

University as a Laboratory – Exploring how engineering education can support industrial needs

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Abstract

Universities have two major tasks; generating knowledge through research and educating students for academia, the public sector and the industry. In this paper, the authors explore how engineering education can support industrial needs on two fronts: creating a case study platform for research and preparing graduating engineering students to become more capable engineers when beginning their working life in industry, by applying the "University as a laboratory" concept. "University as a laboratory", as coined by Henriksson (2017), means that research-based case study projects are brought into educational courses where students are assigned to work as engineering designers, and researchers can observe problem solving patterns and evaluate different methodologies (also presented by Henriksson and Johansen (2016)). Though the concept have been presented earlier (Henriksson and Johansen 2016, Henriksson 2017), a more thorough evaluation is in order to further understand the effects of integrating research and education in the "University as a laboratory" concept. This is done through the performance and evaluation of a research-based engineering design education project in collaboration with automotive industrial partners; a project on lightweight and sustainable product and production development. The study evaluates three aspects of the project; the researchers' view, the teachers' view and the students' view. Data on all three aspects has been gathered through group interviews, observations and written assignments during the project, as well as interviews with participating students one year after the end of the project and workshops with researchers and teachers involved in the project. Analysis has been done on a qualitative basis, to investigate whether case projects are suitable for deep understanding in engineering fields and whether project courses are suitable to test different approaches of integrated product and production development.

Keywords: Engineering education, Case studies, Integrated product and production development, Automotive industry, student perspective

1 Background

Universities are usually described as being given two or three major tasks from society: generating and communicating knowledge through research (this is sometimes divided into one task describing the knowledge generation, and one describing the knowledge communication) and educating students (often for work in academia, industry or the public sector).

Given that engineers often work for 30 to 40 years in the field after their graduation, and technological advancements, engineers need to be able to update their skills and adapt to new environments during their working life. Some have pointed to a half-life of knowledge (Arbesman, 2012) within mechanical engineering significantly shorter than the average working life (Smerdon, 1996). This points to a need for life-long learning and an engineering education focusing on adaptive knowledge rather than technological details.

To gain this adaptive knowledge, students must be able to separate the formulation of the problem from its solution. Students also need to manage complex requirements elicitation and design, for different variants of engineering problems.

Given this half-life of knowledge, universities also need to generate knowledge quickly in order to keep up with technological development. There is a possibility to use student case projects (Henriksson & Johansen, 2016) in a University as a Laboratory setting (Henriksson F. , 2017). This is to create well-documented case studies investigating certain parts of an integrated product and production development project, but there are challenges with using such an approach (Henriksson & Johansen, 2016).

Both these challenges; how to teach engineering students to separate formulation of problem from solutions, and how to generate fruitful knowledge quickly enough to help industry, needs research from the design and product development field.

At Linköping University, a project course is given to the final year students in Mechanical Engineering and Design and Product Development MSc programs. The course focuses on applying skills and knowledge acquired throughout the BSc and MSc programs, but could be an enabler for deep learning within the program. Therefore, a study was conducted on whether this is achieved today, as well as how this course could be integrated with research on integrated product and production development.

1.1 Scope

The scope of this paper is to investigate how education and research can be integrated within a university setting. This is investigated to enable more efficient research and improved teaching for engineering students.

1.1.1 Research questions

Two research questions were formulated to guide the work presented in this paper:

- Is a project course a successful strategy for deep learning in engineering education?
- Are project courses and University as a Laboratory assignments suitable for identifying material selection challenges in integrated product and production development?

2 Theoretical framework

The theoretical framework is built upon two concepts: projects in engineering education, and integrated product and production development. These two concepts are described in this section.

2.1 Projects in engineering education

Projects can be used in engineering education in many ways, both for educational (Hallberg, 2012) and research purposes. When looking at educational use of projects in engineering education, CDIO is one of the main theoretical frameworks that should be mentioned. CDIO is a concept initiated by MIT and several Swedish universities in order to improve graduating students' ability to „conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment“ (Crawley, 2002). This usually means an increased implementation of multidisciplinary engineering projects, aiming at emphasising on the complexity of integrating multiple disciplines of engineering work within a project.

Projects in engineering education have an analogy in the problem-based learning-framework commonly used in medicine for the last half-century (Mills & Treagust, 2003). Though, the main difference between problem-based learning and project-based learning is that problem-based centers around acquisition of knowledge, while project-based education centers around application of knowledge (Mills & Treagust, 2003).

Earlier research shows that the usage of projects and problem-based approaches has positive effects on the students' ability to apply knowledge and critically review an engineering problem given to them (Yadav, Subedi, & Bunting, 2011; Hadim & Esche, 2003), but negative effects on the acquired factual knowledge (Yadav, Subedi, & Bunting, 2011).

2.2 Integrated product and production development

Integrated product and production development is a way of reducing development time in the product realization process, by managing production system development and product development in integrated projects. This could be viewed as a continuation of Integrated Product Development (Andreasen & Hein, 1986) and Concurrent Engineering (Prasad, 1996) with the emphasis on production development in the described methods.

One important factor in integrating product and production development is material selection and introduction processes (Henriksson F. , 2017). Materials are selected due to their properties, both quantifiable and unquantifiable (van Kestern, 2008; Ashby, 2000; Karana, Barati, Rognoli, & Van Der Laan, 2015; Karana, Pedgley, & Rognoli, 2014; Karana, Hekkert, & Kandachar, 2010), from a large number of commercially available materials (van Kestern, 2008; Liu, You, Zhen, & Fan, 2014).

The process of selecting materials in a product can in itself be seen as wicked problems or ill-defined problems, given that is an attempt to find the best solution given contradicting and conflicting requirements and boundary conditions (Liu, You, Zhen, & Fan, 2014; Lönngrén, 2017). To solve this, multiple processes and tools for material selection have been suggested through time (Ashby, 2000; Karana, Barati, Rognoli, & Van Der Laan, 2015; Liu, You, Zhen, & Fan, 2014; Das, Bhattacharya, & Sarkar, 2016; Ramalhete, Senos, & Aguiar, 2010). Some are more specifically geared towards machine elements with only quantifiable material requirements (Das, Bhattacharya, & Sarkar, 2016), while others put a heavier emphasis on the perception of the materials gearing them towards products with significant human interaction (Karana, Barati, Rognoli, & Van Der Laan, 2015).

When selecting materials, a number of challenges has been identified in earlier research. The lack of data regarding the perception of materials is a significant challenge (Karana, Hekkert,

& Kandachar, 2010), along with the lack of comparable data between materials from different suppliers (van Kestern, 2008). Sometimes, material data cannot be acquired on all different abstraction levels needed, something that is vital due to the different material data needs throughout a product development process (van Kestern, 2008). There is also a challenge in understanding the material requirements, since the most demanding requirements might occur in the production process and not during use (Henriksson F. , 2017).

3 Methodology

In order to investigate the proposed research questions, a case study was set up. The case was placed within a course at Linköping University. The unit of analysis in the analysis of the first research questions are the project members, which were students in their final year of an MSc education in either Design and Product Development or Mechanical Engineering. In total, there were seven students; four studying Design and Product Development and three studying Mechanical Engineering. The unit of analysis in the analysis of the second research question is the case and project itself, focusing on the students' work during the project.

In this case, the set-up was to develop a more sustainable car seat in cooperation with a Swedish vehicle manufacturer, focusing on replacing materials with cellulose or plant-based ones. The result should have a significant less environmental impact during its life cycle than today's seats, without compromising quality and safety aspects or induce changes in the assembly process.

3.1 Methodology for answering research question 1

Before the project the students performed started, a project brief and preliminary requirement specification was set up (t_{-1} in Figure 1). This was the start-up information for the project. At the end of the project, a product prototype was presented along with a project report and individual discussion reports from all students participating (t_0 in Figure 1). The project report and individual discussion reports are used as examination in the course, along with some other measures. Approximately a year after the project ended, a brainwriting session was performed by one of the participating students (and one of the authors), resulting in an interview guide and an individual memo. These documents were used in a brainstorming session to revise the interview guide and perform the interviews (t_1 in Figure 1). Finally, the interview notes and individual discussion reports were analysed with the revised interview guide as a framework for analysis (t_2 in Figure 1).

The identification and ranking of engineering challenges has been chosen as the indicator for deep learning and understanding.

3.2 Methodology for answering research question 2

The methodology for answering research question 2 was an observational study of the project (between t_{-1} and t_0 in Figure 1) along with a coded analysis of the project report and individual discussion reports (t_0 in figure 1). This analysis was done in parallel with t_2 in figure 1 but is not visualized. The coded analysis has focused on identifying challenges in material selection focusing on information requirements and ranking requirements when selecting materials.

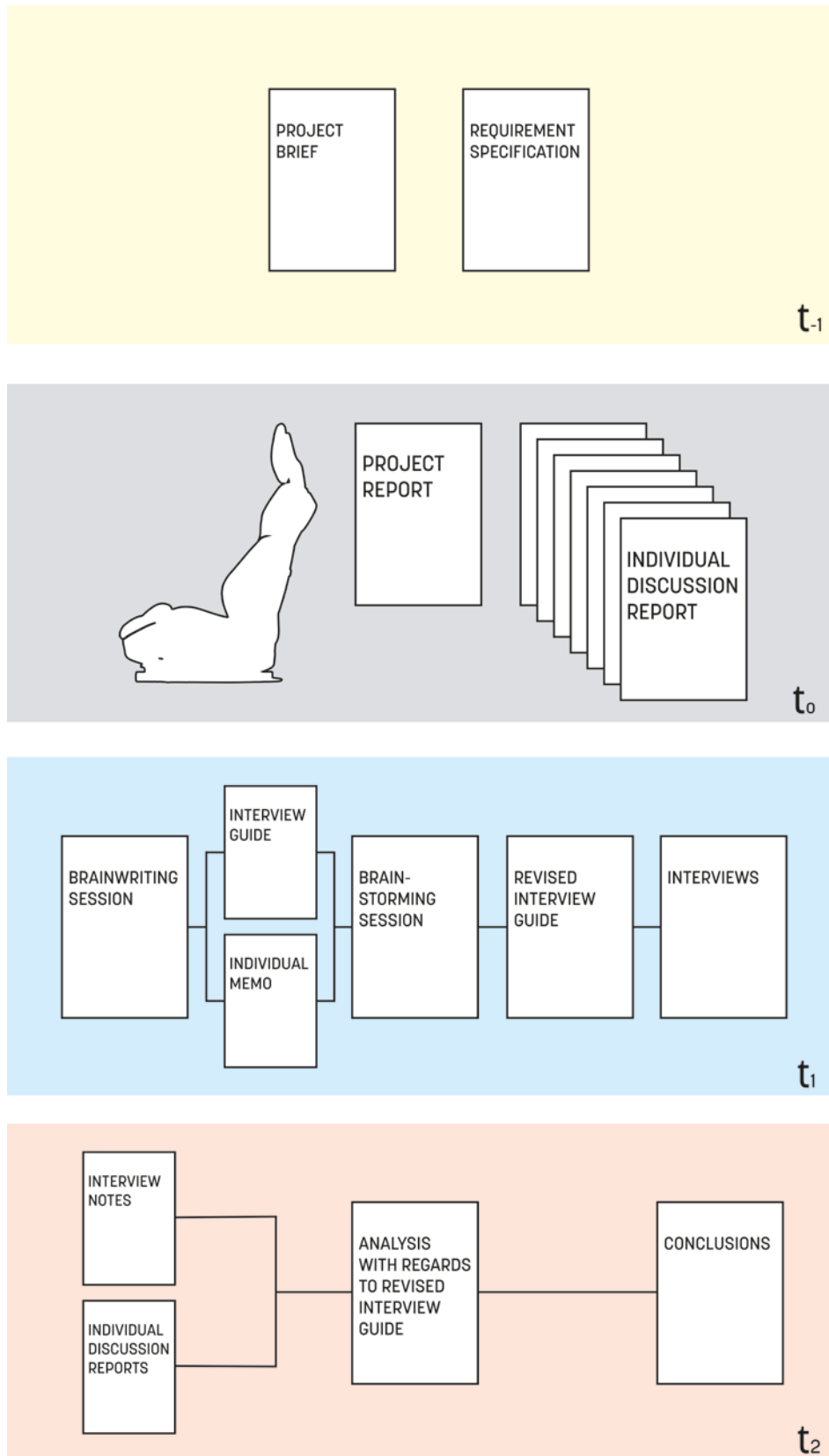


Figure 1. Chronological description of the four phases of the research project

4 Findings

The findings will be presented in chronological order, meaning that findings examined during the project (and thus corresponding to research question 2) will be presented before findings examined after the project (and thus corresponding to research question 1).

The students applied a combination of Ashby's methodology for material selection, with a classification of components with regards to types of material requirements, and Karana et al's method for material driven design (Karana, Barati, Rognoli, & Van Der Laan, 2015), in order to select materials throughout the project. This meant that materials were first selected on their quantifiable properties, and then a user test was performed with relevant materials to make a final material proposal.

During the project, the students found the material requirements identification process complicated and challenging, due to the complex production and use case. As a critical safety system during an accident, the seat has several vehicle impact-derived requirements complex to model and validate without cost-intensive testing procedures. At the same time, the time-sensitive production and assembly of a car seat generate several requirements that the seat needs to be designed in accordance with.

Also, the students expressed challenges acquiring comparable material data, especially when working with novel materials. These materials were not always commercially implemented in mass production, which meant that the students and suppliers had to estimate certain material characteristics and data. This also affected simulations and validation, since material models used in for example FEA modeling were uncertain. Especially, generating reliable life cycle analysis results proved significantly challenging due to the lack of data available.

In their individual discussion reports, two out of seven students explicitly mentioned identified engineering challenges. All students mention learning benefits and give a brief explanation of their accomplishments in the project, and while five students in total mentioned some sort of challenge in the project, three of these were not engineering-related. In their interviews, all students (five out of seven students participated as respondents in the interviews, one student conducted the interviews) pointed at engineering-related challenges within the project, from acquiring material data to converting topology optimization data into a functioning design.

5 Analysis

The challenges expressed by the students with regards to material selection corresponds with earlier research, both the complexity in number of materials to select from (van Kestern, 2008) and the challenges in identifying material requirements (Henriksson F. , 2017) and acquiring comparable material data (van Kestern, 2008). The conflicting requirements (Liu, You, Zhen, & Fan, 2014) and working with products where material experience are central adds to the complexity (Karana, Pedgley, & Rognoli, 2014).

The lack of correlation between the findings of identified challenges in the individual discussion reports and the interviews makes it risky to say whether these projects generate deep learning. Literature points towards this, but given the results in this study this cannot be proven. The students all mentioned learning about engineering challenges in the interviews, implying that some sort of knowledge is acquired, but more than this cannot be said within the scope of this

study. The lack of learning coverage in the individual discussion reports points toward the need for a development of guidelines for the individual discussion reports, rather than anything else.

6 Discussion

Given the lack of deep learning-related knowledge within the individual discussion reports, it seems like there is a need for more extensive guidelines for individual discussion reports. As a preparation for this, the authors conducted a small survey study within the teaching team responsible for most major mechanical engineering-related project courses at Linköping University. Teachers were asked to answer three questions:

- Name the three most important aspects of an individual discussion report
- Name the three most important activities for the student to cover in their individual discussion report
- Name the three most important qualities for you when grading an individual discussion report

The survey was sent to 30 respondents, and 12 out of 30 responded. The respondents were both junior and senior lecturers and researchers and represented all three research groups within the teaching team. While this survey doesn't have any significant scientific value due to the low response rate, the answers pointed towards a clear lack of consensus in what should be included and emphasised in an individual discussion report. A clearer view on what constitutes deep learning, and how this can be expressed within an individual discussion report, is a clear next step in order to be able to validate learning outcomes in engineering project courses.

7 Conclusions and future work

7.1 Conclusion to research question 1

Given the material gathered throughout the study presented, it is not possible to say whether projects are suitable for deep learning in engineering education. This is since the individual discussion reports do not contain information assumed to be connected to deep learning in this study.

7.2 Conclusion to research question 2

During the project, the students expressed challenges similar or identical to what can be found in earlier research on the selection of materials, implying that the University as a Laboratory approach is suitable for identifying challenges and evaluating solutions for material selection and introduction within integrated product and production development.

7.3 Future work

For future work, the authors would propose studies to investigate which characteristics define a suitable project for University as a Laboratory approaches. Henriksson and Johansen (2016) defined some success factors for including student projects in research, but these need further investigation and expansion.

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