Advances in Engineering Education

SUMMER 2013

A Product Analysis Method and its Staging to Develop Redesign Competences

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ABSTRACT

Most product development work in industrial practice is incremental, i.e., the company has had a product in production and on the market for some time, and now time has come to design an upgraded variant. This type of redesign project requires that the engineering designers have competences to carry through an analysis of the existing product encompassing both a user-oriented and a technical perspective, as well as to synthesize solution proposals for the upgraded variant. In the Product Analysis and Redesign course module we have developed a product analysis method and a staging of it, which have proven productive. In this paper we present the product analysis method and its staging, and we reflect on the students' application of it. We conclude that the method is a valid contribution to develop students' redesign competences.

Key Words: Product analysis, redesign, industrial products.

INTRODUCTION

Let us imagine a product development project in an industrial company where the project goal is to design a new and upgraded variant of a product, which has been on the market for some time. The company has set up a suitable design team with respect to size and disciplines to carry through the redesign project. For a successful redesign it is required that the team members not only synthesize a new and different technical solution based upon their knowledge of how the product functions and how it is manufactured, it is paramount that the team members understand needs and expectations from users and other stakeholders. This understanding increases the probability that the new and different solution results in a product, which will be seen as attractive and upgraded by users and potential customers. Thus, for an engineering designer to be able to contribute to a redesign project, he or she must have competences to carry through a comprehensive analysis of the existing product and how it is used and valued by the users. The analysis has to encompass both a user-oriented and a technical perspective, and the analysis result has to provide the engineering designers with an understanding of the product's raison d'être as well as attractive and realistic improvement opportunities. Thus, the team members have to have the following four *redesign core competences*:

1. A *mindset* so they can identify values seen in the users' perspective.
2. To be able *to conduct research* where they analyze an existing product and explore how users use and perceive the product in order to identify improvement opportunities.
3. To be able *to synthesize* solution proposals using creative and systematic methods.
4. To be able *to document* the research and the synthesis results.

The authors of this paper see an educational challenge in staging a course module (Product Analysis and Redesign), in which students develop knowledge, understanding and skills, to prepare them for being able to participate in redesign projects. For the course module we needed curricular materials, but to the authors' knowledge there does not exist a textbook on redesign. We were aware of a textbook in reverse engineering [1], but this book had too narrow of a technical focus. With respect to teaching synthesis (redesign core competence no. 3) there exist several textbooks on engineering design and product design, e.g., [2, 3, 4, 5]. We have chosen to use Cross' textbook [2] because Cross' description of the design process is in line with our understanding, and the level of the text was suitable. However, for the course module to fulfil its purpose we had to supplement Cross' textbook with teaching material and a way of working which develops the student's knowledge, understanding and skills with respect to all four redesign core competences. We have developed a product analysis method and a staging of it, which can enable students to better analyze an existing product with respect to function and manufacture and to analyze how users use and perceive the product.

The structure of the paper is the following. In the next section we describe the theoretical foundation of the product analysis method. Thereafter, we describe the conceptualization of the course module with focus on learning objectives and course means. In the next section we describe the course setup in more detail, before we validate the product analysis method and its staging in the course module. Finally, we conclude.

THEORETICAL FOUNDATION

Our theoretical foundation is composed by the following three elements:

- The *Domain Theory* [6, 7], which represents a composed system theory of products and their use.
- *Visual Thinking* [8] and application of visual design methods [9] because sketching and drawing are fundamental ways of working in design. The use of sketches and drawings enables the engineering designer to explore the problem and solution together [2].
- *Actor Network Theory* [10, 11], and application of socio-technical methods for user-centred insight and analysis.

The fundamental idea in our product analysis method is based on the Domain Theory [6, 7], which states that a product to be designed can be seen by the engineering designer in three domains:

1. The *activity domain* where the engineering designer focuses on the purposeful transformation when using the product, e.g., when a person uses a tumble dryer to dry clothes, the clothes are transformed from being wet to being dry.
2. The *organ domain* where the engineering designer focuses on the product's active elements (the organs), which create physical effects, and their mode of action. For example, in a tumble dryer we find a revolving drum, a heater, and a blower. The revolving drum is the organ that makes the clothes tumble, and the heater and blower are organs, which create a flow of hot air to make the water evaporate from the wet clothes.
3. The *part domain* where the engineering designer focuses on the allocation of the organs into parts, which can be produced and assembled.

The domain theory explicitly states that use-activities are synthesized by the engineering designer, whereas Pahl & Beitz [12] see the product as the entity to be designed and the use-activities and purposeful transformation when using the product as a consequence of the design. Thus, when we base the product analysis method on the domain theory we obtain three analysis perspectives: the activities when using the product, the product's mode of action and the manufacturing of the product.

The goal with the product analysis method is to give the students an understanding of both a user-oriented and a technical side of a product. The students have to develop the mindset that a product is not a technical artifact having value in itself. Value is to be found in the users' reaction when they use the product.

In accordance with the domain theory and the goal to understand both the user-oriented and the technical side of a product, we have developed *a product analysis method*, which encompasses three analysis dimensions, see Figure 1:

1. *Use-process analysis*: To understand users and other relevant stakeholders, e.g., persons maintaining or repairing the product.

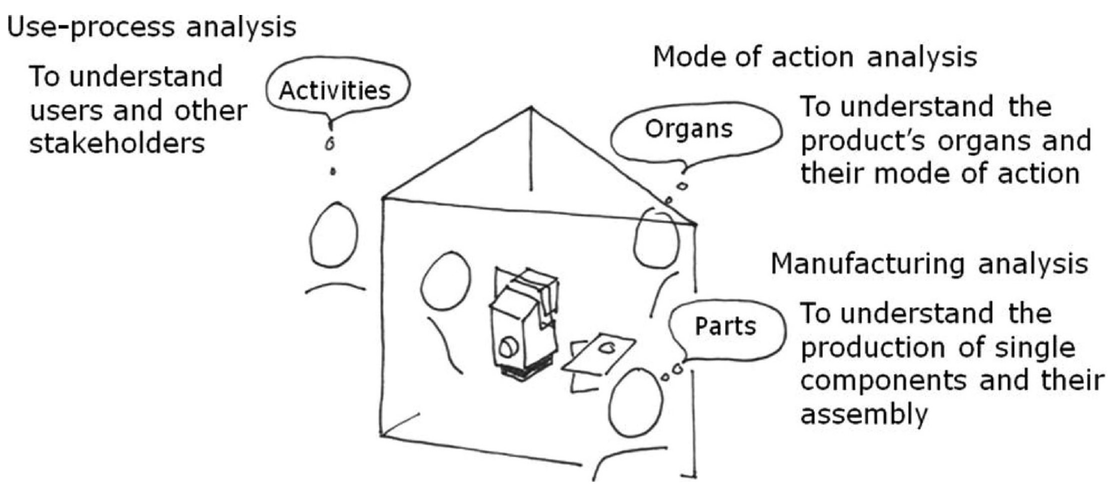


Figure 1. Three perspectives of the product in use. We see a user using the product "inside the prism", and "from outside" students analyze the use-process, the product's mode of action, and the manufacturing.

2. *Mode of action analysis*: To identify the product's organs and their mode of action.
3. *Manufacturing analysis*: To analyze the production of single components (parts) and their assembly into a complete product.

As a means to support and document the research and synthesis we teach the worksheet technique [13, 14], which is based upon principles of Visual Thinking [8] and visual design methods [9]. According to McKim [8] the interaction between the activities *to imagine*, *to sketch*, and *to see* is a fundamental approach to design, both as a means to clarify issues and to propose solutions. Cross [2] quotes from an interview with an engineering designer Jack Howe, who stated that, when he is uncertain how to proceed: "*I draw* something. *Even if it's 'potty', I draw it. The act of drawing seems to clarify my thoughts*." Hansen [13, p. 57] describes the worksheet technique: "*A worksheet is written in a fixed layout with a heading containing topic, name and date. A worksheet forms an information entity, which clarifies a certain topic or aspect, e.g., requirements, setting up solution alternatives, consideration with respect to life phase, or evaluation and decision. A worksheet may be from one page up to 20 pages. Several techniques are used in the worksheet, e.g., writing notes, sketching and drawing, diagrams from experiments, and photos.*"

Thus, *worksheets contain the designer's considerations and arguments during design work*. Figure 2 shows a page from a worksheet on the design of work platforms for ship building.

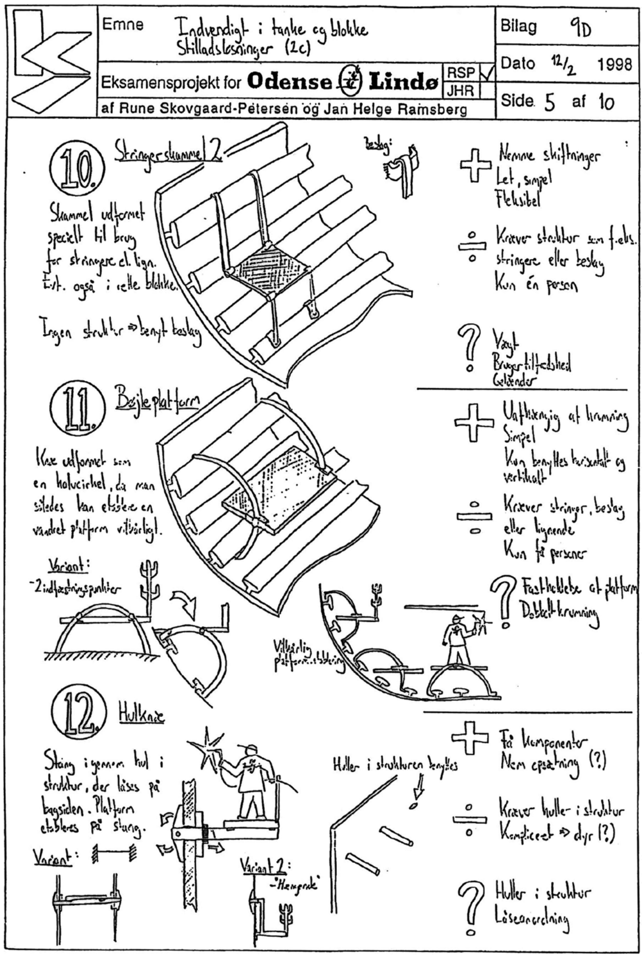


Figure 2. A page from a worksheet on the design of a work platform used inside ships. The page shows three solution proposals and considerations regarding strengths, weaknesses, and open questions, [15].

In order to understand the product from the users' perspective the students have to identify the users' engagement when using the product. Thus, the objective is to analyze the use-process, which is constituted by the user, the user settings and the user's interaction with the product. Actor Network Theory (ANT) and socio-technical methods [10, 11] provide a conceptual framework which can grasp the material and social relations in the use-process, and thereby constitute a theoretical foundation to explore and analyze how users and other relevant stakeholders interact with and perceive the product. According to Actor Network Theory, actors can be human, e.g., users and maintenance persons, and information collection can be carried out by observation of actors in action, such as users using the product or maintenance people maintaining it, or interviews. Other types of actors are non-human, e.g., legislative requirements with respect to the product and its use, maintenance, or disposal, and the information collection can be carried out by discourse analysis of documents. The idea with this ANT approach to use-process analysis is in line with Krippendorff's idea [16] that a designer has to develop a 'second-order understanding' of the product, i.e., an understanding of how *others* understand the product. The *others* are the relevant human actors, which are identified during the use-process analysis.

CONCEPTUALIZING THE COURSE MODULE

We describe the course module Product Analysis and Redesign since it constitutes the educational context and staging of the product analysis method. In this section we describe the course module concept, and in the next section we describe the course module setup. The purpose of this course module is to build the students' knowledge, understanding, and skills, so a student will be able to participate in and contribute to redesign projects in industrial practice in his/her professional career. The three central ideas in the course module design are:

1. The course module shall develop the students' knowledge, understanding, and skills toward the four redesign core competences.
2. The learning objectives, learning activities, and assessment methods have to be aligned [17].
3. Each student team is given an existing industrial product to analyze and redesign.

Learning Objectives

The core of the conceptualization of the course module is the formulation of learning objectives. On the one side the learning objectives constitute an unfolding and operationalization of the four redesign core competences. On the other side the learning objectives have to be obtained through an appropriate set of course means. Thus, formulating learning objectives is our stepping stone from the generic redesign core competences to the specific course means. We have formulated the following set of learning objectives of the course module [18]:

"A student who has met the objectives will be able to:

A. Describe a product's structure, mode of action and embodiment (mode of action analysis).
B. Describe a product's manufacturing and assembly (manufacturing analysis).
C. Identify the socio-technical context, which the product is a part of, and clarify the assignment of meaning in use through interviews with and observations of different actors (use-process analysis).
D. Interpret the results from the three analyses into a number of improvement aspects and on this basis formulate requirements and criteria for a specific redesign task.

E. Create solution alternatives for a specific new embodiment using a combination of systematic and creative techniques.
F. Select solutions and provide further details considering functionality, manufacturing and use.
G. Make a technical assessment of the merit of the solution alternatives with respect to requirements and criteria.
H. Argue for value in use based on the change in the socio-technical context.
I. Make worksheets to document observations, considerations, solutions, experiments and decisions in the work with analysis and synthesis.
J. Read and discuss the worksheets made by others as a means to share collected knowledge in the analytical work and clarifications during synthesis work.
K. Redesign a product based on the relevant analyses and the proposed alternative solutions.
L. Reflect on the quality of the redesign activity and own contribution."

The relations between learning objectives, redesign core competences, and course means are intended to be as shown in Table 1.

Learning objectives A, B, and C contribute to building core competence 2: to be able to conduct research, and they are obtained by a product analysis of an existing industrial product. Learning objectives C, D and H contribute to building core competence 1: a mindset to identify values in the users' perspective, and they are obtained by a use-process analysis and contacting the industrial company. The learning objectives E, F, G and K contribute to building core competence 3: to be able to synthesize solution proposals and they are obtained by and aligned with the redesign task and Cross' textbook. Learning objectives I and J contribute to core competence 4: to be able to document the research and synthesis results, and they are obtained by the worksheet technique. The last learning objective L is intended to make the student aware of his/her personal development of knowledge, understanding, and skills by participating in the course module.

The Course Concept

The imagined industrial situation of redesign - as described in the Introduction - is to identify, select and articulate improvements and enhancements on products belonging to a company's path. The goal of the Product Analysis and Redesign course module is broader, namely not only to build the students' knowledge, understanding and skills towards the four redesign core competences, but also to add general knowledge about technical matters, and to train cooperation and communication in student teams. The basic concept of our course module is to use the mentioned theoretical elements together with the practical means: focusing upon an industrial product given to a student team, to be analyzed, described, evaluated and redesigned.

Learning objectives	Core competences				Course means							
	A mindset to identify values	To be able to conduct research	To be able to synthesize solution proposals	To be able to document	Use-process analysis	Mode of action analysis	Manufacturing analysis	Redesign task	Cross' textbook	Worksheet technique	Industrial product	Contact to industrial company
A		√				√					√	
B		√					√				√	√
C	√	√			√						√	
D	√				√	√	√					
E			√					√	√		√	
F			√					√	√		√	
G			√					√	√		√	√
H	√				√							√
I				√						√		
J				√						√		
K			√					√	√		√	√
L	√	√	√	√								

Table 1. Relations between learning objectives, redesign core competences and course means.

COURSE SETUP

Product Analysis and Redesign is a compulsory project based course module in the 3-year Bachelor of Science in Engineering Education called 'Design & Innovation' at the Technical University of Denmark. The education aims to facilitate the students' knowledge gain, understanding and skills within industrial product design and the scope encompasses mechanical products, product-service systems and workspace design. The uptake to the Design & Innovation program is 60 students a year; there is an even gender distribution, and the typical student is 19-20 years of age. The course module Product Analysis and Redesign is scheduled at the second semester of the first year.

Course Structure and Content

Product Analysis and Redesign is a 15 ECTS-point (European Credit Transfer and Accumulation System) course module and it runs between February and end of June and has a student workload of 420 hours (equals a quarter of the yearly workload). Five ECTS-points (140 hours) are theoretical lectures in manufacturing processes and problem solving methodology. The remaining 10 ECTS-points are the product analysis and redesign activities [18]. 100 hours are allocated to analysis and 180 hours are allocated to redesign. In parallel, the students participate in Technology Analysis [19], which is a 5 ECTS-point course module on Actor Network Theory and methods for use-process analysis.

In Product Analysis and Redesign, we spend six weeks on manufacturing processes. There is a four-hour morning session with lectures and exercises in the classroom, and a four-hour afternoon session in the workshop to try out some manufacturing processes in practice each week. We use six weeks on problem solving methodology with a four-hour morning session with lectures and exercises in the classroom. The product analysis and redesign project is divided into three phases: product analysis, redesign planning and redesign. The product analysis phase lasts eight weeks having an eight-hour full day session weekly, and the teachers are available for supervision three hours in the morning. The redesign planning phase lasts three weeks. Finally, the redesign phase lasts three weeks; one week with a full day session, and two weeks with 40-hours of workload. Table 2 shows an overview of the structure of Product Analysis and Redesign.

Period	Theory	Project	Project milestones
13-week period *Early Feb. – early May*	Manufacturing processes: Lectures and workshop exercises (6 weeks)	First phase: Product analysis (6 weeks)	
		Excursion: Company visits	
	Problem solving methodology: Lectures and exercises in the classroom (6 weeks)	Product analysis (2 weeks)	Report and oral presentation
		Second phase: Redesign planning study (3 weeks)	Goals and plan of redesign
		Third phase: Redesign (1 week)	
Examination *May*	No course module activities during the examination period		
3-week period *June*		Redesign (2 weeks)	Redesign report
		Prepare oral examination	Oral examination

Table 2. Overview of the course module

The course materials consist of Kalpakjian & Schmid's textbook [20] on manufacturing processes, the Design inSite materials and manufacturing database [21], Cross' textbook [2] on product design, and the worksheet technique [14].

Finding Suitable Industrial Products

Each year, it is the teachers' task to find six new, suitable products and preferably also industrial partners. The procedure is that we brainstorm on possible new products. There are four basic criteria that the products have to meet:

1. There should be a plurality of relevant human actors, e.g., users, maintenance personnel, and cleaning people.
2. The products must have a manageable technical complexity that can be handled in the mode of action analysis.
3. Reversible disassembly should be possible and the products must represent a reasonable amount of different materials and manufacturing processes. It is an advantage if there is a production facility for the students to visit.
4. The products have to be of a reasonable size, so they can be handled in the workshop.

Most products are acquired through industrial partners. Industrial partners are identified through web-searches and personal networks. The companies are contacted, and if there is positive response, an email is sent explaining benefits and expectations to the company. The company has to lend out a product that they accept will be disassembled. The student design teams disassemble their assigned products (product dissection) and carry through the product analysis and redesign project. The students reassemble their product prior to its return. The companies are further expected to have one or two meetings with the student team during the project in order to supply the team with relevant information. In return the company gets two redesign reports with user analyses and design proposals on a concept level. The companies get the intellectual property rights and can use the design free of charge.

The Three Analyses

During the *use process analysis* the student team has to identify a relevant actor-network related to the existing product and to collect related information. This is done as fieldwork. The student team has to search for users and other relevant stakeholders, make observations and conduct interviews. Figure 3 shows two worksheets from use-process analyses. During the use-process analysis of an outboard motor [22] the team visited harbours to interview harbour masters, and to interview and observe users. Also the police were contacted to make inquiries about thefts of motors. Figure 3(a) shows the operations involved in mounting an outboard motor on a boat. The use-process

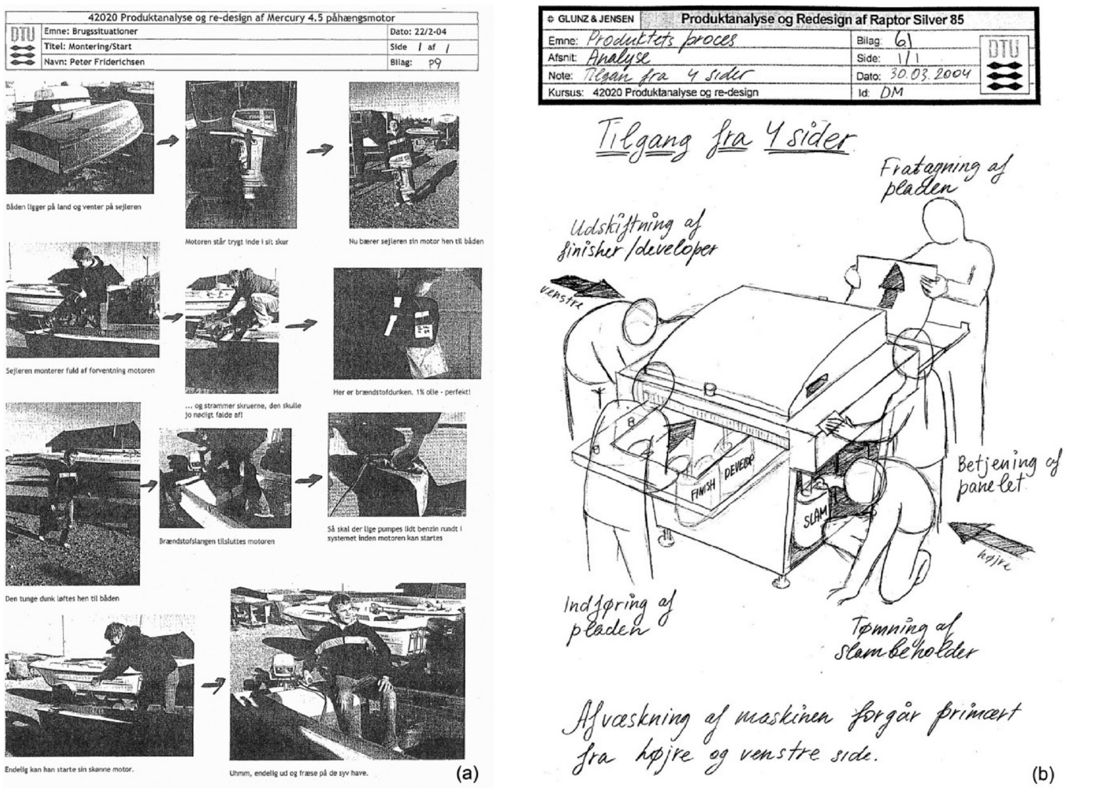


Figure 3. Two worksheets on use-processes. (a): Shows the operations involved in mounting an outboard motor on a boat, [22]. (b): Shows that the developer for large printing films has to be accessed from all 4 sides [23].

analysis of a developer for large printing films [23] involved visits to several printing companies. In an early visit an employee stated that the developer took up much space. The team discussed this statement, and they decided that the size of the developer was an issue. At a later visit in another printing company, the team observed an employee when he explained and showed all use, cleaning and maintenance operations. During his explanation the team realized that the developer had to be accessed from all four sides, see Figure 3(b). If the team could redesign the access to the containers with developer, fixing and waste to be from the same side, it would be possible to position the developer along a wall and thereby save space.

The *mode of action analysis* is carried out in the workshop. The student team takes the product apart (product dissection), identifies the organs and their mode of action. Figure 4 shows two work sheets regarding mode of action of a Christiania bike. Figure 4(a) describes the mode of action of the bicycle bell using two drawings and a flow chart. The student identifies the thumb-operated

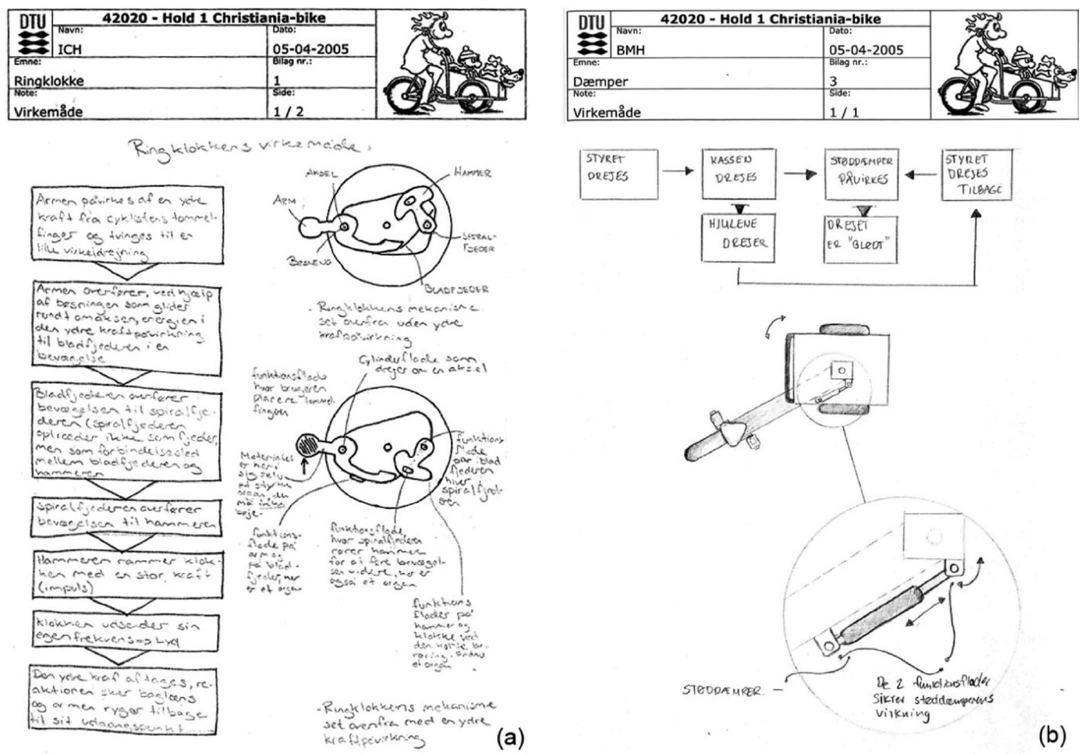


Figure 4. Two worksheets regarding mode of action of a Christiania bike. (a): Shows the mode of action of the of the bell using 2 drawings and a flow chart. (b): Shows the damping mechanism to obtain smooth turn [24].

lever as the input element, and describes the interaction between the rotating lever and the leaf spring, and the interaction between the leaf spring and the hammer. The relatively slow rotation of the thumb-operated lever results in a faster rotation of the hammer, and when the hammer strikes the bell cover, the ringing sound in produced.

The *manufacturing analysis* is also carried out in the workshop. While the student team disassembles the product they identify single components (parts) and reason about the assembly sequence. For each component the type of material and manufacturing process has to be identified. An important element is hands-on experience with the components, e.g., feeling the weight and temperature when holding the component in the hand. Holding is to identify the type of material, and looking for marks from the production process, e.g., cutting marks from a milling machine or angles from a sheet metal bending. Figure 5 shows two worksheets of manufacturing analysis of a concrete mixer.

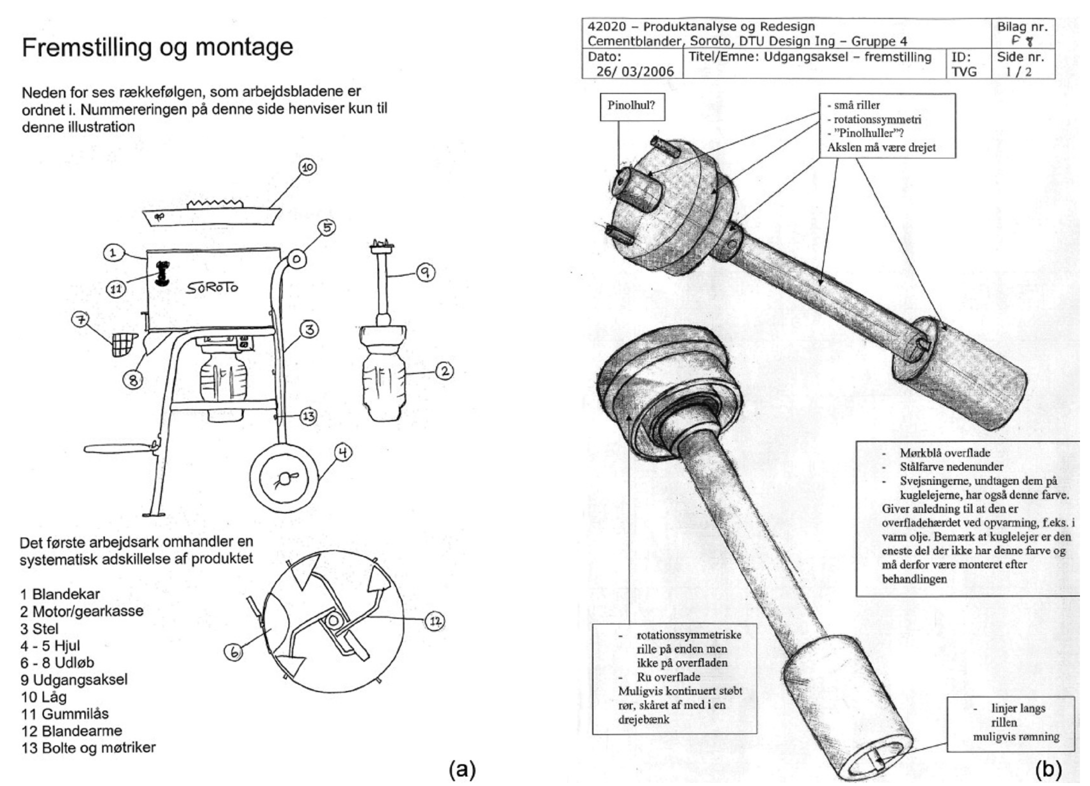


Figure 5. Two worksheets of manufacturing analysis of a concrete mixer. (a): Shows the concrete mixer's components. (b): Shows the analysis of the shaft's materials and manufacturing using marks like machining marks, color and weight [25].

For each of the three analyses we have formulated some inspiration questions to initiate the product analysis. The questions are generic in the sense that they are relevant to many industrial products. As a student team works on the product analysis related to its assigned product and begins to provide answers to the inspiration questions, new specific questions emerge to be answered. Thus, gradually the students' insight and understanding of the user-oriented as well as the technical side of the product grows. Our product analysis method is not characterized by carrying through a given sequence of method steps. The method is characterised by a spiral movement through the three analyses, use-process, mode of action, and manufacturing analysis. In this spiral movement, the student team builds an understanding of "what is good?" and "what could be better?" from the users' perspectives as well as insight into the product's mode of action and how it is manufactured. We apply two stopping criteria for the product analysis. The analysis has to be carried through within a given time period, and the analysis has to result in the student team's formulation of three improvement opportunities.

The Staging of the Product Analysis

There are three important elements in the staging of the product analysis method in the course module, Product Analysis and Redesign. First, we use existing industrial products, which the student teams have to redesign. Each student team is assigned *a product and company contact person*. The company contact person is available to answer questions and to help the team to identify and make contact to users and other relevant stakeholders, e.g., maintenance persons. This is beneficial especially in the initial stage of the product analysis, but the company contact person also has a positive effect on the students' motivation, because he/she is looking forward to see the student team's solution proposals for an improved product.

Second, in order to make an extensive and detailed product analysis within the time frame given we let the students work in rather large design teams. With careful supervision regarding task delegation and knowledge sharing, a large student team is able to carry through an extensive and detailed product analysis. Whereas a large student team is suitable for the product analysis, this is not good for the redesign task. Since the students are first year undergraduates, their technical discipline knowledge is modest, which means the redesign task must not be too complex. And it is overkill to ask a large student team to carry through a noncomplex redesign task. We solve the problem in the following way. At the beginning of the course module the teachers distribute the class into large student analysis teams. In the first semester the students have been working in 10 teams of 6 students, and we use the list of the student teams as input. We make 6 analysis teams of 10 students applying two criteria: each student shall work together with only one student from the previous semester's team, and there shall be almost equal numbers of males and females in the teams. Each large student analysis team has to carry through their product analysis and identify and formulate at least three improvement opportunities, and thereby establish the basis for at least three redesign tasks. Thereafter, the students distribute themselves into two small student redesign teams, and each redesign team selects an improvement opportunity to pursue. We obtain redesign teams of a suitable size, and the company contact person receives solution proposals for an improved product with respect to two different improvement opportunities.

Third, a general idea in the Design & Innovation education is that the students must be able to communicate graphically during design both when they are working individually and collaboratively in meetings, workshops, brainstorming sessions, etc. We therefore require that they work on their hand drawing skills, and for the same reason we postpone the training in computer drawing until the second year. Hand drawing furthermore has the advantage – especially compared to photos – that only the relevant details are presented. The worksheet in Figure 5(a) is a good example of this. The overview of the concrete mixer is much clearer in this type of drawing that only displays the product components in focus. A photo would show a lot of other unnecessary information that would blur the communication. However, photos are often beneficial when documenting a sequence of user operations. The worksheet in Figure 3(a) is an example of this. The photos give a very realistic understanding of the user's perspective when mounting the outboard motor.

Assessment

A three-phased product analysis and redesign project results in three milestones. Each milestone is completed with documents handed in to the teachers. At the first milestone each student analysis team hands in a product analysis report and makes an oral presentation in the classroom. The three teachers comment upon the product analysis and the result obtained. The comments are meant as feedback to clarify misunderstandings, to set directions for the future project work and to prepare for the final oral presentation. The feedback is a formative assessment, and the product analysis report and presentation are not graded. At the second milestone by the end of the redesign planning, each student redesign team hands in a problem formulation for the redesign task and a product design specification. Again, the teachers give formative feedback. At the redesign milestone each student redesign team hands in the final report and makes an oral presentation of the total project. This final report and the oral presentation are used for grading the students. The report includes, on average, 25 pages of text and figures and a substantial amount of worksheets. The grading is done based on the learning objectives, which are condensed into 4 topics: Context (user involvement, insight into use-process and user values), Synthesis (use of methods, solution space, realism), Technical insight (mature/naïve, use of knowledge sources, critical judgement) and Oral Presentation (including answers to questions from the external examiner and the teachers). The assessment is done by the three course teachers together with an external examiner who is an experienced product developer with management responsibilities from an industrial company.

VALIDATION

In the previous sections we have described the course module Product Analysis and Redesign and its backbone, the product analysis method. In this section we will report how evidence was collected to validate the product analysis method and its staging, i.e., how the method and its staging were productive in building the students' knowledge, understanding and skills, and thereby preparing them to be able to participate in and contribute to redesign projects in industrial practice. We carry through the reflection focusing on the following four questions:

- Are the selected products appropriate?
- Has the mindset been understood by the students?

- Does the students' perception of valuable results correspond to the industrial clients' perspective?
- Do the students master to create integrity out of the product analysis?

The validation of the product analysis method and its staging is difficult. There are only vague signals available; there are many other factors, whose influence may be strong; and to link course means and results remains speculative. The validation shall therefore be seen as the teachers' reflection rather than a rigorous scientific validation of an experiment.

Are the Selected Products Appropriate?

We can vary the staging of our product analysis method by varying three parameters: the way we form the large student analysis teams, the number of weeks of the three phases of project, and the selection of industrial products. What is the relative influence of these three parameters upon the students learning in the course module?

1. The way we form teams: This has little influence because all the students are first year students having the same technical and knowledge prerequisites.
2. The number of weeks of the phases: Has little influence because the students have to learn to carry through a product analysis and redesign project, but not to perform a complete analysis or to synthesize significant product improvements.
3. Selection of industrial products: Has large influence because if the teachers select industrial products, where the students cannot identify and get in contact with users to interview and observe, the product analysis will fall apart.

Thus, a key question in validating the product analysis method and its staging is: are the selected products appropriate? In order to answer this question we have to look at the products we selected and the grading of the student redesign teams.

In the years 2003 until 2010 we have worked with a total of 45 products. There were 20 consumer products and 25 professional products. In order to illustrate the range of products we have used in the course module, we have selected nine products as shown in Figure 6.

In Figure 6 we see four consumer and five professional products:

1. The Christiania bike is a carrier bicycle that is primarily used by families with small children as an alternative to a car in urban areas. The bicycle is also used professionally (e.g., for mail delivery), but the professional users constitute a very small market segment compared to the consumer market.
2. The food mixer is primarily used for mixing bread dough and is targeted towards the upper end of the consumer market and the lower end of the professional market.
3. The electrical stove is an ordinary household kitchen element with four cooking plates and an oven.

Figure 6. Examples of products used in the course module. The first four are consumer products and the rest are professional products: 1: Christiania bicycle, 2: Food mixer, 3: Stove, 4: Train seat and table, 5: Oil sampling box kit, 6: Parcel handling in aircrafts, 7: Tilting kettle, 8: Developer for large printing films, and 9: Concrete mixer.

4. The train seat and table are used in the Danish intercity trains. As the students are regularly train passengers they understand the use of seat and table very well. Therefore we classify the train seat and table as a consumer product.
5. The oil sampling box kit is used by the inspection authorities to take samples of oil spills at sea in order to collect legal evidence.

6. The unit for parcel handling is used when loading and unloading parcels in freight airplanes.
7. The tilting kettle is a large pot for preparing food in professional kitchens like cooking potatoes or making stews.
8. The developer is used for processing large printing films used in the printing industry.
9. The concrete mixer is used by masons for preparing the mortar or the light concrete.

At the redesign milestone each student redesign team hands in the final report and makes an oral presentation of the total project. The report and the oral presentation are used for grading the students. The assessment is done by an external examiner, who is an experienced product developer with management responsibilities from an industrial company, together with the teachers. The grading scale applied is the seven-step scale. It has the following grades -3 (F), 00 (Fx), 02 (E), 4 (D), 7 (C), 10 (B) and 12 (A). The grades -3 and 00 are failing, a grade of 2 or better represents passing, and 12 is considered excellent. In the years 2003 – 2010 in total 93 student redesign teams have participated in the course module, and Figure 7 shows the grade distribution of the teams.

Figure 7 shows a good distribution of the grades. In general the student teams perform well, and we have not experienced a student team failing the course module Product Analysis and Redesign. We have not been in a situation where a selected product was not appropriate in the sense the students were unable to identify and get in contact with users and other relevant stakeholders to make interviews and observe users using the product. Therefore, we allow ourselves to conclude that the four criteria for selecting products are valid and applicable.

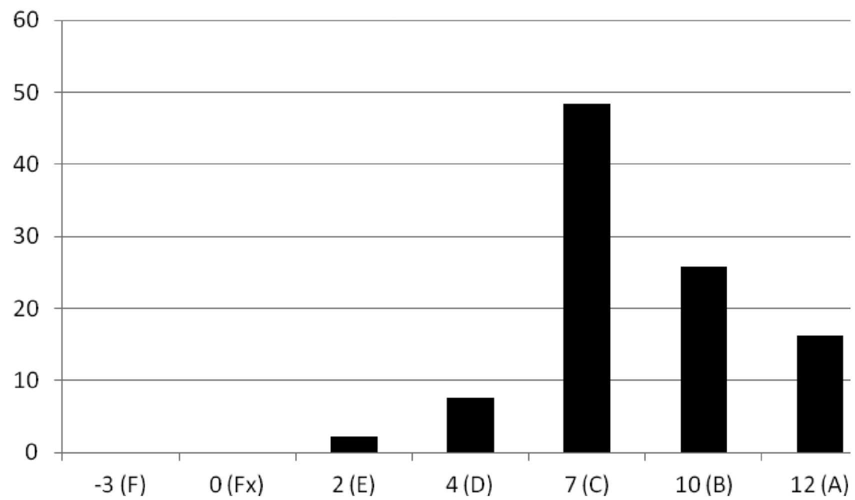
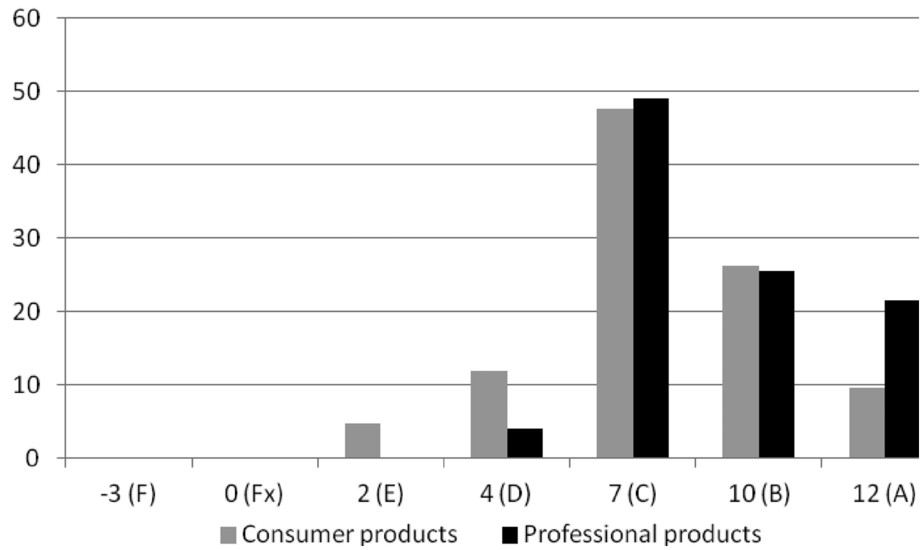


Figure 7. The grade distribution of the 93 student redesign teams. Each column shows in percentage the number of student teams getting the grade. The grading scale goes from -3 (F) to 12 (A), where -3 and 0 are failing, 2 and above are passing, and 12 is excellent.

Has the Mindset Been Understood by the Students?

It is an important objective of the course module that the students develop the mindset that a product is not a technical artifact having value in itself, but that value is found in the users' reaction when they use the product. To evaluate if this objective has been met we can look at the proposed improvement opportunities and the underlying argument, which is the outcome primarily of the use-process analysis. We have observed an apparent difference between the way students handle professional and consumer products. We have experienced that in general professional products are better suited than consumer products in the use-process analysis. Table 3 shows the grade distributions of the 42 student teams redesigning consumer products and the 51 student teams redesigning professional products. For students working with consumer products the average grade is 7.9 (C) while students working with professional products got at an average of 8.8 (C), see Table 3.



	No. of analysis teams (large, 10-person groups)	No. of redesign teams (smaller, 5-person groups)	Average grade
Consumer products	20	42	7.9 (C)
Professional products	25	51	8.8 (C)

Table 3. The grade distributions of the redesign teams working with consumer and professional products. Each column shows the percentage of student teams with the grade they received. Average grades are also given.

Can we identify a difference in the way student teams handle the use-process analysis of consumer versus professional products? Let us look at some examples.

The first example is the three-wheeled Christiania bike (no. 1 in Figure 6 and Table 4) where the analysis team found statistics, which showed that about one third of all bikes were stolen each year. Field studies of users – typically mothers with one or two children - showed that the bikes were rarely locked in a secure way. The mothers were busy looking after the children and handling luggage; so, they often skipped using the additional wire lock that most bicycles were equipped with. The analysis team proposed an opportunity to improve theft protection. Better theft protection should be very easy to handle – preferably with one hand and without using keys. The Christiania bike is often bought by young families to bring children to and from daycare centres. The field studies of users revealed that although transport of children is more often done by the mother, it is the father's task now and then. Since in many families the father is some centimetres taller than the mother, the Christiania bike is adjusted to the mother's height. The analysis team proposed an opportunity to improve the performance of the bike by making it as easy to adjust by the cyclist as a car is to the driver.

The second example is the food mixer (no. 2 in Figure 6 and Table 4), which is an expensive product targeted to the high-end consumer segment, i.e., not for typical students. However, the analysis team failed to get good interviews and studies of users within this target group but relied instead on their own opinions. They proposed that improvement opportunities should be more functionality in the expensive equipment, an aesthetic facelift and facilities for better mobility (the food mixer's weight is more than 20 kg). However, the analysis team did not have any empirical evidence to support that these opportunities were relevant for the high-end consumer segment.

The third example is the stove (no. 3 in Figure 6 and Table 4). A stove is a product all students know from home, and many of them use it regularly. The analysis team were reluctant to search for representative users of this particular stove but relied on their own experiences. The analysis team proposed improvement opportunities with respect to cleaning, appearance and efficiency, but the proposals were not supported by observations of relevant stakeholders.

The fourth example is the developer for large printing films (no. 8 in Figure 6 and Table 4). The analysis team's user studies revealed that the machine could only be placed in the middle of a room since it required access from all four directions, and this was a problem for the printing companies using the developer. If the machine could be changed so it only required access from 3 directions it could be placed next to a wall thereby reducing the need for floor space.

The fifth example is the concrete mixer (no. 9 in Figure 6 and Table 4) where the analysis team's interviewing and observing masons at construction sites identified improvement opportunities with respect to the safety and cleaning operations and the interviews in the company's logistics department found a transport improvement opportunity: if the height of the concrete mixer was reduced more mixers would fit into the standard container and reduce transport costs.

From the examples we observe three cases of good use-process analyses. The analysis teams collected information and carried through observations and interviews with relevant stakeholders, and based upon this material, the analysis teams proposed improvement opportunities. However, the food mixer case shows a use-process analysis, where the team fails to realize that students are not typical users, and therefore the team does not establish contact with users in the target group. Thus, the proposed improvement opportunities are not supported by observations of relevant stakeholders. The analysis team working with the stove had similar problems. They did not abstract from their own opinions, which led to a highly biased use-process analysis.

Table 4 shows our analysis of the use-process analyses of all 9 products from Figure 6. The third column shows the improvement opportunities proposed by the analysis teams. We have underlined the improvement opportunities, which are supported by information collection, interviews with or observations of relevant stakeholders. The fourth column shows the grades obtained by the redesign teams. If we focus on Table 4 column 3, we find very good use-process analyses of both consumer

	Type of product	**Improvement opportunities proposed by the analysis teams. Use-process supported opportunities are underlined.**	**Grades obtained by the redesign teams**
1. Christiania bike	Consumer	3: <u>Theft protection</u>, <u>performance</u>, accessories	7 (C), 10 (B)
2. Food mixer	Consumer	3: Additional functions, aesthetic facelift, mobility	2 (E), 7 (C)
3. Stove	Consumer	3: Cleaning, appearance, efficiency	4 (D), 10 (B)
4. Train seat and table	Consumer	7: <u>Cleaning</u>, <u>adjustment</u>, <u>comfort</u> (3 types), <u>luggage</u>, <u>newspapers</u>	10 (B), 12 (A)
5. Oil sampling box kit	Professional	6: <u>Usability</u> (<u>transparency</u>, <u>sealing</u>, <u>overview</u>), <u>content</u> (<u>oil container</u>, <u>sampler</u>, <u>extra elements</u>)	10 (B), 12 (A)
6. Parcel handling in aircrafts	Professional	4: <u>Ergonomics</u>, maintenance, <u>efficiency</u>, inviting use	10 (B), 12 (A)
7. Tilting kettle	Professional	2: <u>The cooking process</u> (8 topics) and <u>cleaning</u> (5 topics)	10 (B), 12 (A)
8. Developer for printing films	Professional	6: <u>Access</u>, <u>cleaning</u>, four problematic components, automation, <u>ease of use</u>, change of context	12 (A), 12(A)
9. Concrete mixer	Professional	4: <u>Transport</u>, <u>safety</u>, <u>cleaning</u>, appearance	10 (B), 7 (C)

Table 4. Improvement opportunities for the 9 products shown in Figure 6 and the grades obtained by the redesign teams. The improvement opportunities, which are supported by information collection, interviews with or observations of relevant stakeholders are underlined.

(no. 4) and professional (no. 5 and 7) products. We find good use-process analyses of both consumer (no. 1) and professional (no. 6, 8, and 9) products. We find two weak use-process analyses of consumer products (no. 2 and 3), but we have not experienced equally weak use-process analyses of professional products. In the few cases, where a use-process analysis of a consumer product fails it seems to us that the reason is that the analysis team members think that they already know the answers themselves from their own daily practices.

The final grading of a student is not only dependent upon the quality of the use-process analysis. The grading is based on the learning objectives of the course module Product Analysis and Redesign. From Table 4 columns 3 and 4 we observe that there is not a causal link from the quality of the use-process analysis to the final grading.

When we reflect upon the grade distributions shown in Table 3 and our analysis of the use-process analyses carried through by the analysis teams, we allow ourselves to conclude that the product analysis and its staging is productive in building the mindset that a product is not a technical artifact having value in itself, but that value is found in the users' reaction when they use the product. Our analysis and experience tells us that in general professional products are better suited than consumer products in the use-process analysis. The students make a better use-process analysis of products they have no personal experience with, whereas it can be problematic to use consumer products for teaching product analysis and redesign since students know the products in advance and are therefore less eager in consulting relevant users.

Does the Students' Perception of Valuable Results Correspond to the Industrial Clients' Perspective?

The quality of the product analysis and redesign project should primarily be judged by the knowledge, understanding and skills the students acquire. The course module occurs in first year, and students cannot be expected to come up with product improvements that will revolutionize the collaborating company. However, in a number of cases the results have been beneficial to the industrial client. At two occasions, the clients liked the outcome so much that they wanted to participate again in the course module with another product. After the redesign of a spinning bicycle another student team was assigned to the redesign of a cross country, ski-exercise machine. The redesign of a hospital bed was followed by the redesign of a patient lifting device.

The redesign of the spinning bicycle was valued by the client, and many of the improvements proposed by the students are now implemented in the new version of the product. The redesign of the industrial tilting kettle (no. 7 in Figure 6) to reduce the large cleaning expenses proposed a radical solution where a large disposable plastic cup was to be used within the tilting kettle resulting in an almost elimination of the cleaning activity. It would furthermore introduce a new significant business model where the company would get a continued sale of plastic cups. The company liked the idea but feared that the conservative customers would not be in favour of the new design. Besides, there were technical issues about heat transfer that needed to be investigated.

Apart from the concrete design proposals resulting from the redesign, there are other outcomes from the students that are valued by the industrial clients. One outcome is insight from the use-process analyses. The students have a unique possibility of get close to many users and other relevant stakeholders that can be difficult to approach for the industrial clients. A curious student is able to open many doors. The use-process analysis of the developer for large printing films (no. 8 in Figure 6 and Table 4) is a good example. The students design team showed the company client that the client's understanding: "It is good to separate the containers with developer and fixate from waste container in order to obtain an easy maintenance" contradicts the printing companies' understanding that, "If we could access all containers from the same side we could place the developer along a wall and thereby save space." Another outcome is the user network that the students can facilitate. The parcel handling within aircrafts (no. 6 in Figure 6 and Table 4) is a good example of this. The students participated themselves in the parcel handling in the airport and managed to involve the workers in the design activity – a task that is much more difficult to approach by an industrial company.

When we reflect upon these examples where student teams have created relevant user insights and attractive design proposals to the collaborating companies we allow ourselves to conclude that the product analysis and redesign project is a valid and productive way to develop the students' perception of valuable results corresponding to the industrial clients' perspectives.

Do Students Master the Product Analysis Process?

An objective of the course module is to ensure that the students build knowledge, understanding and skills within all three product analysis dimensions: use-process, mode of action, and manufacturing analysis. All student analysis teams conduct the three analyses, but the quality naturally varies. In a previous section we discussed one of the pitfalls for the use-process analyses. However the emphasis on use-process analysis in the course module seems to have helped the students to build the wanted mindset that a product is not a technical artifact having value in itself.

Our approach is to let the generic product analysis questions and the given product motivate and direct which detailed analyses that the students will carry out. The mode of action analysis can be approached in a number of ways. A traditional one would be to describe the functions and sub-functions in the product and what means that are used to make this happen using a function-means tree. We use the 'organ' notion to document the means as descried earlier in the paper. To investigate the dynamics of a product we have good success in using a technique that can be called 'a medium's passage through the product'. This can be illustrated by the concrete mixer (no. 9 in

Figure 6) where we can look at how energy passes through the product. From the power outlet the electricity passes through a cable to a power-switch, further on to a safety switch that detects if the lid is closed and then into the electric motor where a rotary motion is generated. This is an intuitively easy technique to use and gives good insight into especially more complex products.

The manufacturing analysis is supported within the course by theoretical lectures where the different manufacturing processes are explained and students try to operate some of them in the workshop. In general the students make reasonable analyses of how the single components in their products are produced using the earlier described technique, i.e., identification of marks given by the component, where typical marks from the manufacturing process are identified and used to argue for how the part is produced. This is very much a graphical exercise where drawing capabilities are important. Students sketch the single components and preferably also the contours of the tools and dies used to make the components. Insight into assembly will in most cases come from the disassembly of the products done by the student analysis team. When dismantling the products they have to make notes so they can assemble the product again correctly. A part of the manufacturing analysis that often represent difficulties for the students is the account for where changes to the product is easy or difficult to make due to earlier investments in tooling or preferred materials and mode of production. The reason is that this requires a better insight into how industrial production takes place within a company. To supply the students with a minimum of this type of insight an excursion to one or two producing companies is part of the course curriculum.

As described in the previous sections we have observed that the student teams are capable not only of formulating improvement opportunities for their assigned products but also of synthesizing design proposals to improve the product. We see this as a positive signal towards the validity of the staging of the product analysis methods. Our idea that the product analysis is carried through by a spiral movement through the three analyses seems to be productive in creating integrity out of the product analysis.

DISCUSSION AND CONCLUSION

When we developed the course module Product Analysis and Redesign we needed a textbook, but to our knowledge there were none – and are not – any textbooks available for redesign. We decided to use Cross' textbook [2] to develop a product analysis method. In this paper we have presented the product analysis method and its staging within the course module and we have reflected on the students' application of it as a means to validate if it is productive in building the students' knowledge, understanding and skills. Based upon the validation we conclude that the method is a valid contribution to teaching redesign.

Five questions remain to be discussed:

- Is the validation trustworthy?
- Are the four *redesign core competences* adequate to prepare the students to be able to participate in and contribute to redesign projects in industrial practice?
- Is the product analysis method critically dependent upon our choice of Cross' textbook, or is it applicable with other textbooks?
- Can we identify best practice elements, which would help instructors to apply the method?
- Is the product analysis method relevant in different engineering disciplines?

Many factors influence the students' learning, e.g., the organization of the teaching activities, the communication and cooperation within the student teams, the teachers' supervision, and the students' attitude toward the industrial products handed out, the learning objectives and examination. It is not straightforward to link the course means to the result obtained. In the paper we have not presented a rigorous scientific validation of an experiment. However, we collected evidence of 8 years application of the product analysis method on 45 industrial products and close to 500 students, and reflected upon this material and our practice. We are still using the product analysis method in the course module Product Analysis and Redesign.

We have formulated the four *redesign core competences* based upon our understanding of redesign projects in industrial practice. The learning objectives are an unfolding operationalization of the core competences. If the course module is to prepare the students to be able to participate in and contribute to redesign projects in industrial practice, it is important that our understanding of industrial practice is on target, and the core competences are adequate. Do we have any evidence that the redesign core competences are adequate? Yes, the assessment and grading is done by the teachers together with an external examiner who is an experienced product developer with management responsibilities from an industrial company. During the years 2003 until 2010 we used two external examiners alternatively, and both examiners corroborate our understanding that the four redesign core competences are adequate. This piece of evidence is a positive signal, but it is obviously not a thorough justification of the four redesign core competences. In order to make a more thorough justification we could send questionnaires to product development managers in Danish companies to obtain a quantitative indication and interview some Design & Innovation candidates, who have participated in the course module and now work in industrial practice, to obtain a qualitative indication.

We decided to use Cross' textbook [2] in the course module because the amount and level of text fits well to undergraduate students and because Cross' description of the design process is in line with our understanding. However, the product analysis method and its staging is not closely linked to Cross' textbook, because the problem solving methodology teaching is aimed at the redesign phase. We believe the product analysis method could be applied together with other textbook on engineering design and product design [2, 3, 4]. For example, Dym and Little [3] identify "*three 'roles' being played as the design of a product unfolds. Obviously there is the* designer*, and it seems equally clear that there will be a* client*, the person or group or company that wants a design conceived*." The third role of design belongs to the user, as Dym and Little write, "*The users hold a stake in the design process because a product 'wont sell' if its design doesn't meet their needs.*" We think the product analysis method and its staging fits excellent to Dym and Little's description of the three roles: the student team has the role of the designer; the company contact person has the role of the client, who wants the product being redesigned; and users and other relevant stakeholders have the role as users.

We developed the course module Product Analysis and Redesign and the product analysis method back in 2003, and we have run it once a year since then. We believe we have developed a good practice, but since we have not developed any alternatives we cannot claim the product analysis method and its staging is a best practice. However, we might have a best practice element to share with instructors, particularly on the way the product analysis method is formulated. In engineering design textbooks methods are very often described as a sequence of step to be carried through, which is practical for the instructor, because it is easy to instruct the students how to carry through the method. Unfortunately, as instructors we now and then observe students, who focus their attention upon how to carry through the step sequence, but tend to forget the content of each step, i.e., *how to do* becomes more important to the students than *what to obtain*. Our description of the product analysis method is different from the textbook descriptions. We have formulated some generic inspiration questions to initiate the product analysis, and the method is characterised by a spiral movement through the three analyses. We apply two stopping criteria: the product analysis has to be carried through within a given time period and has to result in formulation of three improvement opportunities. This type of method description focusing on *what to obtain* might be a best practice alternative to textbooks' *how to do* method descriptions, since it encourages the students to focus on content of method execution and not step sequence.

Although our product analysis method is developed for the Design & Innovation bachelor program, we believe it is highly relevant in other engineering disciplines. Engineers working in industrial practice, being engineering designers or technical discipline specialists, have to understand that in order to obtain a successful outcome of a redesign project it is paramount to understand needs and values of users and other relevant stakeholders. If a technical discipline specialist develops a new technical solution, which is not recognized as being better and upgraded in the users' or another relevant stakeholder's perspective, the solution has no value and contribution to the redesign project.

In modern engineering education we have to take socio-technical aspects into account. From an NSF workshop on engineering design in the year 2030 [26, p. 1] we find: "*If the US is to capitalize on our research investments in micro-, bio-, info-, nano-technologies, as well as, conventional areas that continually lead to exciting technological advances, we must invest in engineering design tools and techniques in order to convert this research into commercial products.*" The NSF workshop formulates three content recommendations: engineering innovation, social-technical aspects, and design informatics. With respect to the socio-technical aspects, it is stated [26, p. 1]: "*Social-technical aspects: Basic knowledge regarding how humans and social dynamics influence design that involves multiple stakeholders with wide societal roles.*" Thus, from the NSF workshop we observe that any engineer involved in developing research into commercial products has to have socio-technical competences, irrespective of his/her technical discipline area being "*micro-, bio-, info-, nano-technologies, as well as, conventional areas*."

We conclude that the product analysis method and its staging proposed and validated in this paper is relevant for many engineering disciplines, and can be applied in engineering education from first year.

ACKNOWLEDGEMENTS

The authors are indebted to our former colleague Associate Professor Hanne Lindegaard for her enthusiastic and qualified supervision of the student teams with respect to use-process analysis and to Professor emeritus Mogens Myrup Andreasen for his valuable comments and viewpoints to this paper. We acknowledge the anonymous reviewers for their critical remarks and constructive proposals to improve the paper.

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