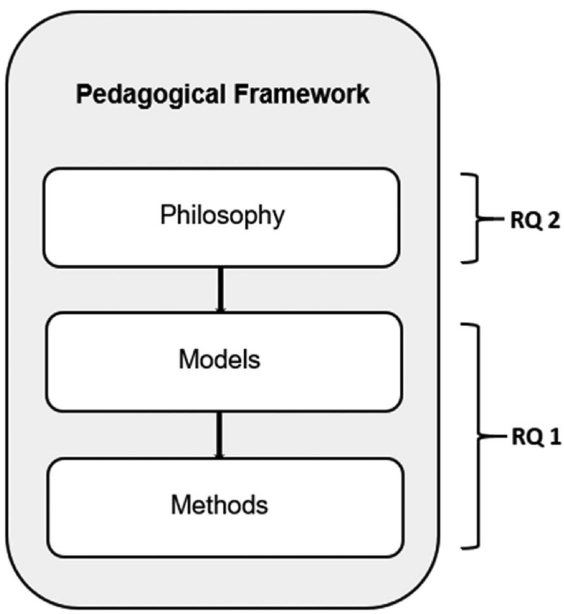

Figure 1. An illustration of the position of pedagogical models as a mediator between philosophical consideration of learning and practical teaching methods, with an indication of research questions aimed at different levels of a pedagogical framework. Adapted from Goodyear (1999).

and experiences are valued and how this mediates pedagogical choices – is critical but underexplored. Zappe et al. (2013) studied engineering educators' beliefs regarding essential competences engineers need to become entrepreneurs, and appropriate instructional practices in teaching entrepreneurship to engineering students – adopting a narrow and formal perspective on entrepreneurship education and only studying entrepreneurship courses. The present study furthers this nascent strand of research by adopting a broad perspective on entrepreneurship and entrepreneurial experiences across the whole engineering curricula.

Accordingly, in keeping with the theoretical stance on educational reform research as outlined by Goodyear (1999) and a broad perspective on entrepreneurship, the paper employs a qualitative case study approach (Merriam 2009) – involving seven project-based courses – to answer the following research questions:

(1) What *pedagogical models and methods* do engineering educators use to infuse entrepreneurial experiences into project-based courses?
(2) How do the educators *motivate* their instructional design choices in terms of the quality of the students' learning experiences, taking into account potential tradeoffs between competing aims?

To bolster the theoretical anchoring of models and instructional design choices, findings are discussed in relation to entrepreneurship education and engineering education research, as well as previous work related to entrepreneurial engineering pedagogy. The paper concludes with implications for educational practice and for research pertaining to a pedagogy which may foster entrepreneurial competences among budding engineers.

3. Methodology and methods

To address the research questions, a *qualitative case-study approach*, is employed. This approach 'is used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context' (Crowe et al. 2011, 1), and is widely used for explorative and theory-building research (Merriam 2009). A qualitative case-study approach is warranted when:

(a) the focus of the study is to answer 'how' and 'why' questions; (b) you cannot manipulate the behaviour of those involved in the study; and (c) you want to cover contextual conditions because you believe they are relevant to the phenomenon under study (Baxter and Jack 2008, 545).

Case studies can involve a single case or multiple cases. While the approach does not stipulate certain methods, interviews, observations, and local documents are staples commonly used for data collection (Crowe et al. 2011). It is often recommended to draw on multiple sources of data to bolster the validity of the findings (ibid.). In engineering education research, the case study has been identified as an emerging methodology with considerable potential to inform educational practice and decision-making (Case and Light 2011).

A *purposive* sampling strategy (Robinson 2014) was used to select cases, specifically courses and the associated educators. To select cases, course descriptions[3] for all courses ($n = 1\ 268$) offered at a European University of Technology were skimmed and classified, resulting in a sub-sample of 120 courses found as probable candidates for providing entrepreneurial experiences. The sub-sample was further examined, assessing for alignment with previous work on entrepreneurial engineering pedagogy. Courses were considered aligned when they were described as supporting student autonomy and reflection, working with real-world problems, making external connections, and designing new solutions (Creed, Suuberg, and Crawford 2002; Mäkimurto-Koivumaa and Belt 2016; Wheadon and Duval-Couetil 2017). To be consistent with the broad perspective of entrepreneurship taken in the paper, *entrepreneurial* courses rather than *entrepreneurship* courses was sought after. Courses with an explicit focus on entrepreneurship or business development were not given any priority (but were not excluded either, if they were assessed to be in line with entrepreneurial engineering pedagogy). Out of the 120 courses, 17 were selected, seeking variation across class-size, educational area, content and organisation. Of the 17 course educators contacted, 14 agreed to be interviewed. Interviews were used to gain a better understanding of how course activities were organised and scaffolded. (For more details about the design of the interviews, see the following section). As a result, seven project-based courses and the associated educators were included in the final sample.[4] The courses ranged in class size from 10 to 100 students and course credits from 6.0 to 15 credits. The projects in these courses ranged from more straightforward projects, such as conducting a user study and conceiving product requirements, to more complex projects, such as developing a technical solution in co-creation with an external actor, or even designing and building a racing car. A list of the seven courses, along with course details, can be found in Table A1 in the Appendix.

In the interviews, questions addressed the design of the courses, including the nature and purpose of the projects and more generally the alignment between learning objectives, activities and assessment. The interview protocol aimed to investigate the educators' reasoning around salient instructional design choices. Any major challenges they (or their students) experienced in running (taking) the course were probed into, in order to explore potential competing aims in the instructional design and the tradeoffs made by educators. Interviews were *semi-structured*, allowing each educator 'to express meaning in his or her own words and to give direction to the interview process' (Brenner 1989, 357). Each interview lasted between 50 and 90 min and was audio-recorded, with the most important sections transcribed verbatim.

The interview transcripts, along with relevant course documentation, were analysed using an *inductive thematic analysis* (Braun and Clarke 2006), a common analysis method in qualitative research. Here a theme 'captures something important about the data in relation to the research question, and represents some level of *patterned* response or meaning within the data set' (Braun and Clarke 2006, 82, italics in original). As the term 'inductive' suggests, themes are not theoretically deduced before the analysis, but are decided empirically, building from the pool of data. Multiple readings facilitated a closeness with the material. Further, the analytical process involved interpreting and labelling individual units of meaning in the data, producing codes. These were sorted and sifted in an iterative way, connecting similar codes, until a set of themes were discerned capturing much of the empirical material without significant overlap between different themes. In keeping with the research questions, the data was coded for (1) pedagogical models, (2) educators' rationale for instructional design choices, and (3) challenges they experience in running the course, including tradeoffs made in instructional design. Quotes from the interviews are used in the following sections to illustrate the themes, using pseudonyms for the respondents.

4. Findings

4.1. Pedagogical models for facilitating entrepreneurial experiences

Relating to the first research question, three pedagogical models for infusing entrepreneurial experiences into engineering education were identified in the sample of project-based courses: (1) learning through *student-framed and user-oriented projects*, (2) learning through *client-framed and student-driven projects*, and (3) learning through *co-creation platform projects*. These pedagogical models are summarised as follows. Table 1 provides additional and illustrative teaching and learning activities for each model, in keeping with recommendations for developing useful pedagogical models (Goodyear 1999).[5]

- *Learning through student-framed and user-oriented projects.* Students work in small teams and choose a project topic of their own interest, with the goal of conceiving a new solution or product in relation to a user or customer need, and to seek out actual users for input on the

Table 1. Three pedagogical models for infusing entrepreneurial experiences into engineering education, with illustrative teaching and learning activities.

	Start	Process	End
Learning through student-framed and user-oriented projects			
Design pre-study project	Students search for problems to solve through design, and choose a workplace, profession or product to work with. Discuss project ideas with teacher. Teacher introduces methods for user study through lectures and practical exercises.	Students observe and interview users and develop design requirement statements.	Students write project report and present their work in front of class. Requirements are used in later course as starting point for actual design.
Business idea project	Students choose project idea, searching for problems or opportunities in their immediate context and generating potential business ideas. Teacher introduces theory and methods on business development through lectures. Invited guests share their perspectives on entrepreneurship.	Students do field work, e.g. interviews, which they subsequently analyse. Students produce visualisation of ideas and business model canvas.	Students pitch their ideas in front of panel of teacher and invited guests. Students produce a video-pitch of their final ideas. Student write project report.
Learning through client-framed and student-driven projects			
Software project	Students are presented with a problem from an external stakeholder. Teachers introduce process methodology for organising software teams. Guests are invited to give lectures on how software projects are organised in industry.	Students create an app or piece of software, iteratively conceiving and partially implementing. Students interact repeatedly with client for whom the product is tailored. Students get process supervision from teachers and reflect on their progression at multiple occasions.	Students showcase their final product to students, stakeholder and invited guests. Students write project and reflection report.
Product modelling project	Students choose among a small number of projects offered in relation to an industry partner. Students meet partner to agree on assignment. Teachers hold introductory theory lectures and practical exercises.	Students work in teams of 4-5. Students finishes continuous hand-ins in relation to the project Students undertake small-scale user-study. Students get feedback on project proposal from partner midway.	Students present project results to class and industry partner, often illustrated in a CAD-model.
Learning through co-creation platform projects			
Performance technology project	Students choose a project related to a hobby or activity of their interest. Teachers introduce basics of supporting performance through technology development. Teams are self-organised based on interest.	Students work in collaboration with an organisation or interest group related to their topic to conceive and design a technological solution. Teamwork is interdisciplinary and students use and contribute with their disciplinary contacts and knowledge.	Students write a project report. Results are delivered to external organisation.
Research project	Students conceive research project idea, by surveying previous work and discussing potential ideas with research supervisor. Students produce a plan for implementation. Teacher introduces relevant theory and work related to the broader area of research to which the student project should connect.	Students do extensive practical work in research laboratory, experiment iteratively and update plans. Students get supervision from teacher and lab-supervisors. Students engage in fundraising, outreach activities and collaboration abroad with other project teams.	Students present and compete with their research results internationally. Students write a final report and poster. Students document their results on a wikipage and tangible research outputs are stored in a depository.
Car-building project	Students conceive product design which is to be implemented and fully realised, a well-performing race car. Teachers introduce process methodology for organising the project work.	Students build and test their product in a team, through iterative experimentation. Students are put in charge of keeping track of their project process. Students seek and manage resources and technical help/expertise from externals. Teachers give supervision, mostly on process.	Students compete with/ showcase their finished product for other project teams internationally. Students write project report. Students are assessed on technical skills and their project management skills.

solution/product. Students are supervised regarding use of disciplinary methods, such as ideation, interviews, and modelling tools. In the sample cases, students' project results are presented to the class or invited guests, who provide feedback, and a project report serves as the main basis for assessment.

- *Learning through client-framed and student-driven projects.* Students work in medium-sized teams on client-framed projects that are arranged by instructors beforehand, with the goal of conceiving new solutions to problems relevant for clients' ongoing practice. Students are supervised regarding use of disciplinary design methods, such as computer modelling and programming, as well as project management methods, such as agile methodology. The clients provide feedback on the students' solutions during and at the end of the projects, and students incorporate this feedback into their solutions. A project report serves as the main basis for assessment.
- *Learning through co-creation platform projects*. Students seek out a learning environment aligned with their personal interests. They conceive a project idea, and connect external stakeholders, who are either sought out as problem owners or as resource providers, with interest in students' project results. Educators help students in finding and contacting these external stakeholders. Students are supervised in using disciplinary methods and more tangible resources, such as research labs, design workshops, and disciplinary networks. Results are showcased to other project teams and external stakeholders.

The first two pedagogical models are mainly distinguished in line with who frames the problems that the projects tackle.[6] The framing can be understood as *bringing in* different, and sometimes even conflicting, *perspectives* into the classroom. In the first model, students formulate the problem, bringing in the *student* perspective and, in this sense, make learning experiences more *personal* to them. In the second model, clients formulate the problem, bringing in the *disciplinary* perspective and, in this sense, make learning experiences more *professional*.[7] The third model represents an amalgam of both perspectives – the personal and the professional – as illustrated in Figure 2.

4.2. Instructional design choices and tradeoffs

In relation to the second research question, the analytical lens proposed above captures two perspectives on the quality of students learning experiences – the distinction between the personal and the

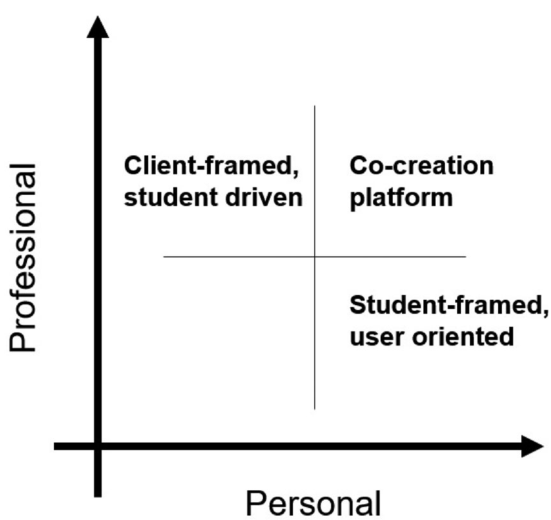

Figure 2. An illustration of how the three pedagogical models tap into two different perspectives – the personal (student) and the professional (disciplinary) – during the problem formulation phase of the projects.

professional. *Across* the three pedagogical models, the teaching and learning activities (see Table 1) can be put under this lens to analyse the role they play in shaping the learning experience.

Even though the educators talked less about making learning experiences *personal*, the following instructional strategies were mentioned in relation to bringing in the student perspective: tapping into students' prior knowledge and experiences, providing autonomy, letting students take a stance on issues pertaining to ethics and sustainability and encouraging reflection on the learning process. The most salient example of making learning experiences personal were those courses where students got to work with project ideas of their own choice and where projects were explicitly connected to students' interest (e.g. sports), with external stakeholders sharing that interest.

Two main arguments were formulated for why it is important to bring in the students' perspective. First, student-framed projects serve as an important complement to many other courses by emphasising problem framing (as opposed to problem solving), self-directed learning, and project ownership:

> It is also about formulating a problem. Formulating a question. That they make it their own. I think that is not very common in courses […] Some find it really challenging, I think they need to practice that (Sarah)

Secondly, although problem identification and framing are challenging, it can be more motivating than being presented with a problem:

> It is quite tough to come up with a project idea from nothing. I don't give them ideas to work from, they have to come up with their own. That's quite tough. It is also handled differently at different universities, sometimes a project is handed to them. I think coming up with their own is an important part. It is more motivating. (Emma)

The educators spoke more extensively about making learning experiences *professional*. To this end, several instructional strategies were employed: letting students use professional methods and tools, inviting guest lectures, letting students present their work to external stakeholders, and study users or workplaces. However, the most significant example of making learning experiences professional was to let students partner up and collaborate with external stakeholders who could provide recurring feedback on students' solutions.

Several educators argued that this is different from what the students are used to; namely, facilitating engagement with complex, open-ended problems with a connection to a concrete social context in which solutions could be implemented:

> I think that this idea of working with value-thinking, customer requests and functions is that in so many other design courses there is a specification on how to solve the problem, like a maths problems, and the students should just do it. […] Our exams are full of those exercises. So there is something important about them being outside of that box, because that is where they will be when they have finished [their programs]. (Robert)

Contacting or collaborating with external stakeholders can bolster student motivation by highlighting how their knowledge is useful:

> They feel like they have struggled for two and a half years with analysis and theory and haven't felt that there is any use to it, that there is no progression, that they haven't learned anything. They want to go out and test, is there something useful about what I know? They probably also have started pondering more seriously, what am I becoming, what could I work with? (John)

Several educators mention that arranging projects with practitioners facilitated a situation in which students had to focus specifically on the aspects of the project that was purposeful and relevant to professional practice, and that this was not the case when students were allowed to independently direct their attention:

> We try to get them to focus on the right things. We teach a process which is about needing to go out and meet the people [that you are designing for]. You might not want to do it, but you have to. (Michael)

> [Students] have a hard time reconciling this idea of delivering customer value with all the technical stuff that they have learned so far. And they feel that the value lies in the database system. It does not, not at all. The customer couldn't care less what database system you are using. (David)

A common learning is that they have put time into optimizing something starting from a limited model of reality, and have constructed something that is too advanced […] What are you supposed to put your time into, is it reasonable to put in that much time? That is the kind bubbles that are burst (Charles)

Insights into professional practice can be gained which are otherwise difficult to grasp by just hearing about practice. Such insights are not necessarily assessed through simply simulating professional practice, because the connection to the underlying purpose of activities motivates the confrontation with unintuitive aspects of professional practice. One of the educators, David, argued specifically that working with an external stakeholder provides motivation for students to confront challenging and unintuitive aspects of engineering practice.

This suggests tradeoffs regarding what kind of learning experiences can be accomplished with the different models. The more mainstream project-based courses seemed to have difficulty in combining collaboration with external partners and allowing students to introduce their own ideas. Indeed, some of the educators talked about the challenge of combining student choice with real industry projects. The student-framed courses therefore often stop either in the conceiving or designing phase, and do not move towards implementation. The educators lamented that students are reluctant to seek out external stakeholders, and that such openness might be too much for students to handle:

We asked the students to look for stakeholders, it didn't work. […] they didn't do it. (David)

Maybe it is too much to ask of them […] I mean, it is already difficult for them to choose products that works (Sarah)

Making commitments to externals in student-framed projects remained optional, and results were not feedbacked to those that had been contacted externally. Several educators spoke to how students created value for them (the educators) through presenting their results: they learned new things and/or got new examples/cases for their courses. However, value for someone external was not addressed.

Some have chosen to work with companies, it happens. (Michael)

5. Theoretical justification for the pedagogical models

To provide theoretical and empirical support for the three pedagogical models and their two underlying design principles, insights from entrepreneurship education research and engineering education research are used. The consequences of instructional design choices are discussed in terms of the nature of the learning experiences facilitated. Specific emphasis is placed on the strengths and limitations of each pedagogical model in terms of facilitating entrepreneurial experiences, in line with previous work on entrepreneurial engineering pedagogy. The paper employs a broad perspective on entrepreneurship, entrepreneurship education and related entrepreneurial competences – i.e. considering how to enable creative and flexible individuals and organisations rather than facilitating business startup (Ball 1989) – and thus focus on competences such as managing uncertainty (Sarasvathy 2009) identifying opportunities (Alvarez and Barney 2010) and marshalling resources (Schumpeter 1942) are central to the discussion.

5.1. Integrating two discourses

A first observation to be made is that only one of the seven courses in the final sample was explicitly related to entrepreneurship in course documentation or recognised as 'entrepreneurial' by the educator. Interestingly, the selection criteria employed in line with entrepreneurial engineering pedagogy (courses that support student autonomy and reflection, use real-world problems, have students making external connections and designing new solutions) resulted mostly in project-based courses without any *explicit* entrepreneurship learning objectives. This indicates a close overlap between experiential components of engineering education and a broad perspective on entrepreneurship education. As such, the study gives empirical support for previous work on entrepreneurial engineering pedagogy which assert that: 'Engineering programs often exhibit practical and experiential approaches and project-based and team learning consistent with best practices in other disciplines' (Rae and Melton 2017, 6). The courses in the final sample can all be considered in line with engaging students in engineering design projects, which has been deemed promising for preparing engineering students for professional practice (Shulman 2005b; Lucas and Hanson 2016). Such projects let students learn 'through' engineering design, understood as simulation of or participation in authentic engineering practice (Crawley et al. 2011; Bernhard, Edström, and Kolmos 2016). Similarly, design-based learning has been put forth as a vehicle for entrepreneurship education (Neck and Greene 2011) and learning 'through' entrepreneurship has gained prominence as a way to conceptualise entrepreneurship education in recent years (Mäkimurto-Koivumaa and Belt 2016). Shulman (2005a) argue that learning experiences situated in authentic professional practice are *pedagogies of uncertainty*, which resonates with assertions that a fundamental characteristic of entrepreneurial action is engaging with and managing uncertainty (Sarasvathy 2009). A significant overlap is observed between what is considered authentic engineering experiences and entrepreneurial engineering experiences. In discussing these pedagogical models and drawing from both engineering education research and entrepreneurship education research, the paper suggests integrating the two discourses in order to further research on entrepreneurial engineering pedagogy.

5.2. Student-framed and user-oriented projects

There is no shortage of assertions that students should be allowed more ownership of their learning (Prince and Felder 2006; Robinson et al. 2016; Lee and Hannafin 2016). As such, the arguments put forth by the educators for using student-framed problems resonates well with general discussions regarding student-centered learning and constructivism, which are salient in both engineering education and entrepreneurship education research, and assert that knowledge is constructed by learners in the interaction between previous and new experiences (Prince and Felder 2006). The development of independence, autonomy and lifelong learning skills are salient in discussions of student-centered learning, highlighting how it is 'critical that formal educational systems prepare students to negotiate and resolve future uncertainties' (Lee and Hannafin 2016, 709). For the educators in this sample, using student-framed projects was considered as facilitating motivation and ability to find and frame problems independently. Entrepreneurship education research tends to emphasise self-directed approaches (Harms 2015; Lundqvist and Middleton 2008) as a main learning vehicle to develop more personalised skills (Williams Middleton and Donnellon 2014). Developing students' self-negotiated agency has been deemed a key consideration for entrepreneurship education (Williams Middleton 2013; Jones 2018). To accomplish this, Blenker et al. (2012) calls for personalised entrepreneurial pedagogy, where learning is situated in the everyday practices and networks of students, and Kyrö (2015) argues that entrepreneurial pedagogy should start from students' previous understanding and interests. This is in line with empirical findings showing how entrepreneurs actively engage in writing their own stories as a means of gaining legitimacy (Rae 2005), and that expert entrepreneurs primarily focus on the resources they have at hand in order to start engaging in shaping an uncertain future (Sarasvathy 2009).

5.3. Client-framed and student-driven projects

Similarly, there are many calls for learning environments that engage students in solving 'real' problems together with external stakeholders, e.g. through using *client-framed problems*. For entrepreneurship education to help students understand and meet the needs of contemporary workplaces, Hynes and Richardson (2007) highlight the potential of students and practitioners interacting in higher education learning environments. Similarly, Jonassen, Strobel, and Lee (2006) outline that engineers should be engaged in solving of problems corresponding to those that they will meet in the workplace. Connecting to practitioners and using real-world problems were considered important by the sampled educators in this study because these facilitate open-ended problem solving, show how technical knowledge can be applied in a social context, and create learning situations in which students address engineering practice which entails challenges, prioritisation and focus in projects that intend to create technology which meets customer needs.

For the educators, the aim is to bolster the *authenticity* of the learning environments. Authenticity of a learning environment is judged in terms of how well activities and contexts correspond to professional practice, or alternatively how well-connected learning environments are to actual workplaces and practitioners (Barab, Squire, and Dueber 2000). Macht and Ball (2016) assert that 'In the [entrepreneurship education] literature, the term authenticity itself is rarely mentioned […], but the underlying argument regarding the real-life focus of education is almost omnipresent' (p. 930). This is apparent, e.g. in assertions that entrepreneurial competences can only be truly developed through 'real-world' experiences (Henry, Hill, and Leitch 2005; Kassean et al. 2015), that students should be engaged in learning *through* entrepreneurship rather than only learn *about* entrepreneurship (Mäkimurto-Koivumaa and Belt 2016), and how curricular entrepreneurial experiences may facilitate authentic engineering experiences (Bosman and Fernhaber 2019). Similarly, Strobel et al. (2013) reviewed extensive work specifying design criteria for authentic engineering learning environments, finding that authenticity is usually 'conceptualized as bringing the learner closer to the realities of the workplace' (p. 144). Learning environments are usually not deemed fully authentic unless students connect and work together with practitioners (Barab and Duffy 2000) who can represent the future professional practice of students.

5.4. Co-creation platform projects

A key consideration for entrepreneurial engineering pedagogy then is how student-framed learning processes and connecting to external practitioners can be combined, such that learning experiences can be truly personal and truly professional. Achieving collaboration between students and practitioners has the potential for mutual benefit (Barab, Squire, and Dueber 2000; Radinsky et al. 2001; Hynes and Richardson 2007), and is a way to engage students in knowledge creation in innovative learning communities (Paavola and Hakkarainen 2005). Learning environments where this is accomplished have been called *idea spaces* (Rae 2017), where students can be well-connected to professional practice and at the same time be sheltered enough so that they have freedom to direct their own attention. Such learning environments have alternatively been called spaces for *co-evolution*, 'a learning context that is neither, and is both the classroom and the community of practice' (Barab, Squire, and Dueber 2000). The co-creation platform projects put forth in this paper seem to facilitate such a space for students, where new ideas and projects can be co-conceived and negotiated. Experiencing such learning environments is intimately connected to students actively creating new ideas and authoring new professional narratives (Levy and Petrulis 2012), that can be transformative for both students and practitioners (Rae 2017).

However, the educators in the sample stated that achieving such a combination can be difficult in mainstream project courses without access to physical spaces other than classrooms, additional alternative resources, and established networks, as such combinations place high demands on the students, and because students can be reluctant to seek out connection with external stakeholders. Some of the educators highlighted how allowing students to choose project topics conflicted with providing a context that could facilitate professional experience, because students' other courses had focused on technical aspects of engineering to the extent that students perceived this to be what was valuable about engineering, rather than the application of technical knowledge to solve real problems. For instance, students might over-embellish specific features of solutions they find interesting or rewarding to work with, and in the worst case end up with designs that are creative but not useful. Conversely, while client-framed problems help to develop professionalism, they can lack the space for more personalised learning where students get to connect a project to their own intentions and sense-make them in relation to their previous experiences. Specifically, working with such problems may lack opportunities to make the project 'their own' and develop their own agency in the project, as commented by one of the educators in the sample. Such approaches have been criticised for expecting students to move seamlessly from their subjective position into the world of the profession (Borthwick et al. 2007, 16). This suggests that a salient tradeoff which educators may be faced with when designing entrepreneurial projects is whether to prioritise developing students' commitment and ownership of learning processes and their capacity to find and frame engineering problems, or to prioritise connecting with and making commitments to practitioners and develop students' understanding of and engagement in professional practice. Through facilitating spaces for co-creation, such tradeoffs seemed to be resolved, but at the expense of additional resources.

6. Implications for practice

To align with assertions that fostering entrepreneurial competences among engineers is primarily a matter of changing the way engineering is taught (Kriewall and Mekemson 2010), implications for educational practice, individual educators and universities are suggested.

6.1. Making learning more personal

Entrepreneurial engineering pedagogy should implement mechanisms which allow students to bring themselves wholly into the learning environment (Boud 1989), including mechanisms to help them do so. Using active learning approaches such as project – and problem-based learning have been recognised as a precursor (Mäkimurto-Koivumaa and Belt 2016). From the study, it is highlighted that giving students the opportunity to frame projects is important for developing the ownership and commitment needed to take on projects with uncertain outcomes. In facilitating a problem formulation phase, a common strategy in entrepreneurship education is to let students reflect on and map out the resources they have at hand (Sarasvathy 2009), i.e. previous experiences, networks, and tangible resources. Ideation exercises, such as those proposed in engineering design thinking (Dym et al. 2005) can help in formulating questions and problems to give some direction in early phases. Project framing should ideally be an iterative process, reflecting the way in which entrepreneurs try out nascent ideas, quickly put to test through interaction with external stakeholders, and re-assess in relation to feedback (Ries 2011; Gemmell, Boland, and Kolb 2012). This way, some of the pressure on students to directly come up with the right project-idea can also be alleviated. If client-framed problems are used, educators should reflect on how students can be allowed to make the projects their own. Putting students in the driver-seat of projects, which is included in the client-framed pedagogical model emerging from the sample, can be an intermediate solution. A further consideration is ensuring that the projects proposed by clients are sufficiently open-ended to allow for students to engage in framing and narrowing down the problem.

To enable a stronger connection between the students and their project experiences, several of the courses in the sample utilised reflection assignments which may serve to make learning more personal. Facilitating opportunity for reflection is usually considered a best practice of experiential and real-world approaches in general (Barab and Duffy 2000; De Graaf and Kolmos 2003) and in both entrepreneurship education (e.g. Neck and Greene 2011; Kassean et al. 2015; Hägg and Kurczewska 2016) and engineering education (e.g. Woods et al. 2000; Shekar 2007). Although reflection assignments can offer important opportunities to sense-make students' own experiences and build self-awareness and self-regulatory capacity (Van den Boom et al. 2004), a key consideration for implementing reflection assignments is that students may struggle with understanding the purpose of reflection. Thus, assignment introduction should be coupled with learning sequences explaining the nature and purpose of reflection and how it relates to the project process (Moon 2001).

Another key consideration regarding assessment is to mitigate potential discouragement of openness and creativity due to overly product and content-oriented grading criteria (Steghöfer et al. 2016; Lackeus and Williams Middleton 2018). Some engineering design courses have been found to rely solely on the quality of the finished design as a criteria for grading, which may push students to take on projects instrumentally and focus on products rather than learning (Bernhard, Edström, and Kolmos 2016). Instead, assessment should focus on learning processes and the manner in which students apply disciplinary methods. An observation from the courses included in this sample, is that basing assessment primarily on project reports is common practice. Such a summative assessment could be complemented with formative assessment as the projects progress to broaden the scope of assessment and capture learning achievement.

6.2. Making learning more professional

Entrepreneurial engineering pedagogy should strive towards making real-world connections. Introducing clients that act as an audience, feedback providers, and project recipients have been highlighted as mechanisms for making real-world connections. If educators do not pre-arrange an external stakeholder, engaging students in self-directed user studies can facilitate a first connection to professional worlds, because the needs of the customer are highlighted. However, students in the courses sampled did not commit to the users they had studied, did not get feedback from the users on their proposed solutions, and thus their design processes are still somewhat divorced from the actual contexts in which their solutions could be implemented. Thus, although guest lectures, field trips, or interviews with professionals can facilitate a first connection, extending this as a more tangible collaboration over time can further bolster the authenticity of projects and thus make learning more professional. Longer-term collaboration can facilitate opportunities to develop interpersonal skills in relation to key stakeholders, such as potential customer, financiers or partners.

Making learning both more personal and more professional also means that educators need to adopt a change-able role in the classroom; from one of lecturing to one of supporting students as they are taking action in an unfolding and uncertain process. The ambition to foster entrepreneurial competence in engineering education poses new demands on engineering educators. The value in pedagogical models then is that they can mediate between a philosophy of entrepreneurial competence that is increasingly established in technical universities, and the day-to-day activities of the classroom (Goodyear 1999). The pedagogical models for facilitating entrepreneurial experiences suggested in this paper offer educators ways of thinking about their teaching, the tradeoffs they face, and the effects of prioritisation.

6.3. Making and supporting space for entrepreneurial learning

In co-creation platform environments, students and significant others can work on a co-evolving project framing, potentially satisfying both that students bring themselves into projects wholeheartedly and that projects are of disciplinary relevance and legitimised by professionals. This indicates that the ambition to develop both professional and personalised learning can be fulfilled, but often costing extra resources in terms of physical spaces and tools, additional student supervision, and management of stakeholders and ideas connected to the platform (Lackeus and Williams Middleton 2015). An implication of the co-creation model is for universities to support the development of such learning environments, for example through maker spaces (Wilczynski 2015; Martin 2015; Wilson 2015) or other arenas for co-creation between students and practitioners.

Supporting innovation in university organisations is not only a matter of creating *new* structures, but also developing a capacity to identify learning environments and communities of educators at the university that are experimenting with new ways of teaching and giving support to these emerging groups (Brown and Duguid 1991). Collaborating with external stakeholders can be challenging for the educator, particularly those with limited industry experience. The educators in the sample acknowledged the uncertainties faced when relying on externals. For instance, stakeholders can back out of commitments and deliver limited attention and feedback to students' projects, often requiring educators to renegotiate terms of engagement before and during courses. As such, educators need support and recognition, e.g. through resources and opportunities for them to discuss their experiences and challenges with other educators.

7. Methodological considerations and future research

While this paper applies a broad perspective on entrepreneurship and entrepreneurial experiences, considered to be in line with discussions put forth in previous work on entrepreneurial engineering pedagogy, the investigation of the pre-conditions for entrepreneurial learning in courses not explicitly related to entrepreneurship point towards questions pertaining to the role of discourse in these learning environments. Even if, from a researcher perspective, these learning experiences are identified as entrepreneurial and discussed within a discourse of engineering entrepreneurship and entrepreneurial competences, most of our respondents did not talk about their course as entrepreneurial. Arguably, the way in which educators and students make sense of learning experiences matters, and the discourses that are pervasive in the learning environment serve as resources for this sense-making (Brown, Reveles, and Kelly 2005; Allie et al. 2009). Future work should investigate the way in which educators, students and stakeholders talk about these learning experiences, and how this influences the communal sense-making of the experience. A key consideration is to understand engineering and entrepreneurship discourse as either potentially complementary or conflicting discursive resources (Rayess, Weaver, and Kleinke 2010), how they are put into play in entrepreneurial engineering pedagogy and what effects on learning are produced when introducing an entrepreneurial discourse in learning activities. As engineering education and entrepreneurship education are themselves interdisciplinary fields involving a multitude of actors and conflicting discourses (Stonyer 2002; Hannon 2005), comparisons of similar activities put forth through different discursive resources could be illuminating for both fields.

The three pedagogical models have focused primarily on the starting point of projects and specifically the problem formulation phase. Although this resonates well with previous research discussing how active learning is designed and the experience it therefore can facilitate (De Graaf and Kolmos 2003; Prince and Felder 2006; Levy and Petrulis 2012), it is recognised that learning is an unfolding process much dependent on the ongoing interaction between educator-learner, learner-learner and learner-stakeholder. Starting from student-framed problems does not necessarily always lead to students taking ownership and feeling committed to their projects, while starting from client-framed problems does not necessarily ensure projects that are perceived as being relevant for professional practice. Future work should test the legitimacy of assumptions pertaining to the effect of starting in student-framed problems or client-framed problems in entrepreneurial projects in engineering courses. Moreover, the kind of experiences advocated in this paper are designed to be challenging for learners, and consequently, sufficient scaffolding needs to be put into place (Kirschner, Sweller, and Clark 2006; Hmelo-Silver, Duncan, and Chinn 2007) – an aspect of entrepreneurial engineering pedagogy that is overlooked in much extant work. Further, there are many empirical accounts highlighting the effect of assessment on learning experiences and learner behaviour, with most emphasising that deep learning can be unintentionally discouraged by the use of instrumental or overly result-oriented assessment (Gainsburg 2015; Bernhard, Edström, and Kolmos 2016; Steghöfer et al. 2016). Future work should investigate assessment practices in entrepreneurial engineering pedagogy. Specifically, this should include addressing which opportunities for sense-making students receive, the role of assessment in supporting the development of entrepreneurial competences among engineering students, the challenges students face in these settings, and the scaffolding schemes that are required to ensure meaningful participation.

This paper has only addressed educators' intentions regarding course design and inquired into educator experiences when delivering courses. It is not certain that their stated intentions correspond to their actual pedagogical practice (Alvesson 2003), and thus future studies might be complemented with classroom observations. Further, to reach a proper understanding of learning and the development of entrepreneurial competences in these settings, the experience of students also needs to be investigated. Tradeoffs between different aspects of instructional design should be explored in more evaluative studies of entrepreneurial engineering pedagogy, e.g. studying whether choices between student-framed or client-framed starting points are reflected in students' self-assessment of their development. Further, to complement earlier investigations that have relied primarily on pre- and post-surveys, there is arguably a need for more qualitative and in-depth investigation to understand how students experience and make sense of their experiences in these settings. Täks et al. (2014) offer one such investigation, exploring the different ways in which engineering students experience taking an experiential entrepreneurship course. The many non-entrepreneurship courses in the sample implies that studying how students experience courses that are entrepreneurial but not explicitly concerned with entrepreneurship should also be addressed by researchers interested in how entrepreneurial competences develop among engineering students.

Inherent to the case study methodology is the reliance on small samples, in order to capture contextual complexity. The pedagogical models identified here are based in just a few courses and in the context of one university of technology. As such, while the sampling procedure is directed at identifying settings and findings in line with and relevant for extant work on entrepreneurial engineering pedagogy, some onus does fall on the reader to evaluate the transferability of findings to their empirical contexts. In terms of future research, a broader study of personal and professional learning in entrepreneurial engineering course might offer additional examples of mechanisms that accomplish the integration of personal and professional learning without the need to add extensive resources. Further, the study lacked discussion about mechanisms to make learning personal. A broader study could specifically focus upon ways of accomplishing personalised learning while still utilising client-framed problems.

This study has helped to illustrate that there are competing goals when facilitating entrepreneurial experiences. Specifically, these include tradeoffs between arranging student-framed projects and seeing to that projects are professionally relevant. Both are arguably important for a philosophy underpinning pedagogical models for entrepreneurial engineering. According to Shulman (2005b) and his extensive work in studying the preparation of professionals, tradeoffs are inherent to any professional education and different disciplines are distinguished by the priorities that they make. After surveying the entrepreneurship education and engineering education discourse, it is suggested that trying to support self-directed action seems more salient in the entrepreneurship education discourse, with Jones (2018) being a prime example, and Blenker et al. (2012) emphasising an educational framework for entrepreneurship education starting from students' resources and intentions. Conversely, there is a more established discourse in engineering education regarding the use of real-world problems and making learning resemble professional practice, so that students can align with this (Strobel et al. 2013; Morelock 2017), for example building from the CDIO-framework and Jonassen, Strobel, and Lee (2006). Of course, to say that such sources are *only* concerned with personal or professional learning, and that engineering and entrepreneurship discourse have focused *solely* on either/or would be an overstatement and a misrepresentation. However, pedagogical frameworks starting from student-centered learning are seen to be especially well-articulated in entrepreneurship education discourse and pedagogical frameworks starting from authentic professional practice to be especially well-articulated in engineering education discourse. Consequently, there is potential in fruitful discussions across the two discourses, that could further understanding of how graduates can be supported to thrive in contemporary working life, with increasing pace of change and need for innovation.

8. Conclusions

By engaging in a qualitative case study of entrepreneurial experiences in engineering courses, including how educators reason about instructional design choices, this paper has identified three pedagogical models for facilitating entrepreneurial experiences in engineering education. Two directions are suggested for educators interested in making their courses more entrepreneurial: make learning more personal and more professional. The paper has illustrated how this can be accomplished in terms of concrete learning activities, and has put forth key tradeoffs to consider. As such, the paper has aimed to make it 'possible for us to engage in more powerful and robust reasoning about what we are doing and what we have achieved' (Goodyear 1999, 2) when it comes to discussion of entrepreneurial engineering pedagogy.

A significant overlap is observed between experiential components of engineering education and learning experiences that have been put forth as entrepreneurial in previous work. Arguably, such learning experiences are similar but have been understood differently in terms of the discourse in which they have been put forth, specifically engineering education research discourse and entrepreneurship education research discourse. Discussion across these two somewhat disparate research streams is deemed a promising avenue for further research into the development of engineering graduates who will thrive and take leadership in contemporary professional practice.

Notes

1. We note that a *qualitative* research approach, with its focus on identifying themes or patterns across the pool of data, is therefore well-suited for exploring pedagogical models.
2. Nunes and McPherson (2003, 499) noted that "the difficulty with the term pedagogical model is that it is very commonly used, but seldom defined in a precise form" — something we have tried to avoid here. Adding to the confusion, other terms are frequently used, such as pedagogical framework, high level pedagogy, and instructional model. Be that as it may, prominent examples of pedagogical models include project-based learning, cognitive apprenticeship, and constructive alignment, to name a few.
3. These are available online and typically involve a one-page description of learning objectives, aims, teaching and learning activities, assessment, and overall organisation of the course.
4. Half of the courses were excluded post-interview because the activities that were identified through course documentation as being in line with entrepreneurial engineering pedagogy turned out to be a very minor part of the courses, instead relying heavily on a lecture-based format and smaller exercises
5. This table also serves as a window on the analytical process insofar as the listed teaching and learning activities were used as codes for deriving the pedagogical models (themes).
6. We join Schön and Rein (1994) in arguing that "[t]here is no way of perceiving and making sense of social reality except through a frame, for the very task of making sense of complex, information-rich situations requires an operation of selectivity and organisation, which is what 'framing' means" (p.30). So, simply put, problem framing means that certain aspects of a situation are foregrounded while others are backgrounded.
7. This is not to suggest that engineers do not engage in problem formulation or problem identification. Indeed, as Lucas and Hanson (2016) note, problem framing is an important engineering "habit of mind".

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix

Table A1. A brief description of the seven project-based courses in the final sample.

Course	Class size (#students)	Credits	Course description
Design pre-study project	20–50	6.0	Imparts methods for researching user requirements of products, students conduct small-scale user study and conceive a product in teams
Business idea project	20–50	15	Imparts perspectives on innovation and entrepreneurship, students develop business idea in teams
Software project	>50	7.5	Imparts methods for agile software development, students develop a software solution in teams and in co-operation with an external stakeholder
Product modelling project	>50	7.5	Imparts methods for product development, students develop product in teams in relation to problem given by an external stakeholder
Performance technology project	20–50	7.5	Students work in teams in relation to an external interest group or organisation, to develop technical solutions aimed at increasing the performance of specific activities
Research project	<20	15	A small student team plans and undertakes a biotech research project
Car-building project	20–50	15	A large student team conceives and builds a car, which they race internationally against other teams, is given process support by a teaching team