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Reflective Practice in Design Thinking, Learning and Performing Product and Process Development

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Introduction

Due to the demographics in most countries in Europe, the need to educate engineers is great. There is thus a big need to convince young people to choose the education towards a profession of engineering to meet the demands from industry. However, the need in industry, regarding engineers, is changing which forces a shift in education to correspond the changing demands of industry. Today a more focus on real projects in collaboration with industry is needed including a change in education from a traditional analytical approach towards a systems approach where the designerly ways of knowing and doing is in focus.

The ability to use and develop knowledge and creativity is considered to be the major strategic factors for future competitiveness. Significantly, knowledge and creativity are not just additional production factors alongside the traditional ones. These are the most meaningful and important resources for innovation and product realization in a company, its innovation capacity to meet demands of uncertainty, flexibility and creativity [1]. Furthermore no company today, that is trying to realize new products, can underestimate the great importance of design from the start to the market introduction. Design is also not just about function, form, style and color. It is also about understanding the users´ need, the product´s message (what story the product tells) as the deeper wishes, values and emotions.

In summary, there is a need for new innovative methods and models that will support and strengthen industry to generate new ideas and realize these into successful products, services, and improved processes. Also, the gap between academic research and industrial practice has to be bridged [2]. This can be done by developing tools and methods based on well-known and familiar design methods [3].

This paper argues that educating engineers based on "traditional" engineering is not enough. It is becoming more and more important to build bridges to other disciplines as "innovation" and "design" and to build "multidisciplinary" environments to be successful in business and in research. The objective of the paper is to discuss how changes in education can prepare students in a better way for future work in the industry. The results in this paper are discussed in relation to Mälardalen University in Sweden and an ongoing attempt to develop the education in engineering design in a multidisciplinary academic milieu.

Background

Expressions like "*design thinking"* is sometimes viewed as mystical and hard to grasp. Missing knowledge or misconceptions about design methods, which differ from familiar standard procedures, can cause these doubts. Still, the rapid progress in the development of new products and processes within the manufacturing industry creates a need for new and improved methods, in order to solve ill-defined problems, analyze and overlook knowledge as well as research for valuable information. Schön introduced a new structure of the practical learning process that includes three steps: learning, reflection and change [4]. Schön argues that the reflection is one of the most important elements for making changes and move forward. The step of reflection requires communication skills in the working team. This can be difficult because the teams often are formed by interdisciplinary members which opens up for questions how the reflective process of designing actually is implemented in practice?

A traditional and analytical view of engineering and product realization is a process of transforming different stakeholders' needs into output information, which corresponds to a manufacturing good design. This process includes e.g. scenario planning, idea and technology management, product planning, product development and production development including logistics, maintenance and recycling. The problems with implementing an efficient product development process can generally be explained by the high number of different phases, and thus disciplines, that all have to collaborate.

The product realization area has its origins in systems theory and the design science paradigm influenced by e.g. Hubka and Eder [5]. This view is based on an analytical approach, which is central to the professional identity of engineers and engineering research. The ultimate goal is to arrive with an economically produced product quickly to the market. The key to do so, for most of producers, have been to work through a chain of decisions by first establish clear objectives of the product, identifying the target market segment and trying to systematically determine the customers wants or needs. Structured design methods have been developed by e.g. Pahl and Beitz [6], and Ulrich and Eppinger [7].

As previously argued, we need to change from solely an analytical and traditional engineering based approach towards product realization. Instead industry must address areas as e.g. innovation, design, multidisciplinary team and environment, teamwork and collaboration, to support the development of the next generation products and services within industry Jackson et al [8] conclude that there is a need to develop and implement new innovative methods and models that will support and strengthen industry to generate new ideas and realize these into successful products and improved processes.

A multidisciplinary approach towards product realization is not a new phenomenon. Most innovative products and services spring not from particular industries or disciplines, but rather across them – the so called *Medici Effect* [9]. Medici referring to the Medici-family in Italy in the Renaissance period, who sponsored people from different disciplines and made Florence to an epicentre, an intersection and one of the most creative eras in Europe´s history. This intersection can also today be a place – a milieu – where ideas from different fields, disciplines and cultures can meet, leading to new ideas, new products and to innovations. Then a multi-dimensional approach is necessary, where engineers, designers, entrepreneurs, psychologists, economists and many more collaborate. Successful companies have implemented such a work practice.

The question then becomes how this multi-dimensional approach is integrated within our engineering curriculum? What type of changes can we within education that prepare students in a better way for future work in the industry?

The engineering work within product realization in industry is mainly done in projects. One could speculate that training in real projects is helping preparing students for the future. Still, project training could be done in different ways. In the paper we will continue discussing the need and ways for educating engineers, with a focus on projects and creativity in the development phase. Some examples of education programs will be analyzed at Mälardalen University in Sweden and an ongoing attempt to develop the education in engineering design in a multidisciplinary academic milieu.

The academic milieu of Innovation and Product Realization (IPR) at Mälardalen University consists of different research groups within Product- and Process Development, Innovation

Management, and Information Design. These three “academic partners” work closely together in an ´intersection´, where ideas from different fields and cultures meet, leading to new ideas and possibilities. It is not a ´marriage´ between our disciplines, but more of understanding, collaboration and using our different mindsets, knowledge and scientific methodologies in a value-creating way for the research community and for the industry. IPR was established in Eskilstuna in 2001 and has since then expanded and worked actively to become an established group within the region of Mälardalen and on a national level.

Methods

The paper is based on literature review and three education cases using different methodologies during product and process development projects at Mälardalen University. The three cases consist of three different courses on advanced level where the researchers have been involved in different ways, this is shown in table 1.

Table 1 Case description, the different courses content.

Course name	Case 1. Product development 2	Case 2. Project management	Case 3. Process development
Extent	7,5 hp	7,5 hp	7,5 hp
Researcher participation	Student	Student and teacher	Teacher
Aim	To give the students a deepened insight in and application of important tools in the process of product development applied to commercial products.	To develop students knowledge in project management and design thinking methodology.	To give the students a deepened insight in and application of important tools for process improvements in real life projects in industry.
Approach	Problem solving	Design thinking	Problem solving and design thniking
Type of project	A local company functioned as a client and asked for an innovative product development confined by time limits, costs and specific aspects.	Concept development with open brief. The result should be innovative and correspond to the need spotted in the understand phase of the process.	Manufacturing industries in the region around the university asked for an process improvement project. The projects have been run by students.
Main steps in process	1. Identify customer needs 2. Target specification 3. Generate concepts 4. Select product concept 5. Test product concept 6. Set final specifications	1. Understand 2. Create 3. Develop	1. Define 2. Measure 3. Analyze 4. Improve 5. Control
Structure of the groups	4-5 members/group, freely chosen based on personal characteristics, homogenous formed by students of the same program.	4-5 members/group, matchmaking between student ´s in order to create a multidisciplinary team with student from design, engineering and innovation management.	4-5 members/group, matchmaking between different nationalities in order to make sure every group has knowledge in Swedish.
Interaction with company	Low level of company involvement	High level of company involvement	Very high level of company involvement
Type of presentation	Visual presentation for the whole class, results in form of a report were presented to the client.	Communication of results in order to handover the continue work to the company.	Visual presentation for the whole class, results in form of a report were presented to the client.

The data collection has mainly been through Participatory Action Research (PAR), were the aim is to study something in order to change and improve it [10]. In this research the focus was to change and improve student knowledge and competence regarding execution of projects, to correspond industrial demands. Though we represent different parts of these courses a systems approach have guided us through the analysis.
The main question has been to analyze the different project courses, in relation to the project training as well as in relation to the need for building bridges to other disciplines as "innovation" and "design" and to build "multidisciplinary" environments.

Case 1. Course in product development, traditional approach
An example taken from a product development course at the Mälardalen University is described to show the classic product development process that is taught under the education.
The course is based on the ability to work in a keenly project as a team and in cooperation with a client. The students chose the project teams freely. The first contact with the client was setup by a short presentation of the company itself and the problem that had to be solved. The company in question was a subsidiary of a company that manufactures industrial furnishings. The company can be classified as new and small with just four employees. The company was founded with the vision to launch and introduce a product to the market that keeps the working space in order and helps to increase the control over the tools. The product lacked a packaging. The following section will briefly describe the product development tools used during the process.
The problem formulation and individual research assisted to understand the problem by putting the problem into words. The problem formulation allowed room for personal initiative and it defined likewise the restriction. One of the fundamental requests was to keep the costs as low as possible. That was justified by the fact that the packaging does not function as a selling utensil but as a guaranteed secure transport. Consequently the task was defined to help the young company to design a packaging for their new developed product that secures an intact transport. The product consists of several components in different dimensions and materials with different fragilities. Supplementary information to solve the details was collected by interviewing employees of a wrapping and packaging company. Elements that affected the concept generation the most were the dimensions of the components, costs, stability, security against damage and the size to make it possible to deliver the product by the local post service.
A variety of tools were used to get an overall picture of the project. One of these tools was a Gantt chart that was updated throughout the project. The chart functioned as a continuous control of the time and resource use. After structuring the project a function diagram clarified what function the packaging should satisfy by divide the functions into one main function, several sub functions and support functions to visualize the importance of the different features. It shows only what should be included in the solution but not how. Simultaneously were a requirement specification made to ensure that both the client and the project group have the same expectations on the final result. The specification can be defined as a contract between the two parts and it describes the common goal. Another tool to translate the customer needs into technical terms is QFD (quality function deployment). Using this tool shows the connection between customer needs and product features and makes it clear what aspects that are fundamental. In addition to that are existing solutions on the market analysed with held of the requirements. The Pughs method helped to compare the different developed concepts to each other. Scoring how exactly they reach the criteria ranks the concepts. A request mentioned by the client was that they wanted to fabricate the packaging in their own locations and if possible use material that already is used for other products in the company. Therefore was the aspect of making the mounting of the packaging as simple as possible and

keep the effort of time and resources as low as possible of interest. DFM (Design for Manufacturing) was used to enable an effective workflow. To reduce waste of time and dissatisfied customers risks were identified by using FMEA (Failure Modes and Effect Analysis). This analysis is structured in different steps. First identifies the damages that can happen and unable functions. Followed by the reason of damage and the consequences. The analysis includes even an estimation with which frequency the damage happens and how serious the effect is. The result of the FMEA is to reduce the defects and make recommendations to adjust the concept. As reasoning after every phase in the project was a PIPS-matrix (Phases of Integrated Problem Solving) filled in. It concludes the experiences and opinions of all group members linked to the project.

Case 2. Course in design thinking, a systems approach

This example uses the idPeo methodology developed by Wikström [11] and is build upon 33 projects during 2007-2011. The methodology is developed for innovative product development and successful cooperation. It focuses on management and flexibility of creative product development within organizations that are dependent on creativity, quality, and time-to-market. The process consists of eight key activities and an emphatic approach to the problem area, it also supports a holistic view with the use of visualization throughout the project. The process is based on three different phases that interact with each other, first the understanding of the problem area or the phenomena to study is in focus. Secondly, the focus is create and in this phase a moving towards a solution takes place. Third, a development of the solution starts with focus on creating solutions. These phases are seen as three approaches in the projects and not as a process with steps to do and gates to pass.

Next a generalization of the approaches will be described with focus on student insights made during the different projects, skipping the first part of the course were the methodology and some team building exercises takes place.

During the first part an understanding of the problem area is in focus. A short presentation of all the projects is presented by the teacher and then a question is posed – what is your contribution to the different projects? This work is to form the teams with a multidisciplinary setting, and to have students that are motivated and feel that they can add knowledge and competence to the group as well, if you put people with different backgrounds in a team they become experts within their field and this supports their self-confidence and self esteem. After this the different groups meet with the company assigned to them in order to get more information about the problem area and the company as a whole. This creates a fundament of understanding the scope of the project. However, the scope needs to be investigated further and this is done using explorative research with focus on ethnographic methods. When the scope is formulated as a design challenge a framing of the area to investigate is performed in order narrow the information search down to a specific area. The information gathering is interrupted with phases of storytelling and communicating within the team, this is to create a common mental image of the area studied. The stories told creates a framework for creating ideas, however the story needs to be concretized in order to support the ideation process. A lot of time is spent on understanding the area and synthesis the information into useful data; this is done using storyboard, scenarios and other concretization tools.

Secondly, after spending about half of the time available, creating understanding, the idea- and concept generation takes place. This is where the gathered information actually transforms into ideas and concept through creative workshops and a generative mindset in the teams. The early ideas generated are seen as starting points for further exploration, so the early ideas generates new concepts and broaden the solution space. The creativity needed forces the team to move from concrete thinking to more abstract thinking, and then back to concrete thinking again. This is to open up identifying themes and opportunities creating solutions and prototypes from. Prototypes and models could be seen as learning objects were they give more knowledge back to the process then invested. Through ideating a great amount of ideas are explored, these ideas are visualized in order to build up the argumentation of the finalized solution in the end. This supports the traceability of the ideas as well as the handover situation where a greater understanding of the decisions made is achieved.

Third, the concretization of ideas down to communicative concepts is in focus. This is actually where the traditional tools in engineering design have its place. However, the traditional tools give one source of guidance and the research and the intuition of the individuals in the teams create a different set of guidance in decision making. The focus is on communicating the core concept and how it responds to the scope and challenge formulated in the beginning of the project. In the handover situation storytelling is central in communicating the concept, this is however done in different ways but always with a focus in how the understanding of the area of interest has guided them throughout the project. The concept is visualized using the media most suitable for the situation, storyboard, prototypes or scenarios.

Case 3. Course in production development, a systems approach

A third example is taken from a process development course at the Mälardalen University. The objective with this course is to give the students a deepened insight in and application of important tools for process improvements in real life projects in industry.

The course is based on the ability to work in a project as a team and in cooperation with a company. The students chose the project teams and organization freely. The first contact with the client was setup by a short presentation of the company itself and the problem that had to be solved. Most of the companies in the course can be classified as SME's, even though also some bigger manufacturing companies also participate. The following section will briefly describe the project work used during the process.

The project follow five main steps with presentations and follow up meetings at each stage; define, measure, analyze, improve, and control. The definition phase includes a problem formulation and individual research assisted to understand the problem. Close contact to the company is necessary in this phase, and the students are required to formulate the problem and specify the project in a standardized project specification template. From a company perspective a fundamental requests was to reduce costs.

In the measure and analyze phases a variety of tools were used to visualize the process and get an overall picture of the project. Examples of tools are Gantt charts, VSM – Value stream mapping, OEE-analysis, problem visualization in fish-bone diagrams.

Moving towards the improvement and control phases a more creative approach is used. This includes brainstorming, benchmarking and company involvement. The projects most often does not include actual implementation, thus the control phase will be a later work within the company. Every step is visualized at the university with some standard information generated in each step, presented to the other students in the class as well as the teachers. A signal system involving red, yellow and green is used to indicate problem. This signal system helps the teachers to focus the resources to help in the right place.

Results

The field of design is becoming more and more important in order to meet the need of more innovative ways to solve problems and make things easier and more effective [12]. The different roles in a developing project are melting together and certain groups like engineers and designers need to work closer together. A method to make the teamwork possible without unnecessary miss-understandings must be available for everybody. The goal must be clearly defined and a common language introduced. Some people use words to define and explain specific things while others use visual skills. The difficulty is to find a balance between following standards and spontaneous, open decisions in the developing process. The process should include certain steps to reach the goal. These steps can differ depending on which method is used to develop new solutions and move the process forwards. One of the most important resources in product development is time and therefore it should be divided in a profitable way.

Discussion

The entire school system of today has programmed our students to find the only answer that solves the problem. However, we all know that there is more than one solution to a problem. Now we have to relearn how to explore ideas as we did in preschool in order to create different solutions to a problem. The three given examples clarify different methods for development resulting in problem solving. One of the main differences between the described cases is the architecture of the project groups and the way the members have been chosen. Building multidisciplinary groups can introduce the students to the need of building bridges between different disciplines, this makes possibilities for the students to expand their views and to interact with group members coming from other backgrounds, having different knowledge and experiences. This requires the ability of communication, to be able to express opinions and explain thoughts to team members with another way of thinking or less knowledge according to the subject. The students are going to meet this phenomenon of mixed project groups in the industry and should be prepared for it. Communication skills reduce misunderstandings and make it easier for all group members to follow the common goal.

Another difference seems to be the extent of using and focusing on certain product development tools, it is not always explained how to interpret the data given from the tools and how to use the knowledge and transfer it into several contexts. One problem in the three cases described concerning interpretation of data is the synthesis of information into useful knowledge. However, in the projects in case 2 which could be considered successful, this synthesis seems to have worked when the teams have used visualization in order to grasp the data. Furthermore, understanding the data has also been visualized using i.e. storyboards, scenarios or role-play. This implies that visualization supports the understanding of the data gathered in the early phases but also in understanding the data received from tools and methods used in designing the solution, in the latter phases.

The time being the usual limiting factor shows how important it is to divide the time into the different phases of a project. It is important to be prepared for spontaneous changes or disturbances during a product developing process. A time buffer included in the project plan can avoid unnecessary shortage of time in the end of the project. The distribution of time varies a lot between the different kinds of developing processes. The idPeo methodology sets the largest amount of time for the problem orientation and understanding before transcending to the creation of concepts and development of solutions. According to Schön [4] the reflective practices of professionals go through four phases; naming, framing, moving and reflecting. These phases are not seen as a linear process but as phases that interrelate with each other during the project. The visualization in figure 1 visualization in reflective practice
–support for management [13] shows a model of Schön:s reflective practice that is adjusted and performed interactively.

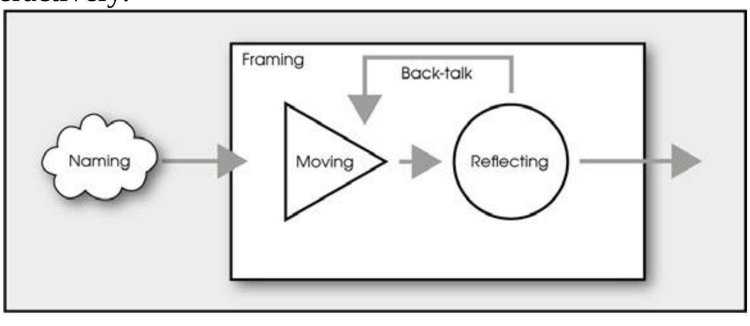

Figure 1 Model to understand the reflective practice by Schön (Wikström, 2012)

There is always the possibility to reflect on the work and modify the frame regarding findings that occur in the moving towards a solution that lead towards the common goal. In comparison to this active process that is developed during the work, the traditional product development process appears linear, seems to move in one direction, and there is no indication for reflection or reframing to ensure an innovative and successful result.

Conclusion

This paper argues that traditional engineering education needs to be adjusted to industrial demands, in three cases describing different courses at Mälardalen University a comparison has been performed focusing on educating students for the changing demands within industry of today. We conclude that three different areas are of importance in order to correspond to industry. (1) the growing demand of multidisciplinary work, (2) management of time for innovative development and (3) the synthesis of data for shared understanding. These areas could be handled within the broad frame of design thinking, therefore we suggests that traditional engineering programs is complemented with multidisciplinary courses in project management with a focus on design thinking.

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