Design considerations regarding the development of an interdisciplinary engineering innovation course involving collaboration with small and micro-sized companies

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Abstract

This paper discusses some of the issues and dilemmas that have come up when designing courses aimed at teaching innovation competencies to engineering students through means of authentic industry collaboration with small and medium sized enterprises (SME). The paper is focused around the phase of designing the course SME Innovation and Intrapreneurship where the aim has been to create a match between the company need for short, result oriented innovation projects and the structured professional and interdisciplinary learning goals for a coming bachelor of engineering. The main dilemmas in the development have evolved around the concept of bridging real-life with a university learning context, the question of how to change teaching and exam structure to support new and different learning objectives, as well as the challenges of handling interdisciplinary teams. The 13 week, 10 ECTS credit course is structured around a shorter *preject*-period of challenging the problem proposed by the company and building the relations among the students necessary to generate innovation and a longer *project*-period dedicated solving the engineering challenge. The CDIO (Conceive — Design — Implement — Operate) pedagogical framework has been used to design the project, and the paper will include considerations on design of the course and experiences with SME-collaboration as well as interdisciplinary collaboration between the students.

Keywords: Interdisciplinarity; Small and Medium sized Enterprises (SME); Project Work; innovation; course design; Industry collaboration.

1 Introduction

In the engineering education we experience a growing focus on stimulating innovative and interdisciplinary competencies among our students (Liebenberg & Mathews, 2010) in order for our students to acquire the needed 21st century skills (King, 2007). This paper strives to answer the questions of: How to structure a learning process in an engineering elective that stimulates the development of inter-disciplinary and innovative competencies among the students? What specific challenges occur when trying to merge an authentic setting and an increased focus on personal competencies into an engineering course setting, and how can the challenges be addressed?

The elective *SME Innovation and Intrapreneurship* has been developed by DTU Diplom, a department of the Technical University of Denmark. The department is mainly responsible for the education of the degree Bachelor of Engineering which is a 3.5 year long engineering education building on engineering industry practice as its core. All BEng educations build on the CDIO (Conceive-Design-Implement-Operate) as the overall teaching paradigm (Crawley & Lucas, 2011). The development has been funded by the Danish Foundation for Entrepreneurship, and is seen as an experiment in the process of transforming the department into a hotspot for engineering innovation and entrepreneurship. Alongside this a much bolder step of introducing innovative competencies as a general Intended Learning Outcome for the whole education (Biggs & Tang, 2011). The driver of this change will be the introduction of a mandatory 10 ECTS element with focus on interdisciplinary and industry collaboration for all Bachelors of Engineering at The Technical University of Denmark in 2016. Where the elective take an elite approach, this step of introducing the 10 ECTS course is posing yet new dilemmas of reaching all students.

For the elite approach in the elective, the choice of industry collaborator has been small and medium sized enterprises (SMEs) with emphasis on micro and small businesses. This because in European economy SMEs account for more than half of the value added, and around half of all employees work in micro or small

businesses with less than 50 employees (European Commision, 2013). At the same time the barriers for university collaboration with SMEs are somewhat more steep than working with larger organizations (Darabi & Clark, 2012).

The paper will proceed with an introductory explanation of the current course design, an introduction to the theoretical background for the development of the course, an elaboration of the design considerations and decisions made in the design of the course, the evaluation methods used to assess whether the intentions are implemented in the course and finally a discussion of the preliminary results on the ongoing course with preliminary recommendations.

2 Course design

The following is a description of the course SME Innovation and Intrapreneurship (Christiansen, Ulrich, & Pontoppidan, 2013) to provide a frame for the later discussions.

The aim of this 13 week long course is to develop the students' ability to work interdisciplinary with innovation in a real-life setting with particular focus on the challenges and benefits of working in a small or medium sized company (SME). The students are in the later stages of their engineering education 5-6thsemester and have a strong disciplinary identity.

The intended learning outcomes of the course are that the students can plan, execute and evaluate a real-life tech-based innovation process resulting in a business proposal and produce a prototype of the final technical solution. This includes selecting and applying appropriate methods, applying technical, user and customer/business perspectives. Process skills involve both reflection and expectation management skills and include both being able to contribute with own core disciplinary competencies but also respectfully challenge the views of others and be able to argue for choices and explain details both related and unrelated to one's own discipline. The students should further be able to demonstrate an understanding of the SME challenges with innovation and explain the intrapreneurial processes they have gone through in the company collaboration during the course.

The first part of the course (4 weeks) is a mainly divergent phase that aims, through creative and entrepreneurial methods, to challenge the initial problem statements from the partner company and learn in theory and practice to work interdisciplinarily.

The transition between the two phases is marked by a planning session where the students plan out their development work together with what materials as well as disciplinary resources and help from the workshops they need.

During the R&D period (week 5-13) which is a mainly convergent phase, the students combine their disciplinary skills, as well as learn new skills, to create a concrete solution in the university workshops and laboratories for one of the formerly challenged problems. The students should during this phase come to an agreed prototype state of their solution.

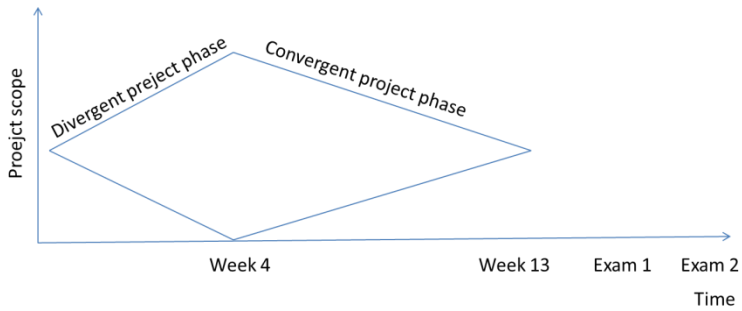

Figure 1 Course Structure

The companies are involved regularly. In the very beginning they present their company and problems. In the transition between the divergent and convergent phase expectations are adjusted and midway in the R&D phase a plan for testing of the prototype or mock-ups is agreed upon.

They are also partakers in the first oral exam which is a presentation of prototype and business proposal aimed at handing over the project to the company and arguing for future business choices. The company pays a small amount (DKK 5.000) to cover extra expenses for materials.

2.1 Evaluation design

In order to have a clearer idea of whether the intentions with the course have worked out or not, a partnership with the educational development unit at DTU, LearningLab DTU, has been set up in order to examine this further. The evaluation is qualitative and consists of: A focus group interview during the course and semi-structured interviews with students after the last exam as well as a focus group with teacher and supervisor group all conducted by LearningLab DTU. Furthermore, the course responsible keeps a weekly reflections logbook and will conduct semi-structured interviews with the company representatives after the course as well as regular check-ins with them during the course.

3 Theoretical Background

The teaching approach is inspired by newer development within entrepreneurship teaching involving a shift away from focusing on entrepreneurship research or writing business plans towards a greater focus on the training of entrepreneurial competencies among the students (Kirketerp, 2010; S. Sarasvathy, 2008). When teaching entrepreneurship you can divide between three kinds of entrepreneurship teaching (Fayolle & Gailly, 2008):

- **Learning to become an enterprising individual:** Primary focus on the personal competencies
- **Learning to become an entrepreneur:** Primary focus on the disciplinary skills and tools
- **Learning to become an academic:** Primary focus on knowledge skills

Where universities traditionally have focused either on the academic side or created business plan courses with focus on the disciplinary skills, the choice for this course was to focus on developing the personal competencies of the students. This was in order to reach as many engineering disciplines as the elective targets, and because the goal of the initiative is to create more innovative students.

Innovation and entrepreneurial competencies are very similar. Perhaps where they both meet best is in the bottom up intrapreneurship perspective where the individual drives the business development in his/her organization (Amo, 2010, p. 147). Intrapreneurship then have clear overlaps with employee driven innovation which is the more focused on internal processes, but still an employee driven process (Høyrup, 2012). In order to determine which personal competencies to emphasize, we looked to innovation researcher Lotte Darsø that defines the competencies as:

- **Innovation competency:** The ability to create innovation by navigating together with others under complex situations. It consists of two types:
  a) **Socio-innovative competencies:** Mastering social interaction that enhances innovation.
  b) **Intra-innovative competencies:** Consciousness & sensitivity in relation to own and others' talents, preferences & potential for development and innovation. (Darsø, 2012)

With a focus on the students acquiring innovative competencies it became important to, as an integrated part of the course, use time and effort to create a safe learning space where the students can work on building personal relations that will help them cross intercultural barriers and work with challenging each other to create new knowledge in the group (Darsø, 2012). This emphasis is supported by Nonaka, a scholar within the knowledge management field, who has studied the process of going from tacit to explicit knowledge. This

process he argues, can be stimulated in a *Originating Ba* where *Ba* means shared spare for emerging relationships and *originating* refers to socialization, (Nonaka, Reinmoeller, & Senoo, 1998)

On top of the innovative competencies it was also wished to emphasize the entrepreneurial business perspective understood as the ability to act on your ideas and realize opportunities, which in entrepreneurship terms can be described as effectuation (S. D. Sarasvathy, 2001). A main component of this ability is self-efficacy, the belief that you can accomplish successfully what you set out to do, even if you have not tried it before (Bandura, 1977). Bandura argues that in order to develop self-efficacy you need four elements: Mastery experiences, modelling or vicarious experiences, a social persuasion from your surroundings as well as judgment of your own personal state (Bandura, 1977).

In order to train these competencies it was decided to create a four week *preject* phase (a small pre-project before the actual project phase) where focus is on knowledge creation in a divergent phase (Darsø, 2012). In this phase great emphasis was put on creating a learning space through social relations. Knowledge mapping exercises, teambuilding, Jungian Type index, visits at each disciplines home workshops, together with introducing innovation tools such as the business model canvas, scenario planning, design thinking etc. was ingredients to stimulate this. However, in order to also create a bridge between the creative early stages of innovation and for engineers the more familiar prototype-development stages, the Build element of CDIO pedagogical framework (Crawley & Lucas, 2011), it was decided to leave the remaining nine weeks to the project part.

All Bachelor of Engineering educations at The Technical University of Denmark work with the CDIO framework. Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context. Conceiving covers opportunity identification to high-level or conceptual design. Designing includes aspects of design process including prototype building. Implementing includes test and verification as well as design and management of the implementation process. Operating covers a wide range of issues from designing and managing operations (Crawley & Lucas, 2011). It argues an equal emphasis on the building blocks of: Technical Knowledge and Reasoning, Personal and Professional Skills as well as interpersonal skills.

4 Course Design considerations

Here the four main dilemmas that came up during the development of the course are described. The intention is to bring these discussions on to others working with similar curriculum challenges.

4.1 How to balance the authentic real-life perspective with a learning space?

One of the benefits of working with smaller businesses is the authentic perspective; there is simply a short time to market on the projects. This however provided a dilemma of ownership. When students take an innovative approach, and their path strays away from the one anticipated by the company, who gets to decide if that is the right way? Should the supervisor or company then intervene? Or let the students stray?

The choice was to address this by emphasizing the learning in expectation management. The students are constantly put in situations where they have to address and negotiate further development and they are encouraged and supported by the supervisor to challenge the company direction, but they have to keep communicating. In order to equal the roles, companies pay a small fee to the institution in order to cover material and travel costs for the students and it is strongly emphasized that submitting a challenge in the course guarantees no results.

The SME's are characterized by having a somewhat shorter time horizon when it comes to getting products on the market (Darabi & Clark, 2012; Greiner, 1972). In this course it has been attempted to shorten the time horizon of the innovation projects in order to fit the SME and it is the hope that students will be motivated by seeing results of their work within a short time frame. The potential downfall is less room for innovation. This decision has created a new dilemma since part of teaching an innovative mindset involves the freedom to challenge the original problem the company has presented (Brown, 2008).

The reformulation of problem might lead one discipline to no longer being needed in the development phase, or might determine that the real problem is not an engineering one. An easy fix to that would be to reshuffle teams after the preject period but that would imply starting over building the social relations, the originating Ba (Darsø, 2012; Nonaka et al., 1998), needed to cross the intercultural barriers, and for the students to get under the skin of a new company and problem. So it was decided that the interests and skills of the students would have to serve as yet another constraint encouraging innovation (Shostack, 1988).

4.2 Product Ownership - who owns the rights to the outcome?

In an engineering development field intellectual property rights (IPR) often present a challenge. What if the students invent something amazing while working on this project? In the development phase of the course two different traditions regarding IPR that split the faculty in half were identified. One belief that can be called the designer approach is that students do the intellectual work and should own all rights, and the other that could be called the business approach is that students would not be able to create anything without the context and knowledge of the company so the rights should belong to them. The former arguing for 100 % rights to the student and the latter 100 % rights to the company.

In interviews with representatives from SME's it was learned that one of the largest barriers for collaboration is the idea that "the university steal our IPR". So the dilemma was at the same time to provide a reasonable scheme for the students as well as not to scare away the companies; and not least encourage all partners to put in their bests efforts not being afraid to "give away IPR". The pragmatic solution, inspired by the Product Development Project at Aalto University, became to draw upon the national law material stating the rights of an employee. The law sketches out a process where the employee (in this case the student) owns the rights to an invention, but the company owner has the rights to demand these rights against a fair compensation.

4.3 What degree of interdisciplinarity to strive for?

In order to ensure that interdisciplinarity or diversity enhances innovation, it must be both "*the availability AND use of a multitude of knowledge domains*" (Justesen, 2007). This can be compared to the differentiation between cross-disciplinarity were several disciplines work side-by-side to solve a problem and interdisciplinarity that demands a cross-over of the dicisplinary frontiers, shared goals, an integration of the different disciplines and development of the shared knowledge (Tress, Tress, & Fry, 2005). In other words, it is not enough to place different disciplines in the same team. Something more is needed, but what?

Another related discussion is the degree of interdisciplinarity in the team. It is obviously easier to see the value in complimentary specializations e.g. mechanics and electronics collaborating, whereas with more interdisciplinary teams it is harder to collaborate but also has more potential for product innovativeness (Henneke & Lüthje, 2007).

4.4 How to supervise outside one's own comfort area?

One of the implications of changing focus in the project teaching is a changed supervisor role. According to Lotte Darsø, teaching or rather *cultivating* innovation competency demands much more than traditional disciplinary supervision, rather the supervisor should act as a guide or coaches for their students (Darsø, 2011). To add on this the more or less specialized supervisors also have to support and/or challenge the students in acquiring interdisciplinary competencies as well as help them manage expectations and help the students maintain a critical approach to their customers, the strong and very engaged SME representatives.

Balancing this while also ending up grading the students might be an impossible task. In the design of the course it was decided that supervisors as far as possible will participate in all teaching sessions in order to both be perceived as part of the team and be able to act as a catalyst for the students to use the curricular as well as each other's knowledge. This opens for an economy challenge that in the development phase has not been an issue, but will be in the coming rounds. Furthermore, weekly meetings between supervisor and team are obligatory in order for the supervisor to be closer to the progress than he/she would normally be in this late stage of the education.

4.5 How to balance the examination of result, process and team contribution?

An obvious dilemma is reaching a constructive alignment in the case of examining contradictory goals. The authentic angle includes more pressure than regularly in learning to succeed with creating something, while teaching innovation entails creating a learning space where it is OK to fail. Furthermore the students in order to succeed with the interdisciplinary learning goals will be even more dependent on each other – it takes two to tango.

In order to align these paradoxes we designed a three-fold exam. One where the result was in focus, the handing over of the project to the company, by means of a persuading business proposal and a business oriented presentation of the prototype. This will count 40 % towards the final grade. Then a more academic oriented exam based on a written process and method reflection as well as a reflective discussion with the individual student on the process, results and learnings which also counts 40 % aimed at the failed project in terms of results but great in terms of personal skills learnings. Finally, to address the issue of interdependence, a peer assessment in which the students agree on a division of points based on effort and contribution in the project is included. This division if not equal, will affect the final grade with 20 %.

With these as some of the main dilemmas in the development we now turn to how the course is planned to be evaluated as well as a discussion of some the preliminary results.

5 Discussion of experiences from the implementation phase

Although the first course is still not completed, it has been possible to observe many positive signs towards accomplishing the intended learning outcomes, creating a trust- and respectful environment where the participants work interdisciplinary and learn from each other and succeeding in introducing an authentic project into a classroom setting. The student team join other activities together and assign their success in these activities to their interdisciplinarity.On top of that some interesting dynamics have already shown themselves: Of the two teams that started on the course, only one team remains. The collapse of one team has provided an opportunity for some interesting reflections on the importance and difficulties of teaching innovative competencies that will be discussed in the following sections.

5.1 Team Interdependency

During the first months we experienced a four person group fall apart. The first student left due to personal reasons, and they never quite regained foothill from there. The supervisors employed a multitude of interventions, but the internal conflicts kept the team from moving forward, further adding to the conflicts. Part was the difficulties of collaboration, and part was what in the supervisor analysis became; lack of maturity on the student side with regards to showing up at times for class and team meetings as well as delivering on promised work. When the second person left, and the problems still remained, the situation was discussed in the supervisor group. Had this happened in a normal setting we would probably have split up the group earlier, but due to the authentic situation of the students having committed to the company as well as the energy spend creating the *originating Ba* in each team, it was unattractive to close the project down and move the two remaining students to the other team. In the end both the students ended up choosing other electives.

This shows the vulnerability of the learning situation when a huge part of the learning is based on interdisciplinary teamwork. Measures need to be taken: First thing is to try to make the entry barriers higher, to weed out students with few basic study skills that elect innovation because it seems easier than other engineering electives. Second is to implement procedures that catch these, and third to make larger teams that are less vulnerable to one person leaving. But this is not the full story. Another issue in this group was the competency of handling uncertainty.

5.2 Handling uncertainty

"I want you to tell me what I should do", was the frustrated response from one of the students in the elective a few weeks before he finally decided to change to another elective. On the supervisor side, this was experienced as the same frustration of week after week having this particular student being late or not doing the tasks we

agreed upon, or being passive and unsure when guided and in general not playing along. One could argue that building the self-efficacy (Bandura, 1977) through mastery experiences was not successful, neither did the environment in the group provide the social persuasion to explore this new field. In other words the course content and learning situation did not serve to stimulate a scaffolding process (Wood, Bruner, & Ross, 1976, p. 90) that enabled the student to act in this new field nor provide structures that could guide this student. On the other hand one could argue that this was more a question of maturity on the student side. Not being able to meet up at a fixed time in class and neither have self-control enough to prepare the agreed material, was a general study ability lacking that this advanced elective could not mend.

In future electives this type of student might be helped more by providing regular course hand-ins, especially during the divergent phase, in order to force a progression and in order to guide the unsure student along the process.

5.3 Company Collaboration

The companies have shown a great flexibility. They have seamlessly adapted the task to fit the interests and showing a high level of ability to include into their organization the students' motivation and skills towards creating new opportunities. With this approach showing a high level of improvisation or in other words the ability to act effectually (S. D. Sarasvathy, 2001).

Unlike anticipated, charging a small amount has not become an issue when recruiting the companies. Rather, or maybe as a result of this, they have been very engaged in the process and provided all the knowledge the students have asked for in a timely manner.

The current experiences indicate that the structure for company collaboration in the elective works well and should be continued. What would be very interesting to look into is whether the short time horizon in the projects, do actually motivate the students as there is a chance that their work will get to the market as well as provide a concrete constraint that inspires innovation or if it rather hinders innovation, leaving the results to be only incremental innovations and the students feeling limited in their approach.

6 Conclusion

An elective, SME Innovation and Intrapreneurship program has been developed in order to create a learning process that stimulates the development of inter-disciplinary and innovation competencies. The elective comprises; a *preject* and a *project* period, supervisors not only acting as subject experts, but also as coaches, and an exam format including both a result oriented hand-in and presentation as well as a team, process and method reflection. The elective stimulates a close communication with the company representatives that sponsor the development. The five major dilemmas of the course design of the elective have evolved around the themes of the meeting between real life and a university learning space, project and product ownership and what content within innovation and interdisciplinarity to teach, how to do it, and how to align the exam format.

Though a full evaluation of the implementation has not been conducted yet, current experiences have indicated that the general course structure works. Especially regarding the aquisition of interdisciplinarity the students show signs of not only functioning together, but having internalized an understanding of their strengths as an interdisciplinary team. This has been supported in the course by a heavy focus on personal and disciplinary contributions and collaboration in the preject-phase, recurrent reflections in class and with the supervisors, and not least alignment with the exam goal of being able to explain the main disciplinary choices in the project regardless of discipline. Development of innovation competencies have been harder to assess during the course so that will be addressed as soon as the course is concluded. However, one important finding is that more emphasis should be put on creating a safe structure for the students to support the transition towards training innovative competencies such as handling uncertainty. Also new responses regarding dysfunctional teamwork need to be developed in order to address the vulnerability of the team-heavy structure.

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