NordDesign 2014
August 27 – 29, 2014
Espoo, Finland

Learning outcomes of a project-based capstone product development course

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Abstract
Product development and front-end project management with an emphasis on learning-by-doing educational philosophy is seen as one possible answer for closing the gap between industry expectations for graduate´s working life skills and the actual learning enhancement provided by the academia. The question is not so much why, nor it is what. For these we have had an abundance of answers since early 1960´s. The question is how? How to implement hands-on doing focusing on relevant working life skills such as project working capabilities in a teamwork setting, design thinking and communication skills, in addition to the actual disciplinary knowledge. This paper reports preliminary results from a work-in-progress study that analyses the course structure, teaching philosophy and learning outcomes of a course that aims to provide relevant product development, team–based project working and project management skills in an open-ended environment to students. The key research question was what kind of learning outcomes were achieved during the course. Secondly how do these results reflect on the intended learning outcomes. The course is an academic year long Product development project –course run by Aalto University and has been up and running using the same course structure since the year 1997. The course is viewed on its structure, teaching methodology, and most importantly through its intended learning outcomes. Data gathering included eleven semi-structured thematic interviews. Analysis was done using approach and elements from grounded theory method. The results show that the structure, teaching methods and the learning outcomes of the course are aligned and correlate with the intended learning outcomes. According to the preliminary findings the courses main learning outcome is that the students have been able to construct meaning for different processes and components in order to achieve successful team–based project work in a product development context. Processes and components include areas such as team work, project management,

communication, doing instead of passively following, working remotely and the importance of prototyping.

Keywords: Team–based learning, Product development, Problem-based learning

1 Introduction

Grand global challenges are growing. Not only globalization and the need for sustainable and holistic innovations per se but that all of these need to be addressed in a very complex context. Especially engineering graduates need to be equipped with relevant disciplinary knowledge of their field and just as importantly with skills such as systems thinking, problem solving skills, synthesis thinking, communication skills and teamwork capabilities [1,2,3,4]. It can be argued that in many projects the process and generic skills are even more important than the content and disciplinary skills [5]. It is not enough that the industry sees the importance of cross-cultural, interdisciplinary and team-based cross-functional operations when designing new processes, technologies and products but also universities need to be able to answer these demands [6,7]. Much talked innovations happen in between disciplinary and knowledge boundaries. Specializations between boundaries and the collaboration between specializations is a prerequisite for competitive advantage and it is also hard to maintain. [8] There are several different examples, structures and programs in higher education that have addressed this field [4,5,6,9]. All of these are very valuable and this work-in-progress study aims to add on to that discussion [4,5,6,9].

1.1 Boundaries of knowledge

More and more complex processes including research and product development are done in multinational projects [10]. This calls for an increasing amount of multiparty, multicultural collaboration spanning over temporal, physical and geographical distances as well as national, organizational, cultural and professional distances [11]. Completing successful projects especially with overlapping national and organizational perspectives is difficult [12]. The existence of several boundaries leads to pronounced imbalance of different resources between the contributors and inhibit collaboration. [11,12] If early stage overall design process is done well, it results in fewer downstream problems such as conflicts between engineering groups, launch delays and costly rework [8]. In an industry project where there are increasing pressures regarding time-to-market and quality, conflicts between different groups such as designers, engineers and marketing people arise. *Actors must work across boundaries. For example early phase product development is an area where it is important.* In a given project it is important to define and describe the relative complexity at a given boundary and also the range of potential circumstances [8]. When novelty increases the need to share and assess new knowledge also increases. This means that there is need for coping with uncertainty and ambiguity [13].

1.2 Problem-based learning, PBL

The product development project uses a variation of Problem–based learning (PBL) in its approach to learning enhancement. PBL is a well-recognized system and teaching method especially for engineering education [4, 14]. Due to its differences in levels of implementation and an abundance of hybrids it is difficult to establish the breadth and depth of the usage of PBL [4]. There are practitioners and communities ranging from one single course to whole institutions using the approach [4, 14]. Characteristics for PBL are [2, 15]:

1) Open-ended, ill-structured and complex, preferably, real-life problems. This is the stimulus for the course process and driver for learning during the course,

2) Learning is student centered,
3) Teacher that is the educator plays a role of a coach, facilitator and a supervisor,
4) Learning takes place in small groups where students clarify the concepts, define the problem, analyze the problem, find suitable explanations, formulate a relevant learning objective, do a background research for further information and finally,
5) Communicate the results and information [15]. This process is enhanced through self and peer assessment.
PBL learning principles, understood broadly, have albeit stayed very much the same at least for the last ten years [4,14,15]. Cognitive and collaborative learning in the context of possibly interdisciplinary group formation and exemplary way of doing combining theory and practice are the bases for PBL [4].

1.3 Design thinking

Design thinking as a concept is not easy to define [16]. However it is without a doubt at least loosely related to product development. Even if design thinking is not explicitly stated to be part of the course in question it still shares the same values of design thinking and that is why design thinking is lightly presented here.
PBL approach is very close to design thinking as well [13, 17]. Design thinking integrates problem forming, solving and design. It is a human-centered methodology combining engineering sciences with social sciences, business and design. It is about problem solving and more importantly about problem forming. Storming, performing and norming can also be part of it but the main focus is that it is a Human-Centric approach and methodology with emphasis on social sciences, business and engineering. [13, 14, 17] The pragmatic manifestation and process tool of this is conceptual, rough and rapid prototyping [17]. The aim for all this is to create radical innovations in a setting where there is nothing but uncertainty and ambiguity. Emphasis must be more in finding the right questions instead of finding the answers and making the decisions. And remembering that there is typically an abundance of "right answers" and "feasible design solutions". How to decide which is the right one? Open solution space is of paramount importance to the process allowing the design team to find their way towards a holistic solution combining complex social, technical and system demands in a dynamic and divergent setting. Generally the concept development phase is divided into four stages: *1) concept creation, 2) concept screening, 3) concept scoring and 4) concept testing [7]*.
Product design and development can be loosely attached to design thinking which is a broad concept and a combination of tools and approaches such as:
1) *Human centred approach, 2) Customer needs based approach, 3) Rapid iterative learning cycles –- Prototyping, 4) Focusing on managing team dynamics, 5)Mindful and co–creative project process, 6) Build to learn – Prototyping, 7) Designing the customer experience – full cycle, 8) Maintaining an open bias towards action (utilizing: do – test – learn cycle) or [observe – prototype – test = learn], 9) Questions should have an equally large or larger role than deciding what to do.*[17]
One way to present the design thinking values as set of skills are shown in the table 1. This set of skills are common elements of design thinking in the managerial discourse. [16]

Table 1 Set of skills that are related to design thinking. [16]

PRACTICES	THINKING STYLES	MINDSET
• **HUMAN-CENTERED APPROACH** People-based, user-centered, empathizing	• **ABDUCTIVE REASONING** The logic of "what could be", finding new opportunities, urge to create something new, challenge the norm	• **EXPERIMENTAL & EXPLORATIVE** The license to explore possibilities, risking failure, failing fast
• **THINKING BY DOING** Early and fast prototyping, fast learning, rapid iterative development cycles	• **REFLECTIVE REFRAMING** Rephrasing the problem, going beyond what is obvious to see what lies behind the problem, challenge the given problem	• **AMBIGUITY TOLERANT** Allowing for ambiguity , tolerance for ambiguity, comfortable with ambiguity, liquid and open process
• **VISUALIZING** Visual approach, visualizing intangibles, visual thinking	• **HOLISTIC VIEW** Systems thinking, 360 degree view on the issue	• **OPTIMISTIC** Viewing constraints as positive, optimism attitude, enjoying problem solving
• **COMBINATION OF DIVERGENT AND CONVERGENT APPROACHES** Ideation, pattern finding, creating multiple alternatives	• **INTEGRATIVE THINKING** Harmonious balance, creative resolution of tension, finding balance between validity and reliability	• **FUTURE-ORIENTED** Orientation towards the future, vision vs. status quo, intuition as a driving force
• **COLLABORATIVE WORK STYLE** Multidisciplinary collaboration, involving many stakeholders, interdisciplinary teams		

1.4 Product development project -course

The product development project (later referred as PDP) -course has its roots in the 1980´s at Helsinki University of Technology originating from the mechanical engineering department. The course is under constant development but for the last 17 year the main goal has been to bring together engineers, designers, business and other students enthusiastic of product development.

The current teaching philosophy is considered to be problem-based learning. The course consists of lectures in the beginning, milestones throughout the course, some workshops for certain skills such as safety, visual communication or prototyping, presentation training and separate training for project managers. However as the course is, on the basis of credits, calculated to be 270 hours during the academic year most of this time the student teams work independently.
The students get a sponsoring company and a real industry challenge that often is open-ended and ill-defined. Students work in teams that consists typically ten students including a project manager and usually at least one remote member from partner universities. Each team decides on their own their approach and ways to solve the given project.
The course aims to provide a working life experience in which students need to adapt to different situations, tolerate ambiguity and unclear goals. The course is normally taken at the end of the studies and for students who study product development specifically have other courses for methodologies.

The course is held at the Aalto Design Factory premises from the year 2008 on at the Aalto Design Factory (later referred as ADF) premises. ADF is an experimental platform of Aalto University that is designed to enhance co-creation, team work and experimentation. In the ADF premises bureaucracy is kept to minimum in order to promote hands-on doing and experimenting instead of just talking and planning.

The PDP –course does not explicitly state to be teaching design thinking. However the course philosophy shares many ideas with design thinking and combines them with problem-based learning. These ideas are for example promoting users and human factors as well as prototyping as much as possible and collaborative working style. The PDP course as well as Aalto Design Factory aim to promote activeness of the students, to give peer-learning experiences and support and facilities to the students. These aligned with design thinking and as such make it important to present design thinking.

2 Methods

To gather the insights of the PDP´s learning outcomes semi-structured interviews were conducted. As PDP learning outcomes have not been studied before, the interview questions were created to cover learning experiences of the course participants. The responsible teacher was interviewed in order to elaborate intended learning outcomes´ point of view.

The student participants had completed the course during the academic year 2012-2013 and they presented different fields of studies ranging from engineering to business and design. The interviews took place within two months after the course had ended. The invitation to the interviews was sent via the course email list. Out of all the approximately 190 students that did the course ten answered as the participation to the interviews was voluntary. Those ten students represented nine different teams out of the total of 19 student teams. The responsible teacher was also interviewed for the intended learning outcomes.

There were four different nationalities and the interviews were conducted either in Finnish or English depending on the interviewee. All except one were masters´ level students across different study fields. The interviews lasted between 50 minutes to 70 minutes, averaging at 60 minutes. All the interviews were audio-recorded and transcribed. The interview content was analyzed and clustered based on the rising themes answering the direct and indirect question of what the students felt that they had learned during the course or what had been meaningful for them.

This study has limitations due to the engineering perspective on the study as well as the sample is not sufficient to make strong conclusions. Two of the authors have close connections to the course as an alumni (two authors) and as a former course assistant (one author).

3 Results

Analyzing the student interview data six main themes rose as the main learning outcomes: 1) importance of project management and planning, understanding what is the role of a project manager, importance of clear delegation of tasks and responsibilities, 2) team work, importance of team building and team culture, 3) importance of good communication, ways and medias of communication, interacting with different people with different backgrounds, 4) being proactive, bold and doing instead of just talking, 5) working remotely in an international environment, 6) basics of product development, how to prototype, importance of prototyping and ideation. These themes are further explained below.

1) Importance of project management and planning, understanding what is the role of a project manager, importance of clear delegation of tasks and responsibilities

All the students commented on this theme regardless if they were project managers in the team or not. The importance of good project management and planning seemed to be very clear after the project to the students interviewed. This is valuable information since managerial activities in different project phases is still widely ignored in management literature [18]. They also mentioned that they should have done more planning thus recognizing the value of good planning. Depending on how well the project manager succeeds it was either great help or hindrance to the project.

> "You get out of a project what you put in. If you want an excellent project you have to put in excellent focus.. It was definitely a holistic undertaking of project management"

> "Then we saw that this kind of planning works.. ..so for March we had very detailed plan maybe for every two days, we had tasks that had to be finished.."

2) Team work, importance of team building and team culture [6,9,13]

The PDP is based heavily on team work and it shows clearly in the results. The students commented that they had learned team work, understanding the value of a good working team and if not how to build one, at least how not to build one.

> *"..strong confidence on what other people can achieve even though they are very different as long as they have the same goal."*

> *"..we spend a lot of time outside design factory, we would have movie nights and make dinner together. Doing this really helped us."*

3) Importance of good communication, ways and media of communication, interacting with different people with different backgrounds [5,6,9,13]

Students found communicational issues very important. Understanding that clear and working communication is not self-evident and thus needs to be considered throughout a project. This included: media for communication and different ways of communicating, as well as having a good relationship with different stakeholders. Students started to value different disciplines and saw that all of them have different yet valuable points-of-views of a project.

> *".. I learned how to justify my choices. In the beginning we were saying that I like this, I don´t like this… then we learned that we have to bring reasons, and engineering reasons why it doesn´t work and not just - I don´t like it"*

> *"..I didn´t know anything about the mechanics.. so I really learned how to talk, to communicate with engineers and designers.. ..they all need to be talked to in a different way."*

4) Being proactive, bold and doing instead of talking [13]

Almost all students reported about the importance of action and hands-on doing for learning. They felt more confident and active and not being afraid to ask for help or opinions from outside the team.

> " PDP has taught me that you can be open to new approaches.. ..the most important thing is just to do things and test them."

> "We tried to solve the problems ourselves instead of complaining to the teaching team. We also had an alumnus that helped us a lot."

5) Working remotely in an international environment [10,12]

Students reported and commented on the difficulties they encountered with remote members during the project, although working with an international team was seen as a positive asset. Students mentioned difficulties with communicational issues or practical issues such as internet connections or time zone difficulties and managerial issues such as finding suitable tasks for remote members.

> "..engaging the international teammates, and they were great, but the amount of work that they could do was limited because when you´re prototyping all of it needs to be done in one place"

6) Basics of product development, how to prototype, importance of prototyping and ideation [5,6,13]

From product development point-of-view, students commented understanding the basics of it. Prototyping and ideation were the two main topics under product development that rose to be the most important in the students´ minds. Prototyping itself was reported to be a very good tool for communication and that stood up as hands-on doing in comparison with the normal lecture based studying activities [20]. Students described ideation being difficult but important.

> "..for the project so the whole process who you are, what are you doing, why you are doing it, who are you creating this for, who is the user and what are their needs.."

The student interviews were conducted in order to discover some learning outcomes for the PDP -course. The official intended learning outcomes were collected from the official course introductions and materials and responsible teachers´ point-of-view was collected through a semi-structured thematic interview. The results are presented in a table 2.

Table 2 Official intended learning outcomes for PDP

Product development course officially	
Team goals	Individual goals
all the necessary development phases are complete and a prototype introduced	to become better aware of the quality of his or her own design, engineering or business skills
by practicing project work in an interdisciplinary team students shall become able to:	to understand the potential and the challenges of the interdisciplinary work
work out project plan & schedule	to understand how successful PD is based on both traditional and exceptional methods and tools
manage resources & risks	to understand Product Development costs and economy
complete a project successfully	to be able to deliver high quality oral and written reports
communicate & document effectively	to prepare for negotiation situations and to deal with agreements, NDA´s and IPR´s

Responsible teacher´s additional intended learning outcomes that were discovered in his interview, are long-lasting learning, finding functional ways working, possibility to learn from others and realizing the value of different disciplines, being proactive, capability to execute and having a good attitude, asking for help, taking offered help and understanding that to you can also learn from failures.

4 Conclusions and discussions

We set out to research what kind of learning outcomes were achieved and how those reflected on the intended learning outcomes of the course. The amount of data and the demographics of the focus group are not statistically nor scientifically broad enough for determining paths of causality between the interview results and the intended learning outcomes for the course. We cannot determine what teaching methods affect what kind of learning. Instead the results section shows implications and correlations between the results and the intended learning outcomes.

We state that the analysis shows relevant themes that arise from the data and they are strongly aligned with the intended outcomes for the course whether official or the responsible teachers´ interview. These are the six themes presented in the results section. These six themes resonate with design thinking as well. The table 1 presented under design thinking can be lightly reflected on the results. We believe that with this data and these results it can be suggested that especially the practices of design thinking were present in the learning outcomes that were identified through the interviews. PDP seems to bring up especially collaborative work style, thinking by doing. PDP does not state to provide expertise on design thinking but these preliminary results suggest that the course does provide some important features of design thinking to the students, even when not stated explicitly as such.

Those few intended learning outcomes that did not appear in the data were mainly in the area of learning of patents and NDAs and the understanding of product development costs and the economy. According to the preliminary findings if PDP aims to give more procedural knowledge and skills in product development one of the possible development points could be that the course would have more checkpoints with structured feedback and more active overall support during the course. This could enhance further learning of the product development processes with relevant methods and tools. There is a need for more research on the topic.

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