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WHAT IS DESIGN ENGINEERING AND HOW SHOULD IT BE TAUGHT? – PROPOSING A DIDACTICAL APPROACH

Martin Grimheden and Mats Hanson

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1 Introduction

Design engineering is being taught at the Royal Institute of Technology (KTH) in the form of a Master of Science program, Design and Product Realization. The program started in August 2003, and has been rated so far by the students as the third most popular engineering program. Each year approximately 100 students are accepted. When the program was introduced by KTH, the subject of design engineering was chosen in favour of engineering design, with the purpose of establishing the program independently in relation to existing programs in mechanical engineering, vehicle engineering etc, and to establish the new program into the area of 'development of attractive products'.

The aim of this paper is to present results from a didactical analysis performed on the subject of design engineering.

1.1 Objectives

Didactics is a field of educational studies mostly referring to research aimed at investigating what's unique with a particular subject, and how the particular subject ought to be taught. The purpose of the didactical analysis is to identify and describe the identity and legitimacy of the subject (what is design engineering, and why should design engineering be taught?) as well as its implications on the educational methods (which material should be taught, and how?).

The paper is structured as follows: In section two we describe the context of this study, providing a background and perspectives from research on education, the interpretation of the concept of design in Sweden and conclude with some examples of the industrial context of design engineering. Section three provides the didactical analysis of the subject of design engineering. In section four we discuss the results of the analysis and the examples, and present some recommendations on how to teach design engineering.

1.2 Methods

The didactical analysis was introduced in Sweden 1990 by Dahlgren [1], with the purpose of facilitating the analysis of the characteristics of a subject, together with the implications for the educational aspects of the subject. The didactical analysis can be illustrated with a set of four questions that is applied to a subject: The questions of identity, legitimacy, selection and communication. The identity is mapped on a scale from a fully disciplinary subject towards a thematic subject. The legitimacy is mapped from formal knowledge towards functional skills.

The analysis of the subject of design engineering is performed on the basis of literature studies, comparisons of educational design engineering programs as well as on data gathered during the development of the design engineering program at KTH.

2 Context

2.1 The educational context

Educational studies are usually performed on three different levels, depending on the scope and purpose of the studies. When performing studies on an individual level, where the individual learning processes are studied, the area is usually referred to as educational psychology. When studies on a society level are performed, this area is referred to as educational sociology.

A study on the scale of a group of students, such as a class, and in particular studies on the relation between the efforts undertaken by a teacher and the learning achieved by his or her pupils, is defined as didactics. This is however only the case in some educational contexts, such as in central Europe and the Nordic countries. In Anglo-Saxon countries the preferred choice is to use the term subject matter education to describe didactics [2].

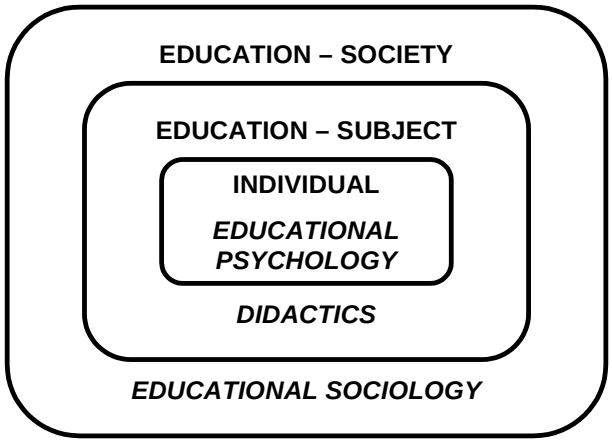

Figure 1. Didactics is defined as subject matter education. From Dahlgren [1].

Most research in the field of didactics aims at describing what's unique with a particular subject, and how this particular subject ought to be taught to achieve the best possible learning outcome [1]. To analyze design engineering according to the didactical approach therefore represents the same aim, to investigate how this subject ought to be taught.

2.2 The language context

In Swedish, the term design (written and pronounced as in English) is most commonly understood solely in terms of aesthetic values such as shape and appearance. It is not used when referring to functionality. Thus industrial design, both as programs at universities and as a profession, relates primarily to an aesthetic education, even if it does encompass areas such as ergonomics and aerodynamics. Education for industrial design in Sweden is normally not an education in engineering. This is also apparent from the fact that the Swedish translation of 'engineering design' is *produktutveckling* or *konstruktion*, with no reference to the word

‘design’. Since *produktutveckling* is also translated to ‘product development’ the result is that ‘engineering design’ in Sweden is equal to ‘product development’ [3].

2.3 Design in Swedish higher education

In recent years the concept of design has been introduced in an engineering context in Sweden in the form of new engineering programs such as the Design and Product Realization program. The aim of these new programs is primarily to make the move from more traditional analytical programs such as mechanical engineering towards the area of product development, however often within the sphere of mechanical engineering. Similar programs are offered at other technical universities. Examples of programs in this sphere are “innovation and product design”, Mälardalen University, “industrial design engineering”, Chalmers university of technology, “Mechanical engineering and industrial design”, Lund Institute of Technology, “Product innovation” at Luleå University of Technology.

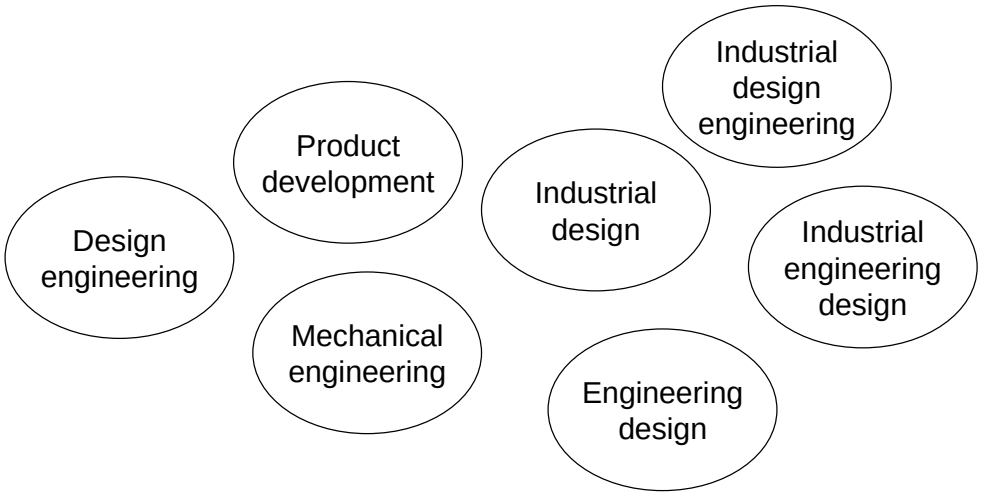

Figure 2. Examples of names and subjects associated with the educational programs in Swedish higher education that relates to design

One of the first engineering programs in Sweden related to design was started in 1999 by Chalmers University of Technology: the Industrial design engineering program. When introduced by Chalmers, the program was aimed at covering the void between the programs of engineering design and industrial design, and was thus called industrial design engineering.

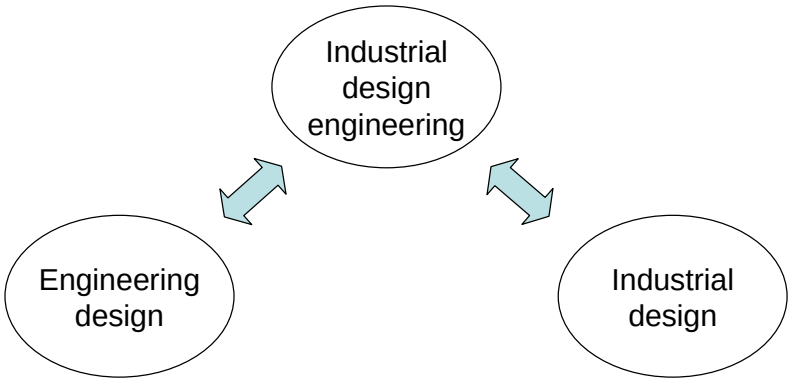

Figure 3. The program of Industrial design engineering, as introduced by Chalmers University of Technology [4]

According to Wikström [4], the program of Industrial design engineering at Chalmers contains approximately 50% courses covering design-related areas and 50% of the courses are covering engineering-related areas. The university accepts 30 students for this program annually, which is rated as the most popular engineering program in Sweden, with eleven first hand applicants per accepted student.

In 2003 KTH introduced its first engineering program on master's level related to design, the program of design and product realization. For this program, KTH accepts around 100 students annually.

When the program of design and product realization was introduced at KTH the ambition was to further establish the area of "Design engineering", to stress the difference with "Engineering design", and thereby also to distance further from the established programs of mechanical engineering which sometimes were translated as engineering design programs.

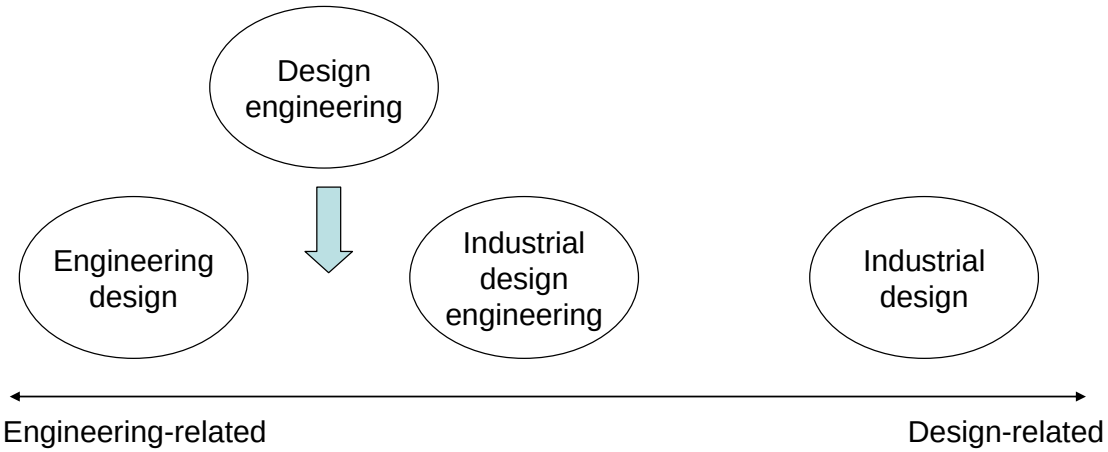

Figure 4. The subject of design engineering, implemented in the form of the program of design and product realization, as intended by KTH

Figure 4 shows the intended aim for the program of design and product realization; to fill a gap between programs in engineering design, which in Sweden is strongly related to the more traditional programs of mechanical engineering and the more artistic programs of industrial design and the smaller and more special programs of industrial design engineering. The aim therefore was to educate engineers, with a strong base in engineering subjects, but with

knowledge and skills in industrial design enough to be able to communicate and collaborate with industrial designers.

One purpose with this paper is thereby to provide a definition of the subject of design engineering, as intended and implemented in Sweden, by KTH, by using the didactical approach.

2.4 The industrial context

One example of the industrial context is provided by Frise et al [5, 6] in two articles analyzing the design engineering body of knowledge, with a special approach towards education in automotive engineering. Frise et al describes the change in required competence for a designer in a product realization team. Previously the designer was mainly responsible for producing drawings, detailing and mainly contributing to the geometry of the respective part. Turning to the current and future situation, Frise et al are predicting that the role of the designer are changing toward the role of a design engineer, with an enhanced skill-set in the entire product realization process. In this perspective, the design engineer combines several of the roles previously associated with the other members in the product realization team, such as knowledge in manufacturing, engineering analysis, components etc. The design engineer now calls on senior specialists as consultants and on a basis of need. The design engineer has evolved into a specialist in communicating and collaborating with experts in their respective fields, with knowledge and skills in the entire product development process.

3 A didactical analysis of design engineering

3.1 The didactical approach

Didactics is here defined as ‘subject matter education’, and the didactical approach aims at analyzing the subject of design engineering to define what’s unique of this subject, thereby providing insight into how this subject ought to be taught. The didactical analysis of an academic subject, as defined by Dahlgren [1], can be illustrated with a set of four questions that is applied to a subject (X).

- Identity (What is X?)
  The identity varies from disciplinary to thematic.

- Legitimacy (Why should X be taught?)
  The legitimacy varies from formal to functional.

- Selection (Which X should be taught?)
  The selection varies from a horizontal representation to a vertical exemplification.

- Communication (How should X be taught?)
  The communication varies from active to interactive.

These four questions together with their extremes are illustrated in figure 5, and will be applied to the subject of design engineering.

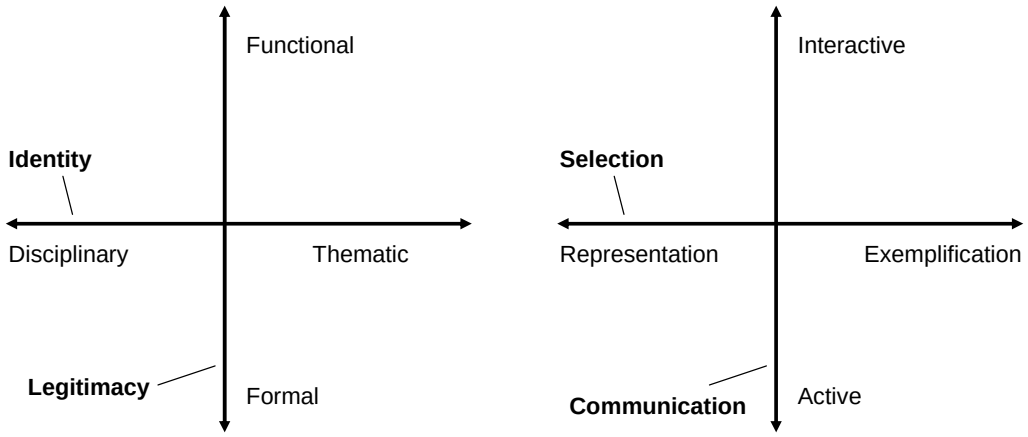

Figure 5. The four questions representing the didactical analysis together with their extremes

3.2 The identity of design engineering

According to the didactical analysis the identity can be described according to the two extremes of either disciplinary or thematic. The question of identity is defined as "what distinguishes the particular field of knowledge?". Most traditional subjects such as mathematics, chemistry and physics are viewed as disciplinary, meaning that there exists a strong consensus in the surrounding society regarding the contents of the subject, the classification and organization of the contents etc. In several cases, the knowledge is organized and developed systematically, and the created knowledge is easily classified into the existing structures.

In the case of design engineering it is obvious that a strong consensus does not exist regarding the identity of the subject. The earlier introduction of higher education in Sweden related to design gave at hand that every university in Sweden giving programs related to both design and engineering have created their own definition of the subject as well as tried to cover different aspects of the area between engineering and design. Most universities in Sweden avoid using the term engineering design when describing their subjects, instead using design engineering, industrial design engineering or simply product development. All programs however have a base in earlier programs of mechanical engineering, and in most cases can be seen as a modernization and natural development of the mechanical engineering programs.

One possible way of identifying the identity of design engineering, as intended by KTH, is to analyze the way the subject is officially communicated by KTH. On the KTH website [7], in brochures published by KTH [8] and in the official reports written as preparation for launching the new program [9, 10] the following descriptions are made of design engineering, when presenting the program of design and product realization:

- The program focuses on the early phases of product development with a largely holistic and systems-based approach [10].

- As a design engineer you will work with problem solving related to the development of new products. The tasks you will perform require creative thinking and the ability to think outside the box to see new possibilities. [7].

- The education in design and product realization gives a holistic view on the development of various products, from refrigerators and cellular phones to robots and

heavy machinery. You will gain knowledge in the product development process, from idea to product, from market analysis, specification, choice of materials and design to production, test, service and recycling [8].

- A degree from KTH Design and product realization could put you in a key position for product development, from vacuum cleaners to airplanes [8].

The keywords in the statements above are product development and holistic viewpoint. Design engineering, as intended by KTH is therefore associated primarily with the themes of product development, with a holistic viewpoint.

To turn back the focus to the didactical approach and the identity of design engineering, the above quotations provide a possible answer to the question of identity: the identity of design engineering can be seen as thematic, where the theme is related to the concept of product development, and a holistic viewpoint.

To broaden the viewpoint further, the identified theme of design engineering at KTH is compared with definitions provided by the American Institute of Aeronautics and Astronautics and by the Natural Sciences and Engineering Research Council of Canada:

- Design Engineering is a discipline that creates and transforms ideas and concepts into a product definition that satisfies customer requirements. The role of the design engineer is the creation, synthesis, iteration, and presentation of design solutions. The design engineer coordinates with engineering specialists and integrates their inputs to produce the form, fit and function documentation to completely define the product [11].

- Design engineering is concerned with the design and development of new and improved products, processes and technologies that satisfy specified requirements in an effective and efficient manner. It includes the creation and development of innovative tools, approaches, methodologies and standards to improve all aspects of product and process designs; state-of-the-art designs of products, processes and process technologies. Design engineering is the enabler of innovation. It is the activity that creates the concepts and designs, and develops the new and improved products, processes and technologies that are needed in industry and in other sectors of the economy [12].

Also in these cases, the same keywords can be used; product development and a holistic viewpoint. Both quotations above however broaden the definition of design engineering to also encompass areas such as creativity, creation and development of tools to improve product development, design as an enabler of innovation, and the designer as a communicator with specialists.

When mapped on the question of identity, we therefore see that design engineering as a field, is best characterized by a thematic identity – the discipline of design engineering is hardly not established, or at least there does not exist a consensus around the definition on design engineering. The core of the subject is hard to identify, and in several cases examples are used to communicate the identity; examples in the form of products the engineer will be able to develop. It can thereby be concluded that design engineering has a thematic identity, where the theme is related to the concept of product development with a holistic viewpoint, as well as creativity, the ability to communicate with specialists etc.

3.3 The legitimacy of design engineering

The question of legitimacy is defined as the relation between the actual outcome of the educational efforts undertaken by the university and the actual demands that are put upon the students' abilities by the society and/or industry at the end of their education. This relation can be described according to two extremes – either formal legitimacy or functional legitimacy. In a simplified model the formal legitimacy relates to formal knowledge, for example knowledge gathered from textbooks that are read by the students. The functional legitimacy relates to functional skills such as the ability to perform concrete work tasks as part of product development. The functional skills are usually not learnt during traditional lectures or by reading textbooks but rather developed during hands-on exercises, laboratory experiments, trial and error etc.

Examples of formal legitimacy in a design engineering context could be when the society or industries request engineers with a certain amount of credits in a certain subject, for example 20 credits in mechanical engineering, based on reading certain textbooks or performing certain experiments. The same companies would require a functional legitimacy if they instead specified the level of skills required within the subject of mechanical engineering, for example that the engineer should be able to design a transmission, to choose an appropriate bearing for an application or design a shock-absorber with certain specifications. Note though that the difference between a formal legitimacy and a functional legitimacy is not related to the depth of the understanding, or knowledge, but in this example to how this knowledge or understanding is specified by the company.

It is important to note the strong context dependency when discussing legitimacy. For example, a student specializing in theoretical mathematics might well fulfill functional needs related to solving certain analytical problems in industry; a competence that might well be regarded as formal in other contexts. In addition, educational methods do not necessarily imply either formal or functional knowledge or skills although certain educational methods are more often associated with either knowledge or skills [13].

The connection between knowledge and skills also makes it difficult to value the students' knowledge and skills. A hiring industry for example might search for a person with a specific set of skills to meet a particular need at the company. However, the same need might not be existent a few years later. At this point formal knowledge might be more important than functional skills: a high level of formal knowledge might facilitate the development of new functional skills etc. When the hiring industry states the actual demands, that is the requirements of the education to the university, there is a great risk that the often short-sighted needs exaggerates the need for specific skills instead of more general knowledge.

When mapped on the question of legitimacy, we therefore see that the subject of design engineering is best characterized by a functional legitimacy. The functional legitimacy is primarily related to the identity of design engineering: since the identity is viewed as thematic and related primarily to the concept of product development, the legitimacy is related to the ability to develop products, from idea to prototype.

To illustrate some requirements from Swedish industry related to the functional legitimacy of design engineering, some examples are gathered from the proceedings of a conference in Gothenburg in March 2004, organized by the Swedish society of mechanical engineers (SMR), with the title "Mechanical engineer or designer – conflict or collaboration?".

- Atlas Copco: The management is increasing the focus on design. The purpose of integrating design in the product development is to enable better communication of the corporate values by the products, visually and tactile [14].

- ITT Flygt: The company have hired design engineers to design a new series of drainage pumps. Even if the pump is supposed to be placed in a sewer for the rest of it's life, a good design could facilitate maintenance and production, as well as make the products appearance communicate reliability, efficiency and power for future customers in printed material and on exhibitions [15].

- Volvo: It is necessary to take a holistic viewpoint on product development. It is no longer sufficient to have mechanical engineers develop new trucks; the design engineer facilitates the holistic viewpoint and enables the integration of form and functionality early in the product development process.

3.4 Selecting design engineering

The questions of selection and communication regard issues such as how the subject should be taught and what aspects of the subject that should be studied. The question of selection can be illustrated using two extremes – horizontal representation and vertical exemplification. Horizontal representation implies that the entire subject should be represented in the education, meaning that the education should consist of samples of each aspect of the entire subject. On the other hand, a vertical exemplification means that one or more examples from within the subject should be studied and in contrast to the horizontal selection these examples imply rather deep studies into the respective fields – depth instead of width.

An example of the question of selection could be the choice of how to plan an education in mechanical engineering. A large number of possible approaches exist, for example when comparing different development models. A course in design methodology could on one extreme focus on one particular design methodology in depth, or on the other extreme on covering a large number of available design methodologies. To focus on one methodology in depth would point towards a vertical exemplification and covering all methodologies points toward a horizontal representation where all methodologies are represented.

As with the previous questions it is not a matter of choosing one of two extremes, but rather about finding the appropriate proportions between these two. Most engineering educations choose both horizontal representation and vertical exemplification; usually the first years are dedicated to the first and the later years to the second.

A connection can be made between the question of selection (the division between representation and exemplification) and the question of identity. If the identity of a subject is regarded as thematic a horizontal representation is difficult to achieve when teaching the subject. If the identity is disciplinary there exists a consensus of the contents, definition and structure, and it is not difficult to find an appropriate textbook in, for example, mechanical engineering, further illustrated by the fact that introductory courses for engineering students are very similar. When searching for a textbook in design engineering this becomes more difficult. Every available textbook on design engineering emphasizes different aspects. It is equally difficult to agree universally on curricula and courses in design engineering since each teaching team reflects the local interpretation of the subject.

A thematic identity therefore implies an exemplifying selection. A similar connection can be made between the question of legitimacy and the question of selection, that the functional legitimacy implies an exemplifying selection.

The functional legitimacy implies a focus on skills, abilities and applied knowledge rather than more abstract knowledge. The applied knowledge is related to the theme, the examples, which in the case of design engineering are illustrated by the keywords product development and a holistic viewpoint. If compared to the earlier example with design methodologies: an education in design engineering, where a vertical exemplification is chosen, a course in design methodology could be focused on learning and using one design methodology. Since the legitimacy of the course and education is related to the abilities to develop products the legitimacy of the course in design methodology could be reached if the design methodology was seen as a tool to facilitate product development.

This is however a controversial standpoint. Several courses in design methodology aims at giving a broad overview of the existing design methodologies; their pros and cons etc. This is definitely a valuable aim, but if the connection is made between the legitimacy and the selection, the opposite could be argued. If the university is educating students into product developers the approach (or selection) should be different, in that case it is irrelevant which and how many design methodologies the student knows, what's relevant is the students' abilities to develop products, by using several tools, for example design methodologies.

An immediate consequence of the above reasoning is the form of the education; if it is abilities and skills in using, for example, design methodologies that are in focus, how could the education be organized to facilitate this? We turn our focus to the fourth and final question: the question of communication.

3.5 Communicating design engineering

The question of communication can also be viewed in the light of two extremes – either as active communication or as interactive communication. Active communication can be seen as a feed-forward (open-loop) control system where the education is based on a prior understanding of how the material should be communicated, or other models of student learning behavior. The interactive communication can be seen more as a closed-loop control system where the action performed by the educator is based on the current status and knowledge level of the individual student or student team.

As described earlier, there is a direct connection between the identity of the subject and the selection of the subject – the thematic identity requires a vertical exemplification as selection. Equally, there is direct connection between the legitimacy of the subject, through the selection to the communication of the subject – the functional skills required by the hiring industry are supported by emphasizing examples, project work, team work, cooperation with industry etc. This in the end facilitated by an appropriate educational form where all education is based on an interactive communication, preferably with strong ingredients on project based work.

To teach design engineering, with a vertical exemplification and an interactive communication, requires an education where focus is on product development; not solely knowledge about the product development process but skills in developing products. A holistic viewpoint requires not solely knowledge in the entire chain of product development stages but rather individual experiences from all aspects of product development.

4 Discussion

The previously presented didactical analysis can be summarized into the following:

- Design engineering have a thematic identity
  (Where most traditional academic subjects are defined as disciplinary)

- Education in design engineering should be focusing on functional aspects
  (When most traditional academic subjects are taught formally)

- Design engineering should be taught with more exemplifying selections
  (When most traditional academic subjects are taught with a representation of the entire subject)

- Design engineering should be taught with an interactive communication
  (When higher education traditionally is taught in an interactive way, from the teachers' point of view)

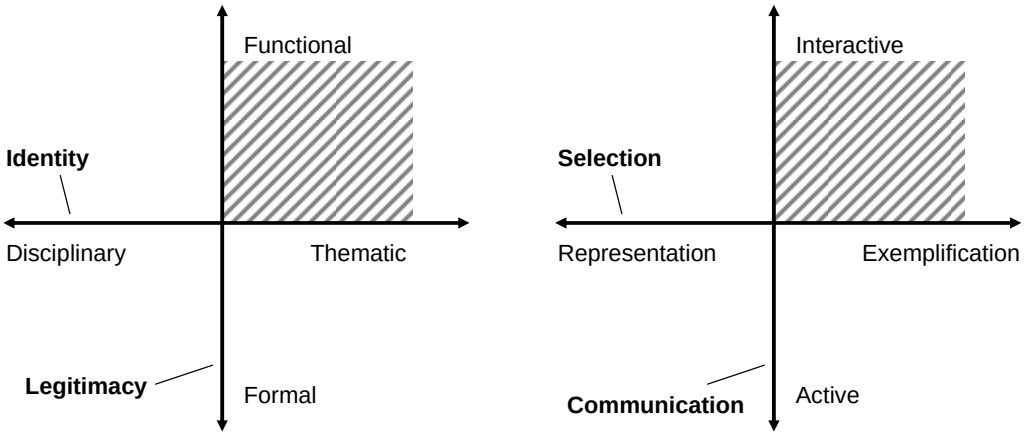

Figure 6. Illustration of the didactical analysis applied to the subject of embedded systems.

The identity of design engineering is defined as thematic. This definition is related to the notion of regarding design engineering as a synergistic combination of design and engineering rather than using descriptions of design engineering as cross-disciplinary subjects or as subsets of either mechanical engineering or industrial design. The keyword is synergistic, synergy between form and function, between construction and production, between engineering and market etc. The keyword also relates to the theme of the identity - the theme of design engineering can thereby be 'synergy'.

The legitimacy of design engineering relates to the relation between the outcome of the educational efforts and the demands by the society and/or industry. In contrast to more traditional subjects such as mechanical engineering, design engineering is regarded with a functional legitimacy, meaning that the industry demands more functional skills than traditional programs, skills such as abilities to work in multi-disciplinary teams, to communicate both form and function etc. The functional legitimacy is also related to the identity of the subject – the hiring industry in many cases represents companies designing and producing attractive products, and to support this process the engineer in most cases needs skills, for example related to synthesis, in favour of formal knowledge measured by grades in the traditional subjects.

4.1 What to teach and how to teach it?

The results of the didactical analysis are strong implications on the educational methods of the subject, the question of selection and communication. According to the analysis, the subject would benefit from being taught in an exemplifying selection, meaning ‘depth’ in favour of ‘width’, or better: ‘everything of something’ rather than ‘something of everything’. Further, the results from the thematic identity and the functional legitimacy is that the communication should be interactive rather than active, with preferred focus on teamwork, soft-skills, communication. To focus on these soft-skills also further establishes the legitimacy of the education, since most students on graduation will work in multi-disciplinary teams.

4.2 Design engineering or engineering design?

The didactical analysis has been applied to the subject of design engineering, on the basis of how the subject is intended by KTH and how this is manifested in the program of design and product realization at KTH. Examples and definitions are also used from other organizations related to design engineering, organizations such as the American Institute of Aeronautics and Astronautics and the Natural Sciences and Engineering Research Council of Canada. Besides keywords such as product development and a holistic viewpoint both these organizations focus on creativity, synthesis and communication in their descriptions of the subject of design engineering.

To further stress the identity of design engineering, as according to the description above, this section will conclude with a comparison with the subject of engineering design. For comparison, the definition of engineering design given by ABET inc, the Accreditation Board for Engineering and Technology:

“Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective.” [16]

When comparing this definition with the definitions of design engineering, it is clear that these are two different subjects. Where design engineering (DE) focuses on product development, engineering design (ED) focuses on devising a system, component or process. Where DE focuses on a holistic viewpoint, ED focuses on applying basic sciences, and perhaps most strikingly, where DE focuses on creativity and synthesis, ED focuses on an iterative decision-making process.

5 Conclusions

The didactical analysis defines the identity and legitimacy of design engineering as thematic and functional – the students should practise and receive functional skills within the core of design engineering, which in this study is defined as the synergy between form and function. Design engineering would then benefit from being taught with an interactive communication and exemplifying selection. Project-organized courses and problem-based education are examples of preferable methods for design engineering, as well as focus on synthesis in favour of analysis, the full picture in favour of details. The aim is to move the educational methods towards a situation where the identity of the subject, an identity that is related to the concept of synergy, forms the base of the education, which would further strengthen the legitimacy of the subject.

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Corresponding author
Martin Grimheden
Royal Institute of Technology, Machine Design
Brinellvägen 83
SE-100 44 Stockholm
Sweden
Phone: +46 8 790 7797
Fax: +46 8 20 22 87
E-mail: marting@md.kth.se