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FROM SYSTEMATIC DESIGN PROCESS TOWARDS TEACHING PRODUCT DESIGNER'S TOOLKIT

Timo LEHTONEN[1], Tero JUUTI[1], Kaisu RÄTTYÄ[2], Jarkko PAKKANEN[1] and Mikko VANHATALO[1]
[1]Tampere University of Technology, Mechanical Engineering & Industrial Systems
[2]University of Tampere, Finland

ABSTRACT
In higher level of engineering education, the training of single development process in the field of product development is no longer sufficient, because our students are employed in such jobs that they need to be able to understand the customer's perspective and the company's business goals in addition to the technical design process. Our purpose is to educate engineering professionals for the future who have a design method tool kit, from which they select tools with apt combination for the future task. The focus of this study is to prototype different learning solution, in which the learning goals and education approach is changed. The learning goal is that every student is skilled with ten methods, familiar with at least 30 methods and is able to find even more methods. The students are trained to identify the key approach of the method and evaluate its suitability for the present task.
In the beginning of the course, students are allowed to choose the subject for their product concept. In the second design session, we make an intervention by presenting "Six Deadly Sins in Product Development". Then we motivate the students by explaining that the methods help to avoid the common pitfalls. In the design studio, descriptions of 30 different methods have been placed on the walls. The methods are grouped according to their purpose to enable efficient choosing. We ask students to choose methods for a tool kit that they can answer to all mentioned common pitfalls.

Keywords: Product design education, Design methods, Problem based learning, Metacognitive skills

1 INTRODUCTION

In higher level of engineering education, the training of single development process in the field of product development is no longer sufficient, because our students are employed in such jobs that they need to be able to understand the customer's perspective and the company's business goals in addition to the technical design process. In the past, we taught the systematic design process because it provided a good understanding of product design. The disadvantage was that the student's user centric, organisational centric, and society centric design methods and skills required in development projects did not grow due to strong focus on the systematic design process. Our purpose is to educate engineering professionals for the future who have a design method tool kit, from which they select tools with apt combination for the future task. The focus of this study is to prototype different learning solutions, in which the learning goals and education approach is changed. The learning goal is that every student is skilled with ten methods, familiar with at least 30 methods and is able to find even more methods. The students are trained to identify the key approach of the method and evaluate its suitability for the present task. The education approach considers a variety of design methods and processes rather than supports only one design process.
This research uses educational design research strategy [1]. The strategy is chosen because it reveals the different layers of teaching design and the theoretical framework building. This research focus on how new approaches towards teaching product development was implemented based on the existing course to meet the revised learning goals. The learning goals are based on several sources; some of them are earlier studies in this field, some originate from curriculum planning and previous results of the course. The course design principle to have authentic tasks and design challenges to increase motivation and capable practitioners for the industry is part of the curriculum planning. [2] The assessment goals were derived from our earlier study [3]. Primary approach is to reward the unique

thinking and questioning the given information, secondary approach is to reward also on the quality of the content of the assignment work. Also the situational leadership model was used to drive students towards "involved learner" or "self-directed learner". At this level, the teacher is a facilitator and delegator rather than an authority or salesperson [4]. Also the teacher's knowledge on typical student misconceptions in this subject matter and habits learned during previous studies [5] was used.
The goal of this research was to find new teaching and learning solutions towards the use of very important metacognitive strategies needed in typical new product development project. The research approach combines case study research [6] and ethno methodological [7] practices. The primary researcher acted both as teacher and observer and had discussions with other researchers after the teaching sessions. The other researcher conducted an online self-assessment for students and participated to the last session where students presented their results and overall learning outcomes were discussed with students.

2 CHANGING REQUIREMENTS FOR THE DESIGN WORK

One can ask justified question of what change has made us to think that we should teach metacognitive ability to select suitable design methods instead of generic systematic design process. After all our university has taught systematic design process for well over 25 years. This change comes outside of the university. It is a change in the way of making product development and a change in the roles that your student will have when they graduate and start their working careers.
In the early history of engineering design, it was adequate that designer had good skills on mathematics and physics and has good knowledge on earlier designs in his area of application. A textbook *La Locomotive a Vapeur* (1938) [8] about designing steam locomotives written by André Chapelon, is a good example of this. Chapelon is often credited to be one of very few locomotive designers who tried to bring a rigorous scientific method to their design. He relied on experimental method and tried to find out why a certain design worked better than another did. However, most of the 912 pages of this book are used in presenting earlier locomotive designs. In his search of better efficiency, he did not present special design process for locomotives to supplement the basic scientific query approach. This approach was adequate, because the scope of his work was limited to achieving better and more efficient steam engines. One of Chapelon's contemporaries who adopt his methods was Nigel Gresley who developed fast passenger locomotives for London and North Eastern Railway. One of those Gresley designed locomotives class A4 4468 "Mallard" is often mentioned as world speed record holder of all steam locomotives [9].
During the 1950's and early 1960's the amount of new product development was increasing and looked evident that there will be shortage of experienced designers, who have learned their trade in traditional way by familiarising themselves to earlier design solutions. An idea of generic systematic design process started taking shape. The ideal systematic design process would rationalise the design work so, that it would be easy to teach designing in university environment without specific application area content. There are many significant textbooks in this topics, but let us mention here only few Robert Matousek *Konstruktionslehre des allgemeinen Machinenbaues* (1957, English translation *Engineering Design – A Systematic Approach* 1963) [10], Gordon L. Glegg *Design of Design* (1969) [11] and Gerhard Pahl and Wolfgang Beitz *Konstruktionslehre: Handbuch für Stadium und Praxis* (1977) [12]. The last mentioned gained popularity as university textbook and was translated in many languages. Even they were steps ahead in teaching methodologies; the core and the scope of the design work did not change a lot. If we take our example, the locomotive design, the problems with the main functionality remain the same: how the traction force could be developed and transferred to the rails.
When we analyse the design work of a locomotive as it is described above, we can see that it is possible to have clear requirements and problems can be formulated to clearly defined tasks. As far as we are in this kind of situation, the design process approach has served quite well. However starting in the late 1990's, the work of product designers was apparently changing. The most important development projects tend to be development of new technical environments instead of creating new applications that suit to existing environment. First cellular phone developmental phases were combining traditional telephone and radio communication technology to mathematical routing algorithms. Even though the combination was novelty, its components were known and use cases were mainly same as traditional telephones. This was no longer the case, when SMS-messages were developed. This was the first step on the development where cellular telephones were less telephones

and more something else. In creating new technical environments, the design problems are no longer well defined. The systematic design process, which expects us to be able define the requirements at the start, does not help us in this situation. The modern developer must have ability to adapt his working methods. It is not enough to develop skills, but in addition to have metacognitive skills and to be able to learn and adapt.

Pintrich [13] has defined three types of metacognitive knowledge; knowledge of strategy, task and person. Strategic knowledge is knowledge of general strategies for learning, thinking, and problem solving. Different learning strategies are grouped into three general categories: rehearsal, elaboration, and organisational learning strategies (Weinstein & Mayer, 1986). Organisational strategies consist of outlining, concept mapping, and note taking, where the student makes connections between and among content elements. Similar to elaboration strategies, these strategies usually result in better understanding and learning than rehearsal strategies. In addition to these, students can have knowledge of several metacognitive strategies that will be valuable to them in planning, monitoring, and regulating their learning and thinking. The knowledge about cognitive tasks includes knowledge that different tasks can be more or less difficult and may require different cognitive strategies. An important aspect of learning about strategies is the knowledge of when and why to use them appropriately and this is the main learning goal of our course. The third type of metacognitive knowledge deals with self-knowledge. It consists of self-awareness, self-efficacy, motivational beliefs and self-esteem [13].

3 WIDENING THE PROBLEM BASED LEARNING TO THE PROCESS SELECTION

Teaching metacognitive skills is not straightforward. The teaching situation setting must be such that the students would have real need for thinking what they are doing and why they are doing it this way. In small groups it is easier for all students to catch up the idea, that they are no longer working by instructions given by the teacher but they had to find working methods of their own.

3.1 Open ill-structured problem

20 students participated the course having 10 learning sessions during the course. The students already have some years of work life experience. In the beginning, the student groups are allowed to choose the subject for their product concept. They are asked to develop a product that would have real business potential. The product could be novelty, which market is missing or it could be improvement to an existing product. Our students have learned innovation methods in earlier courses and they are also familiar business model canvas visual tool [14] so they are able to develop and select ideas for topics and assess them in accordance the business potential. This task is an open and ill-structured problem. There are no restrictions on application area or the improvement sought after. The students are not actually seeking for solution, but exploring possibilities. This approach is thought to stimulate innovativeness [15]. The students were able to find interesting ideas. One group started developing furniture looking at a cricket farm for domestic use, where it would be possible to raise crickets for food. Another group started to develop a new way of loading beverage products on cargo pallet and dismountable special platform for boats used in water skiing. One group started developing an intelligent truck swap body loader.

3.2 Intervention

The students possessed minimum required set of methods at the start of the work. They had methods for idea generation and they had one tool for assessing the business case. The groups started happily their development work and soon they reached their first concepts for new products. They would be able to develop their product by trial and error as André Chapelon has done many times before them. Nevertheless, how would they ensure excellent solutions without similar skill and insight on application area that Chapelon had? At this stage, we intervened the process and asked, how they make sure that theirs development projects will not lead to failure? We present them six reasons for failure in product development, what we call “Six Deadly Sins in Product Development”. This list we have collected from our industrial partners. The six failures were:

1. The solution is optimal for design engineer, not for customer and business - for example, there is no point in minimising weight, if it leads the company to lose profits.

2. Product Intention - The desired product properties are unclear or not valid - the developed product will probably not live up to customer's expectations.
3. The concept is selected early on and the selection criteria are not explicit - it is vital to know whether another concept is more viable when changes occur.
4. Design Fixation - the team is stuck with their current design - the team and individuals are reluctant to make any rework and they oppose the change.
5. The contribution and value creation of some disciplines are missing - critical part of the value creation is not managed as the team is lacking key competences.
6. The project communication material is neglected and the presentations lack of credibility. The methods that students have might be able to handle some of these topics, but not all. So the teachers propose that groups would take in use more development methods and tools.

3.3 Design methods fair event

Students often think that design methods are abstract and difficult to understand and use. We tried to challenge their misconception by arranging design methods fair event, where we stressed that most design methods in product development are possible to present on one A3-size paper. Here we used the Delft Design Guide [16]. It is a textbook, which present 70 approaches, tools and methods for design. The layout in the book is made such a way, that every approach, tool and method has one opening. We attached a selected set of 40 methods and tools on the wall around the design studio. Then we asked the student groups go round and select such methods that help them to avoid six mentioned reasons for development project failure. Students were allowed to decide, how many methods they will need in their specific design task. When some groups kept on asking, how many methods they will need, they were told no more than two.

To make the selection more concrete, the students took the printouts of the methods they had chosen. We had included little gaming element to selection and there was limited amount of prints available and so only limited number of groups was able to choose certain method. Students we told, that it is possible that they won't find selection of methods that fulfils their expectations. Then teachers promised to present more methods and approaches – we had those 30 presentations from Delft Design Guide that we had left out. At the end of the event all groups had selected theirs methods. Then all groups made a short presentation of what methods they have chosen and how they will help them to avoid failures in the six mentioned points. This was an important part of the learning day, because the student groups had possibility to learn from each other and teachers had opportunity to see how students had understood the methods they had chosen. The key learning points for this day were that there are a large amount of methods available and it is very much depending on developers' choice what methods he/she will use. In addition, we want to help student to see that even it may take time to master a method, it is often easy to understand its goals.

3.4 Creation of product designer's toolkits

We used four hours in the design methods fair and that is very short time to get acquainted to number of methods. We didn't expect that all groups would be happy with their original product designer's toolkits. So the groups were allowed to change their design methods and at that stage there was no restrictions as to how many groups selected a same method. Reflecting was an integral part of the course. At the start the students had expectations of what the methods will bring to them. In the end the design work we asked them to make reflection how well their expectations had been fulfilled. At the end of the course the students were asked to evaluate how they did reach their design goals. We also asked them to report how much the chosen methods affected the result. We also asked them to consider, what they would do the same way next time and what they will do differently.

4 THE LEARNING RESULTS

As our research approach combines case study research and ethno methodological practices, the primary researcher acted both as teacher and observer. Thus it is suitable to report results, which can be measured and observations separately. The results of students' self-assessments are presented in figure one. The students were asked to assess the number of design tools they can use and their ability to choose appropriate design tool for particular design challenge two weeks after the last session. Thirteen persons answered the questionnaire out of twenty participants.

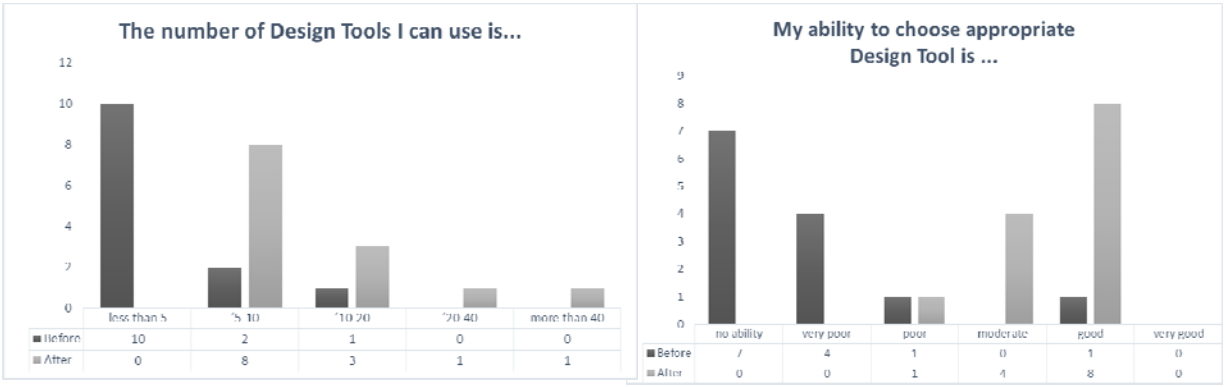

Figure 1. Results of the student's self-assessment on the number of design tools they can use and on their ability to choose appropriate tool for each design challenge. The bars on black indicate tools they can use before the course and on grey after the course.

Based on the results, the students adopted several new design tools. They also reported major learning regarding their ability to choose an appropriate design tool. Familiarity with 30 methods was generally not achieved, but maybe this goal is too high taking account the time available. Their self-assessment reflects the learning observed by the teachers quite well. The grades given to students were very good and most of the students' group exercise works were very good. All groups were successful of delivering their exercise in time. According these results, the course was successful. For the teacher, this teaching experience in this course was very pleasant. The students liked the freedom of choice, and on the other hand, they did not complain that the support would have been inadequate. The other researcher participated to the last session where students presented their results and overall learning outcomes were discussed with students. The students were naturally not able to compare their experience on corresponding experiences on our old courses, but they were satisfied with this course and felt that they have learned usable skills. Students had the possibility to give feedback of the course. The feedback included appraisal for the course like below.

"It was great to experience how university courses can be both inspiring and useful in giving sharp and hand fit tools for design work. These results can be shown with pride."

In the past, we have received feedback from our alumni for some years that, the engineering is not done as it is taught at university. With this teaching development, we are possible available to narrow this gap and thus develop industrial working methods in the long run.

5 DISCUSSION

The need for new course originates from the changed approach towards teaching product development. Analysing the learning goals emphasises us that the course should include large exercise, which should be based on practical design task that is as authentic to real development projects as possible. This approach is also supported by the research of good learning contexts by [17], highlighting the importance of reflective learning and relevant learner activity. The learning goals dictated that teacher-centred approach won't fit very well but instead situational leadership model was used to drive students towards "involved learner or self-directed learner". To achieve this, we have to overcome typical student misconceptions in this subject and persuade the students to change their attitude toward using design methods. The key element to achieve this was design methods fair event, which pedagogically reached its goals. We have earlier tried to teach product designer's toolkit approach, but we have not succeeded to change the responsibility to build the toolkit from teacher to

student. Thus we feel that the concept of design methods fair is very promising and it should be developed further in the future teaching experiments.
The downside of the research approach was that the sessions were not recorded. This would have made the analysis more credible. The student's self-assessment on their skill level was compared to their tangible results by the teachers. The perceived abilities and the actual outcomes were coherent and this increases the credibility of these results.

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