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DESIGN THINKING CHALLENGES IN EDUCATION

Åsa Ericson[1], Mattias Bergström[1], Andreas C. Larsson[1] and Peter Törlind[1]
[1]Luleå University of Technology, Sweden

ABSTRACT
Product development processes are commonly represented in sequential models covering the necessary stages from planning to product rollout, while processes to take needs into the development activities show other aspects, namely that understanding needs requires, for a product developer, additional skills. In our curricula for engineering design education we apply some aspects of design thinking to bring together (a) business savvy, in terms of understanding people's needs as market opportunities, and (b) product development process, in terms of team-based creativity and collaborative skills, with (c) the basic engineering knowledge. This is a demanding aim, much because the approaches, methods and mindsets differ widely from what the students are used to. Hence, in this paper we elaborate on our efforts to educate engineers in design thinking to provide insights into some challenges for engineering design. Three key challenges are identified, (1) integrative approaches are not straightforwardly implemented, (2) training of 'soft' capabilities to provide a change in thinking, and (3) social competence to make use of design thinking.

Keywords: Design thinking, needfinding, design education, engineering design education, empathic design

1 INTRODUCTION
Companies invest a great deal of money and effort into the development of new products. Despite this, nearly nine out of ten products fail within two years of release [1]. One possible explanation for these failures is that the products do not actually meet and solve a customer need [1][2]. In addition, failures in market uptake can have its roots in the engineers' abilities to empathize with customers. Historically, the engineers' lack of profound knowledge concerning customers' needs took its expression in the assumption that just because the engineers' personally would like to use the state of the art devices, everyone would [3]. Today, due to a paradigm shift toward Product-Service Systems, which can be explained as: the continuous development of a solution that meets a perceived customer value in a long-term business relationship, *'understanding customer needs'* and *'being customer focused'* is increasingly important for companies to achieve product innovation. However, merely having a *'we know our customers'* attitude is not the equivalent of focusing on people's needs [1], or applying design thinking [4]. Zooming in on needs widens the scope of the product development domain, and involves both *thinking* and *acting* activities. This calls for new methods for heterogeneous teamwork and team-based creativity, in turn challenging contemporary development processes, but, also the engineering design curriculum.
Educating and training future engineers to meet the companies' expectations is a task for a technical university. Traditionally, the education programs of engineers focus on, e.g., mechanical, electrical, software or construction areas [5]. Consequently, the common literature for engineers focuses on the product as a physical artifact [6][7]. In turn, the engineering activities, as described in literature, embark from product specifications for the products that they should develop. Such specifications do not, however, guide the developers in how to address needs. Instead, they convey the precise description of what the product has to do and usually consist of metrics and values [7]. Based on these premises, the engineer becomes well trained to solve relatively well-defined, mainly technical, problems.
The basic engineering programs at our university are no exception; our students are firmly up to date with product development literature and various kinds of support for engineering activities, e.g., Computer Aided Design and Finite Element Analysis tools. We also offer complementary courses that deal with product development from a need perspective and hence which also convey at least some aspects of design thinking [4]. However, the performance of such courses is demanding in teaching and in learning respectively, much because the approaches, methods and mindsets differ widely from

what the students are used to from their other engineering classes. To avoid reiterating an 'over-the-wall' approach [5], where the activities, and the emerging understanding of needs, are disconnected, the engineers are recommended to take part in the activities that deal with generating information about customer behavior and perceptions [3][7]. Here, the context for generating customer information should be in the procedures of normal, everyday routines for those potential customers [8], an experimental setting will not do. This fact has put forward courses based on student projects performed under realistic conditions, and lectures that intertwine assignments and theory. In addition, understanding needs is not a straightforward process. Needs are often hidden in workarounds, i.e., the customers are so accustomed to current conditions that they do not think of it as a predicament. Rather, they perceive that something is, for example, hindering them to be effective or making them annoyed. However, they realize that all known choices lead to unsatisfactory solutions. Such a dilemma, or a problematical situation, is not a problem in a logical sense; hence, it has not *one* given solution [9]. Analyzing and defining the problem in parallel with finding the needs is the key for product developers, and such iterative processes are at the heart of developing innovative products [2]. A development process that take needs into consideration makes it necessary to make use of other methods than commonly practiced in engineering design education, i.e., observations as opposed to surveys and interviews, since *"what customers can't tell you might be just what you need to develop successful new products."* [8]. Hence, educating engineers to develop solutions based on needs is also to introduce 'non-traditional' methods that require training of special abilities and attitudes. In short, our curricula for engineering design education strive to bring together (a) business savvy, in terms of understanding people's needs as market opportunities, and (b) product development processes, in terms of team-based creativity and collaborative skills, with (c) the basic engineering knowledge. Yet, this aim has shown to be challenging, since it can be described as an aim to teach design *thinking* [4]. Product development is commonly represented by stage-gate models going from a market opportunity, via design and production to product launch. Design thinking, on the contrary, can be described as a system of spaces where different sorts of related activities form a continuum of innovation, and it feels chaotic for those experiencing it the first time [4]. So, learning design thinking insists on 'going with the flow'. How can we make students 'play the game' during the lessons and in exercises, and how can we make them comfortable with ambiguity? And, what are the difficult parts for students and how can we support their learning? Hence, *the purpose in this paper is to elaborate on our efforts to educate engineers in design thinking,* a general contribution from doing so is to provide insights into the challenges for engineering design.

A delimitation of the study presented here is that it is not framed by a pedagogical point of view. For example, design thinking and an intuitive-contextual perspective on learning [10] has many similarities. It is, for those acquainted with such theory, doable to apply this view also, but as mentioned that is not done in this paper. Another delimitation of the study presented here is that design thinking can be a guiding principle for a whole development process, from how to get an initial idea to product rollout. However, we focus, in education and research, on early phases of development, i.e., from creating initial ideas and concepts to selecting a product concept to develop further. Also, the fact that design thinking affects the whole company is acknowledged, e.g., strategies, management styles and organization [11], while out of scope of this paper.

Next, the methodology for this study is presented, followed by a presentation of the theoretical framework, which also gives a brief overview of our rationale for the design thinking education. The empirical findings describe the students' experiences; these are interpreted and discussed in the light of the rationale for our design education. The paper ends with a concluding remark, and implications for implementation of design thinking. Our research activities are performed with the intentions to implement design thinking in industrial processes, the education activities are a way to try out and disseminate research results. Also, educating future engineers in design thinking has a direct impact in industry, where they will be employed as managers, project leaders, product developers etc.

2 METHODOLOGY

On an overall level, the empirical basis consists of data generated in courses for design thinking, as well as experiences from teaching and supervising in student projects. In one of the final-year courses for students in the Mechanical Engineering MSc degree program, Design for Wellbeing offers a

guiding framework, which has a strong focus on understanding needs and applying creative methods [12] to address challenges related to people with disabilities, which are currently underserved by design. The aim is not about 'fixing' people by developing assistive products and technologies, rather the aim is to increase humans' feeling of wellbeing and empower them to participate in society on equal grounds. In the educational activities related to Design for Wellbeing, the planning and management of projects was included as a part of the student projects. Accordingly, students also got training in coordination and collaboration. The supervising activities within the Design for Wellbeing context have been performed during 2004-2007, and excerpts from interviews with these students are presented in the theoretical framework in this paper. In particular, the teaching in two master courses, called 'Product Development Processes' and 'Creative Concept Development' serves as a base for the study presented in this paper. The excerpts from these students are presented as viewpoints from students in this paper. A method to generate the 'voice of the students' have been an 'I like, I wish' exercise, pioneered at Stanford. After each lecture the students were provided with two Post-it notes, one for expressing what has been particularly interesting useful (I like) and one for expressing what they would have liked to experience (I wish). Approximately, a total of 60 students have participated in 20 lectures for 2008. The justification for this method is that it provided us with experiences and constructive feedback from engineering students 'exposed' to design thinking education for the first time. The method produces primarily qualitative data based on, e.g., interpretations, understandings and perceptions, which are aimed at producing a 'contextual' understanding of experiences, rather than verifiable results.
The choice of theoretical framework for this paper stems from the underpinning rationale in the courses.

3 THEORETICAL FRAMEWORK

This section provides a short overview of the theories that are relevant to our work and how they support the rationale for the design thinking in our courses. A perspective of designing and design thinking is the starting position. An overarching view of a personal knowledge system is the base for introducing development processes from two perspectives. Wicked design problems give insights into the complexity of innovative products and the processes to design them. In the end of this section, demands on a future engineer regarding competences etcetera are presented.

3.1 Designing and design thinking

We are not attempting to once and for all define design and design thinking. Rather, we strive to present a lexical explanation of the terms in the context of our engineering design education.
The word design is used in a plethora of ways, in a diverse set of areas and by a vast variety of spokespersons. For design education, insights into at least two different perspectives are useful. We use the word in the context of engineering design, where a common idea is that something that is discrete and can be manufactured, i.e., a thing [5],[6][7] is a vital characteristic. The word 'design' can be used as a noun or a verb [13]. When it is used as a noun the focus is on the *thing* which is designed and thereby can be referred to as 'a design', e.g., a physical artifact in engineering design.
Design as a verb converts the view from the outcome of the actions to the actions of doing design, e.g., what can be called designing [13]. Again, designing is not restricted to engineers alone, since designing can be viewed as a transformation process, i.e., changing a less desirable existing situation into a preferred one [14][15][16]. The emerging Product-Service Systems paradigm widens the engineering view of design by the integration of a service perspective in early development phases [17]. Our engineering education is built upon a development *process* view to encompass various designs.

3.2 A personal knowledge system

Johnson [18] elaborates on a personal knowledge system and provides a point of view where 'artistry' *"…is made possible through a particular kind of interaction that unfolds between the practitioner and the situations he or she engages.* […]*…artistry is possible when both ends and means are open to clarification and shaping by the skills, knowledge and interest of a practitioner in situations where ambiguity, risk, complexity and indeterminacy abound."* (pp.14-15). She concludes that this situation is true for development of strategy, but this could also be true for the development of processes for innovations. The personal knowledge system, as visualized in Figure 1, shows that artistry is possible by making use of developed knowledge, the upper right part, *and* generating new knowledge, the lower left part. The 'mastery' approach is *"...an effort to match an existing situation to a preexisting solution and then progress by following a predetermined set of instructions."* (p.15). Mastery is a technically difficult mission. The 'originality' approach is *"...an effort to use personal capabilities and intentions to generate both a desired outcome and to find a way of achieving this outcome with the materials and resources at hand."* (p.15). Being able to combine these two approaches makes 'artistry' [18] or 'integrative thinking' [19] possible. Also, there are similarities to 'ambidextrous thinking' [20], where art and science, and body and mind are fully used by designers.

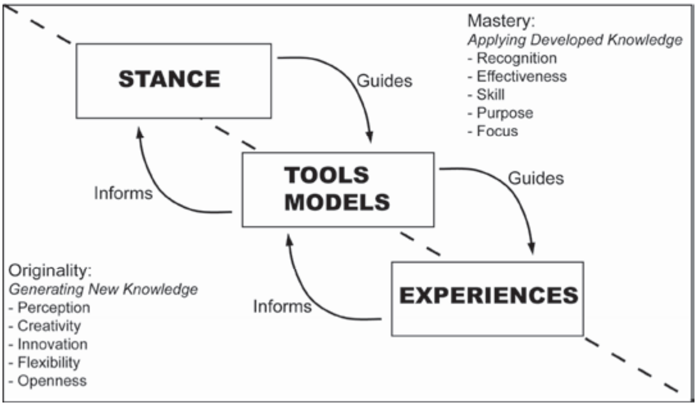

Figure 1. A personal knowledge system, after [18][19]

In our view, the 'mastery' approach is similar to following a development model as presented in product development literature [6], [7]. The 'originality' approach has similarities with, for example, the processes of finding needs [2], [11] or, an open innovation process where taking in ideas from outside and flexibility is vital [21]. The combination and use of such diverse streams is a key for our engineering education. But, also, it is becoming clear, a main challenge.

The 'Tools/Models' box in the middle of Figure 1 is interesting for education, since the question *"With what tools and models do I organize my thinking and understand the world?"* [19] can be used for the students' reflection of identity and motivation, the 'Stance' box in the figure. As teachers, we can provide them with new tools and models, and encourage them to critically reflect on them. Commonly, the intersection of possibilities, constraints, uncertainties and differences is said to be the fertile soil for breakthrough innovations. Yet, not easily accessed.

3.3 Wicked design problems

Rittel and Webber introduced the term 'wicked' problems in 1973 [22] to explain the nature of problems of social policy and that the way science dealt with such problems was troublesome. They pointed out that a problem solving approach seeks to find 'optimal solutions', definitive and objective answers to social problems, while such problems has a relational complexity that calls for a different methodology. In such cases, "*...one of the most intractable problems is that of defining problems (of knowing what distinguishes an observed condition from a desired condition) and of locating problems (finding where in the complex causal networks the trouble really lies)."* (p. 159).

Wicked problems fit into the situation of the development of innovations where the information in early phases is sparse. The early phases includes problem definition, since *"...before designers can solve a design problem they need to understand some basics – such as what they are designing, what it should do and who should use it and in what circumstances."* [23]. To generate such information going to the customers' place [2] and observing people [8] seems like a good advice. Those who actually develop products, i.e., the design engineers, are recommended to engage in the information generation activities. Yet, the challenges include how to focus closely on people's behavior, without suggesting solutions and jumping into conclusions [2].

We have found that the very basic of being exposed to a wicked design problem is a challenge, where the attitude towards the situation can prevent students to acknowledge the fact. This can be exemplified by an explanation from a Design for Wellbeing student:

> *"As an engineer, I like to take a thing, a product, look at it, twist and turn it, and then improve it or make it better".*

The starting position in existing products and the incremental improvement of them, or the 'mastery' approach [18] is a barrier for students to overcome if they should learn how to understand needs. A way to do that might be to introduce wicked design problems early in the education, but based on our experiences the students then lacks knowledge of development process models (the 'mastery' approach) and cannot envision what they should observe and why they should do that.

3.4 Understanding needs

Marketing people is commonly those that are responsible for generating information about customers. According to marketing literature, the customer should be at the centre of the company's strategy [24]. This means that the people inside the company should take the perspective of its final result, i.e., from the customer point of view [25]. In product development, such an outside-in perspective is at the heart in customer oriented or human centered design approaches, for instance in emphatic design [8] or needfinding [2].

Maslow use the word *need* to represent a whole spectrum of circumstances in the Needs Hierarchy, a scale that start with *basic needs*, e.g., air, water, food, followed by *protection needs*, e.g., safety, security. The next levels are *social needs*, e.g., love, *esteem needs*, e.g., recognition, respect, and, finally *self-actualization needs*, e.g., beauty, goodness. It is recognized that Maslow's Needs Hierarchy provide a useful description of needs, but it is also not specific enough to inform product developers [26]. Still, it can be argued, that needs are difficult for users to express [2] and are embedded in routines and workarounds [8]. Needs can be characterized by their connection to current solutions, situations or behaviors, the categories are [26]:

- *Qualifier needs*, an immediate type of needs that is a result of a problem with existing solutions, can be described in terms of enhancements of the product. The solution does not change the use of the product.
- *Activity needs*, needs that arise in specific activities of a person, can usually be described in this context and in terms of existing products. Joined with qualifier needs, solutions might replace current products and, oftentimes also change how products are used.
- *Context needs*, needs that are a result of the situation in which people live, work, or operate. These needs are more goal-oriented, and might not be perceived or are not immediately articulated by people. Together with activity needs they might drive solutions of new product families, where the products support each other or, solving needs the other creates.
- *Common needs,* most basic and universal needs that people usually are aware of, but, routinely, they try to meet these needs by meeting more immediate activity or context needs. Context needs and common needs lie outside the solution space for most single product, larger systemic solutions could meet such needs. Working toward solving common needs *"...can be a powerful way for firms to stop predicting the future and start creating it."* [26].

In product development literature the word need is oftentimes mixed with all sorts of related terms. For example, in Ulrich and Eppinger [7], the word need is used to *"...label any attribute of a potential product that is desired by the customer; we do not distinguish here between a want and a need. Other terms used in industrial practice to refer to customer needs include customer attributes and customer requirements."* (p.61). In our view, this blurred view is a weakness in product development and not particularly helpful to find, identify and generate, for example context needs and common needs. Consequently, activities to generate information in early phases might miss recognizing an innovation potential. In this context of generating customer information for product development it makes sense to differentiate needs from requirements [27]. Where, briefly, needs are hard to express and cannot be generated by asking people what they need, and requirements can be asked for and described of people in relation to existing solutions or product. Yet, we acknowledge that both views are important, thus in engineering design education students have to be acquainted with methods to generate rich information on people's behavior, use of products and the product itself.

A focus on needs has the implication that needs abound in different behaviors, situations and contexts, and as the categorization of needs reveals, one solution cannot meet all needs. To meet some needs, improvement of features might be enough, while other needs may require massive changes in thinking [26]. Some of the students from the Design for Wellbeing projects had some difficulties with their 'thinking' about needs. They had made an all-encompassing and lengthy investigation into their area of application, and after a long effort to categorize and decide on what needs to focus, they happily announced:

> *"We will try to meet as many needs as possible. Our product will meet all these needs."*

Commonly, when focusing on requirements, measures and quantity are important priorities. So, they applied their 'normal' way of thinking on this wicked problem. Later, it showed that they had to make a new analysis, since it was not doable to be informed in product development by their first attempt. Also, for these students, the observations in the area of application caused some problems in terms of what to observe. They thought, it appeared in later discussions, that they could see needs in a direct way, that the needs they sought for were readily available in the area and should just be collected. They spent two weeks at a retirement home for elderly observing the elderly people's activities, or rather they made the observation that:

> *"Nothing happens, they just sit in their chairs or rest in their beds."*

The students were really upset and felt that all their efforts in generating customer information were wasted, in particular as they compared their approach with another student project that had an improvement perspective and had made surveys. That group was way ahead of them, and had a lot of information to guide their product development. After being coached and supported by the teaching team, the students slowly became aware of that they had made insights that could provide for a breakthrough innovation. They had found that the elderly needed stimulation to help lessen, for example the symptoms of dementia, but also help to socialize with relatives and staff. In the interviews after finishing the course, the students explained that observing and interacting with their potential customers made them aware that:

> *"You are not doing the product for yourself; you are doing it for someone else."*

There are different ways to interact with people, users or customers in design work. Kaulio [28] presents three dimensions of such interaction:

1. Design *for* customers – products are designed on behalf of the customer. The knowledge base for the design is data on users, general theories and models of customer behavior.
2. Design *with* customers – focus on customer preferences, needs and requirements in a 'design for' approach, but different solutions/concepts are displayed for the customer to react on proposed design.
3. Design *by* customers – customers are actively involved and partake in the design of their own products.

Literally interpreted, a design approach that focus on needs could fit into the dimensions of designing *for* customers and designing *with* customers, while design *by* customers might not necessarily focus needs. The idea of involving lead-users [29], i.e., people that are ahead of the mainstream and develop their own products, might instead insist on development processes apt to bring in such collaboration [30]. Customer oriented or human centered design approaches require unusual collaborative skills that many companies have not developed [8], which might be a reason to why such approaches only have been implemented in a small number of cases. IDEO, a leading design firm in the US is one company that bases its innovation processes on understanding needs [11].

3.5 Process Perspectives

A first glance at the IDEO approach to innovation, they admit, can seem totally chaotic, but there is in fact a well-developed and continuously refined methodology for the work, *"...it's just that we interpret that methodology very differently according to the nature of the task at hand."* [11]. In light of the development of 'artistry' [18], this can be viewed as having abilities to integrate both a 'mastery' approach to guide work and an 'originality' approach to inform designers to modify their processes, models and tools.

The basic early steps in the IDEO methodology, or as they call it *"a method to our madness"* are [11]:

- Understand the user and the constraints the user perceives.
- Use a variety of techniques to observe real people in real-life situations.
- Visualize concepts and those who will use them.
- Evaluate and refine prototypes in a series of quick iterations.
- Implement.

Quick iterations are emphasized, and as the work unfolds during these iterations the view of users, their behavior and needs gets clearer and, in parallel, a design vision for the potential product arises. Conformity is not searched for to understand needs, rather the efforts targets diversity. Crazy users, rule breakers and the understanding that *"people are human"* are seen as sources for creativity, not a problem to be solved [11]. There are challenges on the milieu for this kind of innovation processes; the organization has to embrace a creative environment. For example, the management style will be challenged, since everybody has to *"...feel comfortable enough to poke fun at each other – even at the boss..."* [11]. An informal context is essential to make people more open to share ideas and thoughts.
Documenting the users and their behavior in a visual way, e.g., using photos/videos and storytelling, is important to communicate the findings to the members in the design team. Another significant issue is the use of many and rough prototypes, e.g., swiftly put together of everyday things or the use of sketches to prototype a service. In one of our courses we have had an exercise called 'engineering charades', where the students should use their body to visualize a typical technical problem. Based on our experiences of the students' willingness to 'play', it was decided that this exercise should be performed in pairs, which turned out to be a success.
A generic product development process, for example as described in Ulrich and Eppinger [7] is divided into a sequence of steps and activities. The steps are:

- Planning
- Concept development
- System-level design
- Detail design
- Testing and refinement
- Production ramp-up

Such a process is also iterative in its nature. The third step, system-level design, includes identification of service issues, but experimental prototypes are built and tested before that step. Accordingly, a service perspective might not have an impact on the design alternatives of the product. A limited number of prototypes are built and these are oftentimes in a state of pre-production, that is, they look like products ready to launch. The motivation to build such prototypes is to capture the functions and appearance of the finished product. This kind of prototypes does not encourage the designers to provide feedback, thus preventing teams to innovate [4]. Yet, such prototypes are useful for field test and evaluation.
In our view, the processes outlined above complement each other. Imagine a product development process on a continuous timeline, going from a vague idea to a product rollout, it might be possible to argue that there is a point from beyond which innovation and creativity is not wanted. In industry this can be seen in the difference between R&D activities (corresponding to our research focus on early phases) and in industrial product development (corresponding to production and manufacturing of the product), creativity in the latter causes disturbances and are detrimental. Here, we argue that our master courses aim to educate engineers for R&D at companies, but they should possess multidisciplinary and collaborative skills and be able to 'see the whole picture'. An innovation process, like IDEO's become a highly collaborative process and challenges the social competences of our students, but also their attitude to recognize the seriousness despite the informal and playful way.

4 Characteristics for an Engineering Designer

For organizations, the competitive business environment extends the demands on their co-workers. The situation is described by one company as: *"There is fierce competition out there, which means we require the best supply chain, the strongest finance operation, the most creative deal-makers, the greatest customer focus and the finest engineers to help take us into the future"* [31]. In addition to the vision to be a trusted business partner that delivers 'excellence' [32], a number of key attributes is identified. These attributes define what the company expects of all their employees [32]:

- *Courage and integrity* – people should demonstrate the drive, commitment and courage to, in an ethical and professional manner, contribute to the company objectives.
- *Judgement* – to draw accurate conclusions, peoples should be able to analyze a variety of information and be able to use sound reasoning.
- *Breadth and business understanding* – to develop products, services and strategies people should apply business knowledge and awareness.
- *Influence and working together* – recognizing that people influence each other, effective communication and adapt behavior appropriately is a key.
- *Delivering and managing work* – people impact positively on business performance through decisions and actions that deliver results.

The idea that an engineering designer needs to possess capabilities and knowledge outside the realm of the core engineering discipline is also presented from the perspective of research, science and knowledge [13], and touched upon in product development literature [7].
The knowledge, abilities and characteristics that an ideal engineering designer should possess are extensive. For instance, Hubka and Eder [13] provides a model of what knowledge, skills, characteristics etc. an ideal engineering designer should possess.

Knowledge, Understanding	Abilities, skills, faculties	Personal characteristics, attitudes
General knowledge	Memory	Productivity
Languages	Logical thinking	Perseverance
Literature	Synthesis ability	Willpower
History	Cost awareness	Honesty
etc.	Visualization abilities	Responsibility
Mathematics	Combination gift	Duty awareness
Geometry	Creativity	Openness
Physics	Mental flexibility	Thoroughness
Chemistry	Methodical working mode	Conscientiousness
etc.	Information procuring	Care
Technical branch knowledge	Decision ability	Contact readiness
Basic	Representation ability	Broad horizons
Specialized	Concentration ability	Objectivity
Design	Punctuality	Critical attitude (including self-criticism)
Manufacturing	Leadership	
Materials	Organization	Self-confidence
etc.	Orderliness	Enthusiasm, delight in designing
National economics	Personal bearing	Readiness for cooperation
Legal knowledge	Precise expression	Constant study
Psychology	Persuasive power	Fairness
Ergonomics	*etc.*	Psychological typology
etc.		Psychic stability
		etc.

Figure 2. Ideal Engineering Designer model [13]

In our view, the traditional product development literature covers only a small part, namely technical branch knowledge. To widen the engineering perspective it becomes necessary to bring in additional disciplines. In general, engineering design programs are planned for some eligible courses, where, for example, economics and project management are recommended. However, in this way lessons learned in those courses will certainly benefit the students, but will not bear directly on engineering design activities. A challenge for engineering design education is to employ a more holistic perspective and to find ways to educate the 'soft' aspects, for instance, mental flexibility and enthusiasm. It is our belief that courses in design thinking is a way to come a bit closer to such an aim.
Besides professional designers, people from outside can have a personality profile that is needed for a design thinker [4]. Such a profile includes [4]:

- *Empathy* - that is they have the capabilities to imagine the world from multiple perspectives, e.g., colleagues, clients, users and customers (current and prospective). Also, they take a 'people first' approach to design to observe, identify and meet human needs.
- *Integrative thinking* – they do not rely on either/or choices, rather they have the ability to see all of the salient aspects of a problematic situation, even though these might be contradictory. This

ability is used to create novel solutions that go beyond existing alternatives.

- *Optimism* - when they are facing the challenging constraints of a given problem they believe that at least one potential solution is better than the existing alternatives.
- *Experimentalism* – they recognize that innovations does not come from incremental tweaks, so they pose questions and explore the situation in creative ways that goes into entirely new directions.
- *Collaboration* – they have significant experiences in more than one discipline, they are enthusiastic interdisciplinary collaborators who are, for example engineers *and* marketers.

T-shaped people

At the heart of providing outstanding engineers is the philosophy to create 'T-shaped people'. One of the pioneers in the educational area is the Stanford d.school, listed as one of the best design schools [33]. Stanford's product design program has produced leaders in innovation for 50 years, and they are now seeking to educate T-shaped that *"...maintain the depth and focus of a single discipline while adding a "crossbar" of design thinking that drives the integration of multiple perspectives into solving real problems."* [34].

5 VIEWPOINTS FROM THE STUDENTS

In the following, a number of viewpoints from the students are presented, interpreted and put in relation to the rationale for the learning in our courses. Since we are aware of that the outline of our courses is different from the traditional, time is dedicated to go through the course memo and to talk about the students expectations. The expectations on the course contents range from:

> *"Don't really have any expectations. I'm very open-minded. Hope to learn something that I can use."*

to:

> *"My expectations are that I like to learn more about product development processes. What to do when I have an idea for a new product or how to get ideas for new products."*

Some students express, in our view, expectations of getting a 'cookbook' for product development:

> *"I wish to learn the different ways to improve and/or solve any problem; learn how to apply the different strategies, with optimum time, money and resources."*

Writing course memos that put the course intentions into words is hard work, and, of course, the memos are interpreted differently by the students. In general, there are students that do not care to read the memos; they might apply for the courses based on the courses' reputation, and, there are students that carefully read memos. Students that expect a 'cookbook' might get disappointed, since the courses are aiming to provide students with abilities to put together a tool-box of their own, i.e., to write the cookbook themselves. Also, the abilities to expand and adapt the contents in the tool-box are part of the aim for the courses.

Further, expectations are expressed on the course outline:

> *"The course feels really interesting. Not only because of the product development view, but also because of the way the course is held with discussions and seminars. I haven't worked that way since senior high school, five years ago. I'm really looking forward to it."*

The courses are intentionally designed to be different due to the subject for the education, i.e., solving wicked design problems and creative methods. In our view, to apply creative methods to solve wicked problems the students have to 'learn by doing'. This view has, in our context, a two-fold meaning for learning. First, the students have to reflect on their doing, which generates learning of the underpinning reasons for a certain method. Second, the students can identify the shortcomings of that method and based on them search for a more appropriate method or make suggestions for improvement of the used method.

In general, the students seem to ask for more information and theory, as well as lectures based on the textbooks, i.e., the recommended articles and books. This can be seen in several excerpts, for example:

I wish: ... the lecture had more information from the textbook.
... we had more 'background' before the last exercise.
... that all the slides in the lecture were gone through.

... that we have easier access to more information on this subject.
... to have the material available before the lecture.

This wish for more information about the theoretical framework can be interpreted in different ways. Asking for lectures based on textbooks might indicate two things. First, that the student are used to have teachers that apply this mode of lecturing, i.e., going through the text in the books. Second, the statements can indicate that the students are lacking structure to guide the exercises. The nature of the exercises is mainly a wicked problem or open design problems. Since lectures and exercises unfold in parallel, this might be the case. Statements about the exercises show that, for example:

I wish: ... that the assignments where a bit more structured.
... the teamwork was more structured.
... the team project were a little bit more specified.
... more explanations of the exercises.

We, continuously, remind the students that it is okay to feel frustrated and uncertain about the design assignments that we provide in exercises. We emphasize: *"Uncertainty and ambiguity are part of creative design. We do not expect that you will deliver a best optimal solution in only 10 minutes, just play the game"*. We want the students to practically try out the methods and tools. We are well aware of our fuzzy initial input in the exercises that we assign to the students, but it is fuzziness for a purpose. The rationale is to train the students' abilities to think outside the box, look beyond the obvious etcetera. Time is a constraint in real life development processes, but also, a creative session should not be too long. In our courses we have time limits for the exercises, something that is necessary, but more time should maybe be spent on supporting reflections, individual and in groups. The students are assigned to write their reflections in a logbook. The contents in these logbooks vary, but overall it seems like a hard task. Teaching design thinking seems to insist on planning for dialogues and reflection. The students have expressed wishes in line with this, for example:

I wish: ... that we had more time to talk in groups about the subject.
... we had more time to get deeper into the subjects.
... that we could try to both explain and build Lego.
... that my brain was less confused.

Also, the students expressed that they found the courses useful. For example:

I like: ... the creative parts where you have to think. Makes deeper knowledge.
... the exercise. I liked that it was brief info first, then exercise, then deep info.
... that the exercise proved what was said in the lecture.
... the rapid exercises and that we have to do some 'unprepared' presentations.
...that we got the chance to use the theory.
... the creative sessions in the lecture, it's always fun to do something practical.

I wish: ... that we do more of these exercises.
... all my classes were like this one!

6 CONCLUDING REMARKS

In this paper we have elaborated on our efforts to educate engineers in design thinking. We have claimed that design thinking is a key to find solutions to wicked design problems, e.g., utilize creativity to innovate on the basis of an understanding of people's needs. In the study presented here, we have provided some insights into the students' difficulties when exposed to education focusing on design thinking. From these difficulties three key challenges could be identified:

- Approaches where developed knowledge, e.g., established development models, and new knowledge, e.g., modification of the process to suit the task at hand, should feed input into one process are not straightforwardly implemented.
- A more holistic view in education, where 'soft' capabilities are trained to provide for a change in thinking.
- Social competence, making use of design thinking requires collaborative skills.

In our courses, a process perspective that preserves ambiguity provides a basis for design thinking. Bringing design thinking and innovation together is not magic, and it is not a game for the lone genius.

Briefly, with our approach we emphasize that problem definition is at the heart of breakthrough innovation. In our courses, the students struggle to widen their view of engineering as only problem solving activities, and they are doing well. In our opinion, product development is as much about attitudes and mindsets as about practical skills. Our expectations it that our students will experience a wider 'palette' of product development strategies in our classes, and that they will feel empowered to act on the needs and opportunities that they observe in their daily lives.

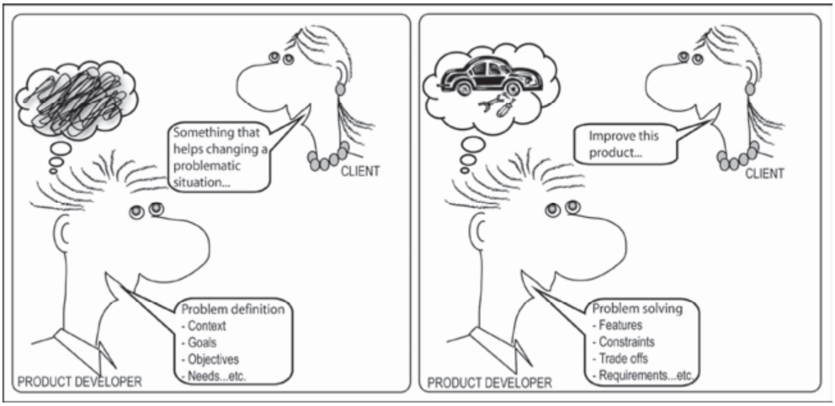

Figure 3. Problem definition and problem solving

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Contact: Åsa Ericson
Institution/University: Luleå University of Technology
Department: Division of Functional Product Development
Postal Code, City: SE- 971 87 Luleå
Country: Sweden
Phone: +46 920 49 20 61
E-mail Address: asaeri@ltu.se

Åsa Ericson received her PhD in 2007 and is currently a researcher at Luleå University of Technology. Her thesis was addressing the areas of need-based approaches for engineering design. Participatory design and user-oriented approaches, as well as their subsequent methods and techniques frame her research interests.