Implementing design-based learning in engineering education
Case Aalto University Design Factory

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INTRODUCTION

Design is one of the fundamental processes in engineering. The nature of design work is becoming increasingly complex, as the straightforward technology-driven design tasks have been replaced by ill-defined, ‘wicked’ problems [1], which typically have no definitely correct solutions that can be identified beforehand. To tackle these problems, today’s engineering graduates need to possess strong communication and teamwork skills as well as a broader perspective of the social, environmental and economic issues that concern their profession. The academia and industry have awakened to the fact that many graduating engineers, although well informed of the disciplinary knowledge, do not possess the design thinking and working skills necessary in the complex and multidisciplinary product development environments [2]. Also the students themselves are calling for more constructivist, student-centred, hands-on teaching and learning strategies [3].

Even with a widespread recognition of these needs [4], the predominant model of engineering education has still remained similar to that practiced in the 1950’s with large classes and single-discipline, lecture-based, teacher-centred delivery of theoretical knowledge [3,5]. The existing engineering programmes are too focused on engineering science and technical courses without providing sufficient integration of these topics or relating them to industrial practice, failing to provide sufficient design experiences to students [3]. Providing these experiences is essential for the development of design thinking skills. Approaches to instruction that further connect knowledge to the context of its application [6] and develop the necessary skills to successfully handle the ill-defined, complex design problems [7] are thus called for.

In this paper, we discuss the need for, and the application of the design-based learning (DBL) model that integrates the benefits of problem- and project-based learning into a design-specific teaching model. This study discusses a case example that highlights the advantages and challenges of implementing the DBL principles in engineering education. The study depicts the experiences of teachers and students engaged in the DBL activities within the presented setting of an experimental education platform; the Aalto University Design Factory. The results reflect what the students and teachers themselves perceive to be valuable in the environment contributing to the application of DBL and some of the most important enabling factors associated with the application DBL.

1 DESIGN-BASED LEARNING IN ENGINEERING EDUCATION

Design studies and education are generally conducted from specific disciplinary viewpoints, where a field develops strongly focused academic traditions to meet the needs of that field [8] – the education of engineering designers differs significantly from the education of for example architects and fashion designers. However this might mainly be a reflection of the increasingly specialized technologies the designers have to master and have less to do with their ways of working.

The specific and common approach and abilities shared across design disciplines have long been acknowledged within the design community [cf. 9]. These skills and abilities specifically professionalized in the fields of design have since been referred to as *designerly ways of knowing* [10], and most recently, *design thinking* [11]. Lately, the supposed abilities of designers to create creative and useful outputs have drawn tremendous attention also outside the realm of design, as is evident from the recent buzz around design thinking. This discussion focuses on the ways designers work and approach problems; issues that are not connected to disciplinary expertise, which typically has been the main (or sole) focus of engineering design education.

To address the challenges and needs discussed above, elements of problem-based and project-based learning have been implemented in engineering education [3,12,13]. In the following we provide a brief overview of these approaches, and describe how the design-based learning approach may counter some of the issues associated with problem- and project-based approaches.

1.1 Problem- and project-based learning

Problem-based learning is a student-centred teaching model, where a problem forms a basis for the learning process; students work in small groups, and the teachers guide their work as facilitators or tutors rather than teachers. Problem-based learning represents to a large extent the dominant approach to teaching design thinking in engineering education, and addresses the development of those skills, through e.g. problem-based approach, group work, reflection, and open-ended outcomes. [3,12]

Project-based learning bears many similarities to problem-based learning. However, engineering academics are typically more familiar with the concepts of projects in their professional practice than with the concept of problem-based learning. It is based on engaging learning experiences that involve students in complex, real-world projects through which they develop and apply various project work and substance related skills and knowledge. Learning requires students to draw from many information sources and disciplines in order to solve problems [14]. Also the effects of project-based learning are in line with those of problem-based learning: the students are generally motivated, demonstrate better teamwork and communication skills, and develop better understanding of the application of their knowledge in practice as well as the complexity of the issues involved in professional practice. [3]

Despite of their obvious advantages, the implementation of problem- or project-based learning has mainly taken place in individual courses rather than adopting either one as a major part of the curriculum [3]. Team assignments typical to these models tend to have unsatisfactory results if they are not grounded in real life cases [12]. It is also a significant challenge to build up a common language across disciplinary boundaries and to benefit from the previous knowledge and experience of the multidisciplinary team members. Students have been reported to often lack the ability to connect interdisciplinary subjects to their own narrowly defined fields of expertise and fail in identifying and valuing the contributions of multiple fields to complex problems [4,12].

While the problem- and project-based learning approaches address many of the elements of design thinking, they leave some of the key issues unattended. Some educators consider problem-based learning inadequate for solving the loosely defined, or “wicked" design problems of the engineering field [15, 16]. The possibility of misconceptions in problem-based learning might lead to construction of false knowledge [3]. Some educators also see project-based learning often leading to doing for the sake of doing [6]. Furthermore, he students who participate in problem- or project-based learning may lack understanding of engineering fundamentals. Finally; evaluating the effects of these models has been very limited [17].

1.2 Design-based learning

Design-based learning (DBL) was introduced in 1997 at the Eindhoven University of Technology to build experiences upon practices [13]. It is a project- and problem-based instructional approach that aims at educating students on design thinking. It has also been referred to as Learning by Design [18]. The multifaceted, interdisciplinary design process is capable of producing new knowledge in a way that is analogous to the scientific inquiry process [19]. Solving design problems in project-based setting provides a natural and meaningful venue for learning both science and design skills. The collaborative nature of design provides opportunities for teamwork [13,19].

Being based on active learning, DBL situates the students at the centre of a learning process. As in problem- and project-based learning, the role of a teacher changes from being a lecturer to facilitating the learning process. Typical stages of DBL include defining the problem and identifying the need, collecting information, introducing alternative solutions, choosing the optimal solution, designing and constructing a prototype, and evaluation. The design process is parallel to problem solving [19]. Features of professionalization, activation, cooperation, authenticity, creativity, integration, and multidisciplinarity are central to the DBL process [13]. DBL addresses the development of design thinking skills directly, than problem- and project-based learning approaches. This is manifested in for example the explicit attention some of the key elements of design thinking such as interdisciplinarity, prototyping and experimentation [cf. 20].

Despite of being implemented for over the past 10 years in practice, the concept of DBL still requires further development. Even though some examples on the ways of teaching design thinking in higher education are available [e.g. 12] empirical research on DBL in higher education has so far been largely absent, while design approach for teaching science concepts has often been examined on a middle-school level [19, 21]. To discover in what respect DBL can be considered either as preparatory for the design practice or as a vehicle for learning specific design elements requires empirical research in collaboration with engineering educators conducting DBL-like courses [13]. In the following, case example of implementing DBL is presented to partly address these needs, highlighting some key enablers and antecedents of implementing the DBL principles in engineering education.

2 AALTO UNIVERSITY DESIGN FACTORY AS A DESIGN-BASED LEARNING ENVIRONMENT

To shed light on supporting the implementation of DBL, we discuss a recent effort in Finland to promote student-centered, design-based approach to teaching along with interdisciplinary collaboration amongst university students, faculty, researchers, start-ups, and established companies – the Aalto University Design Factory (ADF).

For this study, altogether 53 students and 12 teachers from the fields of engineering and science, business and design were interviewed between 2010-2011 on their experiences at ADF. Of the interviews, 14 student and all teacher interviews explored the experiences of the community members with an open-ended story-based format, inquiring how they had ended up at the ADF, and what had happened since. This data was supplemented with 39 student interviews focusing on their work on a year-long project course with a DBL-approach executed at ADF.

An analysis based on grouping interview segments according to thematic similarity conducted by five researchers resulted in descriptions of the experienced typical characteristics of interaction, action, support and personal work at the ADF, as well as in the perceived characteristics of the ADF entity itself. The results do not offer proof of whether these perceptions are accurate in an objective sense, but they reflect what the students and teachers themselves perceive to be valuable in the environment, why they have chosen to act on such a platform and what the costs and benefits have been for them. This paper does not attemp to to provide a thourough overview of the interview results (including exhaustive listing of categories and themes), but rather to describe some of the most important findings related to antecedents and the implementation of DBL.

2.1 History and origins of Aalto University Design Factory

The origins of ADF relate to a merger of Finland’s three leading universities of technology, art and design, and business in early 2010. The new institution, named Aalto University, has according to its strategy aimed to open up new possibilities for strong multidisciplinary education and research. These strategic objectives of Aalto University manifest themselves in the operating principles of ADF, which was founded in 2008 to be the first physical education environment shared between the three schools. The foundations for ADF were however laid long before the preparation of the merger. The Laboratory of Machine Design at the Helsinki University of Technology had already joined students across the engineering disciplines in a product development project course since 1997, and had in addition brought in industrial designers from the University of Art and Design since its early ears. Towards 2008 students from several other disciplines had become regular in the course. The Laboratory of Machine Design had also become a hub for other interdisciplinary education, such as the International Design Business Management programme, an established collaboration between the three universities to later form Aalto. In order to better support this interdisciplinary cooperation and the education of product developers, a research and development project funded by a number of companies and the Finnish Funding Agency for Technology and Innovation, called the Future Lab of Product Design (FLPD) was conducted during 2007 and 2008. In 2008 the FLPD experiment was scaled up to form ADF.

2.2 Supporting design-based learning at ADF

ADF functions as a platform for interdisciplinary product development education, research and industrial collaboration, and, on a wider sense, a catalyst for a culture of experimental and design-based learning in higher education. ADF has strived to achieve these aims by providing a non-hierarchical, constantly developing collaboration environment for students, teachers, researchers and business practitioners across hierarchical, professional, and disciplinary boundaries. ADF itself does not organize teaching, but provides physical spaces, mentoring and practical support for teachers and students. ADF is a 4000 square-meter facility with spaces for various types of formal and informal activities ranging from meetings and individual project work to large-scale events and prototyping. The spaces include informal facilities, such as a community kitchen, which are aimed at providing the students the possibility to relax amongst work and spend time together with other members of their teams and courses. During 2008-2010, ADF hosted 32 courses for approximately 900 bachelor- and master-degree level students, 12 research teams, 7 resident firms (with dozens of companies collaborating oncourses and research), as well as a multitude of training activities for both academics and practitioners.

3 STUDENT AND TEACHER EXPERIENCES AT ADF

In this chapter, the manifestation of DBL elements and key enablers for adopting the DBL approach drawn from the experiences of the students and teachers are presented alongside quotes from the interview data.

3.1 Manifestation of DBL elements and their perceived value at ADF

The interviewed teachers value the Design Factory foremost as a facility enabling more possibilities for interactive and motivating teaching than other more traditional settings (large lecture halls, auditorium-like spaces and fixed furniture). In contrast to the dominant teaching styles at their own departments, the teachers felt that ADF staff, spaces, facilities, and ways of working encouraged them to teach in a more student-oriented, problem-based, hands-on way. They were eager to experiment with teamwork and interdisciplinary teaching incorporating real-life problems.

The majority of the reported pedagogical developments had to do with interdisciplinary courses and cooperative arrangements with other ADF courses, ADF staff members, and industrial and NGO partners. Some teachers described radically developing their teaching philosophy and practices taking advantage of the possibilities offered by ADF. For example, some teachers implemented new hands-on methods, student projects, video presentations and product development exercises into their courses. Many teaching developments were also related to new ways of giving and receiving feedback from the students.

Design-based course work was described as interesting, motivating and fun. Seeing the physical results and concrete impact of one’s work motivated the interviewees. The teachers stated that DBL activities resulted in eagerness to learn. The students valued the hands-on approach of the ADF courses and the possibility of different levels of prototyping and model building, and reported feeling highly motivated to giving their best and learning as much as they can. The students described doing more than was required, pursuing goals persistently, and acting outside their comfort zone. Students also described realizing and clarifying what kind of work they want to do and how they see their own role. On the other hand, motivation sometimes led to having an overload of work, and the increased amount of self-guidance in learning activities left some students hoping for more feedback on their work. Other than these, no negative effects of DBL were identified.

”the learning outcomes were so good, I finally saw that the students were really learning something (…) How the students reflected their own view of learning changed during the course (…) You could see that they had learned a lot about themselves, the subject and working together. The learning was not restricted to just science (…) I was happy that I had given them something beyond the substance” (teacher)

3.2 Key enablers for adopting DBL approaches in teaching at ADF

Constant physical presence of peers from different disciplines and backgrounds was experienced to enhance immersion to the interdisciplinary learning experience. Especially the teachers stated that ADF provides potential for ad hoc collaboration by bringing people with diverse backgrounds physically close to each other. The highly concrete interdisciplinarity and internationality of the ADF community was described to widen the perspective and knowledge base of the teachers and students, providing tangible benefits of interdisciplinarity.

”It is great when you have different teachers from different departments. So you get to see a bit of their ways of working, how they do things. So you can spread the knowledge you have and also receive it from others.” (teacher)

Informal atmosphere and blending of work and leisure time was emphasized by both students and teachers as supportive of interdisciplinary project-based work. ADF was described to provide an important common home base and relaxed working facilities for their project activities. Having a common and neutral physical home base was seen important in supporting the work of interdisciplinary teams. Both students and teachers reported engaging in open and informal sharing of ideas, knowledge, and expertise within the ADF premises. Especially the teachers had initiated development for the common good, suggested new activities, initiated interaction, and expanded their work through the ADF network.

The teachers felt that the **flexibility and lack of bureaucracy** at ADF affords faster and easier DBL-based development than the more traditional environments. However, more systematic procedures and efficient information flow were called for. The readily available and freely usable spaces for model-building and prototyping (as opposed to fixed working times) were seen as essential for development of ideas through experimentation and prototyping. Also, according to the teachers and students, the unpolished ADF spaces convey a message of being allowed to do things differently and provide opportunities for the use of various teaching methods.

”I can sit here for longer periods of time, thinking about the ideas I want to implement in the project. Then I have these tools available downstairs, so I can just go there and I don't need permission, ’can I use your, can I do this or that’. So.. it's like, a kind of an independent atmosphere, whatever you want you can do there.” (student)

Providing both **inspiring examples and practical support** was depicted as major factors in crossing the threshold to implementing alternative, DBL-based approaches. Providing pedagogical role models and inspirational course examples enhanced the pedagogical development motivation of the teachers. Both teachers and students reported becoming more courageous and receiving practical help for their activities at ADF. Receiving practical help for experimentation greatly increased the likelihood of concrete action, with also the facilities and atmosphere described as encouraging experimentation especially by the students.

4 DISCUSSION AND CONCLUSIONS

The findings confirm and illustrate the motivational effects [24, 25] and practical benefits of implementing DBL in science education with both teachers and student displaying convincing evidence of positive outcomes, such as the development of the crucial communication and team-working skills [2] in addition to disciplinary expertise. The findings explicate the characteristics of DBL found at ADF, namely student-oriented, project-based, hands-on, interdisciplinary teamwork incorporating real-life problems. The physical platform supportive of design activities enhanced wider implementation of DBL approach across disciplines. In contrast to the mismatch between the straightforward problem-based learning [3] and the loosely defined, wicked design problems [2], DBL was seen as a natural way of improving interaction, motivation, teamwork, and learning results.

The study contributes to the understanding on antecedents and enablers of the application of DBL by illustrating some key factors in the context of ADF. Practical help, positive examples and an atmosphere supportive of the DBL activities were seen as essential in moving from traditional ways of working towards more unfamiliar alternatives associated with DBL. Support was valued both among the students and teachers. Physical presence of different disciplines and possibilities to informal group interaction, as well as a shared physical home space seemingly contributed to the integration of disciplines and understanding the value of the others expertise often found difficult to achieve [4,12].

In brief, implementation of DBL in engineering education can be supported with spaces, interaction, and ways of working. A common home base and physical closeness enable interdisciplinary group work. Open, informal interaction between various parties of design process lowers the threshold for collaboration and integration. However, more attention should be paid to providing feedback throughout the learning process. Practical support, examples of successfully implementing DBL in practice, and encouraging atmosphere are critical for experimenting with DBL.

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