FOUNDATIONS FOR A NEW TYPE OF DESIGN ENGINEERS – EXPERIENCES FROM DTU MEETING THE CDIO CONCEPT

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ABSTRACT

Since 2002 a new design-engineering education has been in operation at the Technical University of Denmark. It fulfils the requirements in the CDIO concept but builds in addition on a change in what is considered core disciplines in engineering. Three fields of knowledge are represented almost equally in the curriculum: natural and technical sciences, design synthesis and socio-technical analysis, which adds to the dominant focus in engineering on natural and technical sciences. Combined with the integration and coordination of disciplines, a series of projects providing a progression of challenges to the students learning, and a focus on the outcomes of the learning processes of competences needed in design engineering, the curriculum represents a radical innovation in engineering curriculum.

The paper describe the foundational elements of this educational program and present an assessment of the key factors that has made this program attract new groups of students to engineering including an almost equal recruitment of male and female students. In outcome and performance terms the educational program at the same time has delivered a quite efficient study environment for students. Since 2007 graduates have finished every year and an evaluation of the education based on the graduates and their employers' experiences supports the visions of the curriculum and adds to what is needed to reform engineering education.

The paper presents a critical comparison of the CDIO basic standards and principles with the learning content and experiences from the design-education at DTU and raise three questions to whether the advice provided by the CDIO syllabus satisfies the stated principles. The critique points to the following: (a) conceiving not being taken serious in the CDIO syllabus, (b) a too narrow view of engineering knowledge ignoring socio-technical insights, (c) the importance of engineering practices and competences in creating authentic assignments, (d) to reverse the hierarchy of topics and disciplines, and (e) a need for mechanisms to coordinate curriculum and cross-disciplinary cooperation. The creation of successful reforms in engineering education does not alone result from introducing project or problem based learning in the classroom. There is a need to focus on the objectives and disciplinary support for project assignments understanding the scattered character of technical disciplines. There is also a need for introducing measures that support teams building and continued cooperation among teachers to overcome the isolation.

KEYWORDS

Design-engineering, socio-technical competences, team work, authentic projects, disciplinary integration.

INTRODUCTION

Since the 1990s questions have been raised by industry and educational planners both in the US and Europe to the scientific orientation of engineering education as it has developed since World War II. The problems include a lack of practical skills in modern engineering training, a mismatch between the need of industry and the scientific knowledge taught, and the kind of analytical qualifications as objectified knowledge being awarded in engineering education compared with visions of engineers as creative designers and innovators of future technologies. With its emphasis on science and knowledge structured around technical disciplines, engineering education has developed into an education of highly technically skilled, specialized cooperative workers rather than innovative and creative engineers of technology for society. Following the continued development of technology has lead to an increasing number of specialized fields and educational program characterized as 'expansive disintegration' by Williams [1] critical accounts have pointed to a need for reforming engineering education.

From this critical outset the knowledge and broad innovative orientation needed to produce creative design engineers able to cope with contemporary technological change have been as missing in engineering education. Several educational initiatives have addressed these issues in the last two or more decades outlining plans to reform engineering education. Some focus on engineering curriculum or the pedagogy and learning modes employed; some develop completely new engineering programs based on new technologies. These approaches seem to be confident in the achievements of engineers in society and argue for the continuation of a traditional science-based engineering curriculum [2,3]. Other initiatives combine business, management, and organizational understanding with engineering, or they alternatively emphasize the creative design aspects of engineering integrating aspects from other initiatives.

Common to most initiatives has been that they share the view that technology and the natural sciences are the two basic contributors of knowledge to engineering. They do not raise critical issues related to the social and institutional dependencies of technology. Engineering schools and professional institutions at large have supported the idea of a close relationship between science and technology by even asserting that natural sciences form the core foundation of engineering. Also contemporary developments in the natural sciences and engineering sciences have blurred the boundaries. New approaches of techno-science seem to be gaining ground as the characterization of the ties between modern science and technology, leaving neither one in a subsidiary role [4]. These new approaches do though recognize technology as a contributor to scientific achievements and thereby change the relationship between nature and technology. The question is whether these accounts are satisfactory in understanding and coping with the contemporary problems in engineering education in relation to the demands from engineering practices at large?

In this article the focus will be on the role of engineering design in contemporary society and the knowledge base and skills needed to perform engineering design. Based on a brief historic account of the controversies in engineering between practice and theory and concerning the core knowledge base the engineering education in design & innovation program will be introduced. The emphasis in the presentation and discussion will be on the combination of learning strategies and disciplinary knowledge components that constitute the curriculum and the program at large including its research foundation. From the outset engineering competences in design synthesis and socio-technical analysis building on the research field: Science and Technology Studies (STS) have been foundational for the reform of engineering education implied. These additional components have also been agenda setting for the teaching of mathematics and technical subjects.

Several of the reform components found in the design & innovation program are also included in the requirements set up in the standards and syllabus of CDIO that is the acronym for a engineering reform initiative emphasizing that the four basic activities in engineering: Conceive, Design, Implement and Operate, should also be reflected in engineering education [5,6]. Of special importance for this paper is the advice given by CDIO on how to learn to conceive problems and carry out the design synthesis, which we will discuss and contrast to the approach taken in the DTU design engineering program. We seem to agree on the rather ambitious claim that engineers should be trained to 'build systems and product for the betterment of humanity' [A,p.4], but what does it take? Another topic of relevance is the structure of knowledge and the ideas of what is fundamental and in which order in the learning process should topics and disciplines be introduced. Despite this CDIO initiative's visions for reforming the engineering education with more focus on engineering practice, the fundamental in engineering education is still perceived as in-depth technological and scientific knowledge, since the baseline assumptions is that: 'The development of a deep working knowledge of technical fundamentals is and should be the primary objective of undergraduates engineering education' [5,p.5]. This implies a questionable hierarchy of knowledge as outlined in the syllabus [6,p.55-56] and a build up of design skills with the outset in technical knowledge [6,p.108]. In the last section of the paper these contrasts will be discussed.

ENGINEERING EDUCATION – A BRIEF HISTORY

In order to understand today's situation in engineering education and the emphasis on scientific knowledge, we must consider one of the most important historical changes in engineering education – the construction of a science base for engineering. This development resulted partly from the increase in public and military funding of engineering research during World War II, partly from attempts to develop a more theoretically based foundation for engineering. The program to establish a science base for engineering created an elite group of theory oriented universities and technical schools of higher education in both the United States and Europe. At the outset there was a gap in engineering curricula between science classes based on high degrees of mathematically formalized knowledge, and the more descriptive and less codified technical subjects. Controversies resulted in positioning technical sciences as secondary, or applied, in relation to the natural sciences. However, the new era of expanding technical sciences lessened these controversies because of its increased focus on innovation and awareness of the close interactions between specific areas of science and technology.

During the first half of the 20th century, polytechnic universities had to fight for acceptance. They were acknowledged for their foundations in science, but were questioned about whether they could conduct independent scientific research; or were limited to practical experiments with technical improvements and practical implementation. These controversies manifested themselves in the acceptance of doctoral studies at technical schools of higher education. In Sweden and Germany, as in many other countries, decisions about what should qualify as scientific achievement and who was qualified to judge were very controversial. The controversy ended with an acceptance of technical or engineering science as a distinct area of scientific inquiry, although the image of engineering science as merely applied natural science continued to dominate many discussions about the character and role of technical sciences. Sponsorship of fundamental studies in a variety of areas supported the trend away from practice-oriented research and education resulting in critique from industry [7].

The post-war decades saw the rise of systems engineering and thinking as broadly applicable engineering tools [8]. Systems sciences that include control theory, systems theory, systems engineering, operations research, systems dynamics, cybernetics and others led engineers to concentrate on building analytical models of small-scale and large-scale systems, often making use of the new tools provided by digital computers and simulations [9]. Whereas systems engineering of the 1950s could be narrowly analytical and hierarchically organized, new ideas of technological systems in the 1980s and 1990s focused on the relationship between technology and its social and industrial context. This new relationship and understanding of the natural and technical sciences is reflected in the notion that engineering as techno-science developed in the field of sociological studies of science and technology to reflect the new intimate relationship between these fields of science [10].

Changes in the foundation of engineering education, with the expansion of science-based technical disciplines, also has led to changes in the curriculum of traditional vocational schools of engineering, as well as funding for research. Though having different names, ‘polytechnics’ in the United Kingdom, ‘fachhochschulen’ in Germany, and ‘teknika’ in Denmark these schools shared common characteristics in recruiting students from groups of skilled technicians and supplementing their training with a theoretical education, while maintaining a focus on industrial practice. As a result, the schools inherited the experience-based, practical knowledge, and skills of students who had previously worked as apprentices in construction firms, machine shops, and industry. At the same time, the decline in the apprenticeship training of craftsmen and skilled workers began to undermine the recruitment lines of the polytechnics [11].

Conflicting ‘ways out’ – specialization and new modes of learning

The growth of the use of technology in the later half of the 20th century, in combination with the large investments made in engineering research by industry and by research institutes and universities, has resulted in tremendous growth in the body of technological knowledge, the number of new technological domains, and specialized technical science disciplines [12]. Differentiation in engineering specialties put pressure on engineering education to cope with the diversity and to keep up with the frontline of knowledge in the diverse fields. These developments have also resulted in a growing number of new specializations in engineering. Changes in the demands for specialization created tension between generalized engineering knowledge and the specialized knowledge needed in individual domains of technology and engineering practice. Examples of these specializations include highway engineering, ship building, sanitary engineering, mining engineering, power generation and distribution engineering, offshore engineering, aeronautics, microcircuit engineering, environmental engineering, bio-engineering, multimedia engineering, and wind turbine engineering. This development called ‘expansive disintegration’ [1] reflects the combined expansion of the number of technologies, specialties and disciplines on the one hand, and the continued disintegration of what once was the unity and identity of engineering on the other.

General pedagogical reform based on project-oriented work are also argued for giving students a broad understanding of engineering work and problem solving, with less emphasis on theoretical knowledge represented in the courses and disciplines [13] which is also found in e.g. the CDIO initiative [6]. In a less radical manner many engineering schools have tried to add certain new personal skills to their requirements and curriculum by complementing the natural and technical science teaching with training in communication skills, group work, and project management. These are competences that are implied in the project-oriented model and in the less demanding problem-based learning model.

The dominant role of technology demands multidisciplinary approaches, and challenges the science-based, rational models and problem-solving approaches. These demands have given rise to new areas of engineering education. For example, in the field of environmental studies, the need for new approaches in industry based on cleaner technologies and product chain management challenged the already established disciplines in sanitary engineering based on end-of-pipe technologies and chemical analysis. Another example can be found in the field of housing and building construction engineering. The need for integrating both social and aesthetic elements, as well as user interaction in both the project and use phases of construction, led to several attempts to overcome the traditional division between civil engineering and architecture.

The decade of the 1990s was not the first time that concerns about the role of technology in society had surfaced, but this time the questions raised issues of a more fundamental nature concerning the content of engineering education and the impact on technology exemplified with controversies about highway planning, chemicals in agriculture, nuclear power plants, and the social impacts of automation. The concerns questioned the role of knowledge about technology and some critics demanded a humanistic input into the curriculum with such subjects as ethics, history, philosophy, and disciplines from the social sciences [14]. This idea was based on the assumption that engineering students, through confrontation with alternate positions and opportunities to discuss social and ethical issues, would be better prepared to meet the challenges of technology. However, in many engineering education programs, these new subjects have ended up being add-on disciplines often not integrated with engineering and science subjects, contributing further to the disciplinary congestion in engineering. Changes in the role of technologies in a society where consumer uses, complex production, and infrastructures are increasingly more important, have led to more focus on the integration of usability and design features. The traditional jobs in processing and production have not vanished, but new jobs in consulting, design, and marketing have been created. These new jobs demand new personal and professional competencies, and require new disciplines that contribute to the knowledge base [15].

New approaches to design and disciplinary boundaries

During the 1990s, several engineering schools started new lines of education emphasizing engineering design skills and introduced aspects of social sciences into the curriculum of engineering design. These additions included technology studies, user ethnographies, and market analysis. The development of new and diverse technologies also reflects the limitations of technical sciences in being able to cover all aspects of engineering [16]. Examples of these reformed engineering programs can be found at e.g. Delft University in the Netherlands, Rensselaer Polytechnic Institute in the U.S., the Technical University of Denmark, the Norwegian University of Science and Technology, and several other places.

The description of an engineer’s contemporary competencies might include the following: ‘scientific base of engineering knowledge’, ‘problem-solving capabilities’, and the ‘adapt knowledge to new types of problems’. The focus is more often on problem solving, and less on problem identification and definition [17]. This is ideally taken up in the CDIO standard as conceiving, but not explicated were much in the latter detailed curriculum plans presented [6]. This focus emphasizes the problem of engineering identity in distinguishing between engineers as creators and designers versus analysts and scientists raising question about the foundation of synthesis knowledge and design skills. The underlying assumption in most training given by engineering schools on engineering problem solving is that engineers are working with well-defined technical problems and methods from an existing number of engineering disciplines. This assumption does not answer the question as to whether engineers are competent in handling the social implication of complex technologies, and the even non-standardized social and technical processes where the problems are undefined and involve new ways of combining knowledge.

In this relation the limitations to engineering sciences and their models become a crucial part as does the understanding of technologies as hybrid constructs building on several both disciplinary and practice based knowledge components and embedding assumptions of use and social relations related to specific localities and historical settings even though these may become part of standardized socio-technical ensemble [18]. The other crucial aspect for engineering technology of the future is the handling of design challenges coming from the even more dominant role of technology in society and for the environment. This must lead to a redefinition of what the core competences of engineering comprise.

THE DESIGN & INNOVATION PROGRAM AT DTU

Since 2002, the Technical University of Denmark (DTU) has offered a new engineering education in design & innovation. This new bachelor and master program of 3 plus 2 years length represents a fundamental rethinking in engineering education. With an enrolment of 60 new students per year and twice as many qualified applicants, this new initiative is considered as a success by DTU. The new curriculum is targeted to meet the demands for competences from industry and society in the context of globalization and new cooperation structures in product development and innovation. The design & innovation education contributes to the renewal of the educational profile of DTU and is regarded as one of the recent major successful strategic developments.

An important motivation from the university management's side for providing the new education in design & innovation has been an interest in attracting more and new types of students having good grades from their high school graduation but not being attracted by the traditional engineering education curricula. The new educational profile has proven valuable for this purpose as it has recruited almost 50% of its students, from groups who explicitly would not have sought admittance to the engineering programs. The education has also been able to attract almost as many female as male students.

In the following sections the basic ideas and experiences from the development of the new engineering curriculum is described drawing on planning documents, curriculum plans and papers from many authors [19,20], however the main reference is an article by Boelskifte and Jørgensen [21]. Special emphasis will be given to the new type of knowledge and skills adopted with the socio-technical and synthesis dimension of the education. This is of significant importance and is accompanied by research activities in the fields of sociology of technology, innovation economics, organization and design synthesis from design thinking and engineering.

Socio-technical analysis and design synthesis

In preparing for the curriculum planning leading to the design & innovation education a revision of the disciplinary and skills content of what had become design engineering teaching within the mechanical engineering programs was put on the agenda at DTU. Taking the outset on one side in the competences needed by engineers to carry out design work in practice on one hand and bringing in the experiences from the two faculty groups initiating the new education at DTU new topics and disciplines were taken up. The overall composition of the new program was illustrated with the flower model shown in figure 1 illustrating the three basic knowledge and skills components of which the program should build. The three components were seen as equally important for the training and learning process of the students.

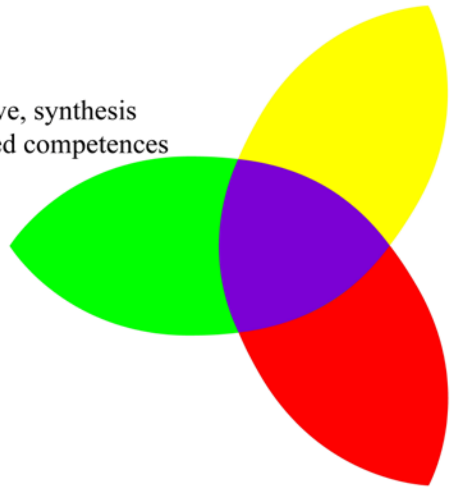

Figure 1. The multidisciplinary approach in the design & innovation education.

While the ‘reflective technological engineering competences’ are comparable to what might be seen as the core of traditional engineering education the idea of adding the demand for reflectivity was to point to the need for teaching this domain knowledge from the perspective of design. This entails a relative change in focus from optimizing within a given technical paradigm and concept to focus on the technologies features and qualities as a functional contribution to the totality of a design. This does not imply a rejection of problems of optimizing use and calculating specifics, but to provide a focus often lost in technical domain courses to be able to compare concepts and alternative technologies to reach a well functioning design.

Of the two other components also the ‘creative, synthesis oriented competence’ are included in many design oriented courses and projects in engineering education. Though the context in which the students operate often is provided from the position of an existing design concept or the application of an existing technology. This perspective of engineering design provides a conventional focus on the engineer’s contribution mainly emphasizing the application of technological principles and the optimization of given concepts. Rather little attempt is given to the development of new concepts and to the involvement of users perception of what the functional demand as well as other aspects of use might imply. This has resulted in a dominantly introvert and technology determined type of design methods and models very useful to classic technology confined design tasks, but not providing e.g. the tools to analyze and include users in setting the design criteria and defining the design specifications. A variety of assessment tools have been developed to help engineers compare different conceptual solutions but most often constrained within the universe of functional specifications so common to engineering. The synthesis oriented competences of the DTU design program has therefore attempted to include user investigations and involvements as a basic mindset from the very first semester and also build the re-design activities of the second semester on studies of the use and problems related to existing products and technologies to provide the students with toolsets and approaches to tackle the demand side of products, services and systems.

The third component – the innovative socio-technical competences – is quite new to most engineering programs. Though it e.g. is taken up also in the design program at Rensselaer Polytechnics and is mentioned as an important challenge in the NFS-report 'ED2030: Strategic Plan for Engineering Design' [22], only few engineering curricula have included these topic as part of core basics of engineering. At some engineering universities socio-technical subject can be taken as electives and may be integrated in courses on the history of technology being part of the 'liberal arts' requirements for engineering education.

In the design engineering program at DTU a reverse strategy was chosen not viewing these topics as an add-on, but as core and basic competences needed as much as the mathematics skills by the students. This has resulted in a number of courses included in the program informing the students project assignments but given the status of being (social) science disciplines of their own right. The choice of theoretical foundation for teaching socio-technical subjects was based on almost two decades of experiences with teaching sociological and economic disciplines in the DTU engineering programs. During the 1990s theses experiences were evaluated and a search for new and more interdisciplinary approaches was initiated. This lead to an inclusion of the emerging disciplines – often still considered interdisciplinary – of the economics of innovation or broader 'innovation studies' and the sociology of technology inspired by constructivist views. The new disciplines were revolutionizing the field of science and technology studies (STS) by observing that social behavior and mechanisms are seamlessly weaving together social and material phenomena and objects.

Bringing in approaches from actor-network and other theories from the STS-field to analyze design-scripts, actors sense-making processes, assignment of qualities to technologies, arenas of development, co-design processes, material mediation and the staging of innovative activities these new topics have provided tools for design engineering students not only to understand and constructively analyze the context and use of designed artifacts, but also providing them with tools to understand the importance and limitation of the different spheres of knowledge provided in engineering.

Combined with the integration and coordination of disciplines, a series of projects providing a progression of challenges to the students learning, and a focus on the outcomes of the learning processes of competences needed in design engineering, the curriculum represents a radical innovation in engineering curriculum. Thus, the design & innovation education aims to give competencies to work within a spectrum of considerations and values from a diversity of professional specializations as well as user groups from everyday life settings.

Thematic semesters

Design can be defined as applying technologies in a social context. Neither subjects taught in basic sciences nor the technological subjects prioritize synthesis in content or means. Yet technology must be adapted to fit assignments or be part of innovation processes. This utilization of technology must be experienced if the student is to develop design competence.

The education opens up in the first semester by exposing the new students to the complex world of users and technology with the theme 'Meet the world of technology'. The semester includes courses in mechanics and materials, product design, and user analysis and visual communication. The semester also motivates and creates identity, introducing the mode of studying connected to synthesis, reflection and awareness. The project subject is 'User Oriented

Design' where contributions from all the different courses are integrated by the students in their analysis and problem solving.

The second semester theme is 'The good product'. Focus is on understanding the complexity of manufacturing i.e. from the first ideas to the production, introduction and use of a physical product. This sequence is studied from various approaches: functionality, properties, construction, production, methods and the socio-technical context (users, use, producer, sales, competition, culture etc.). In this semester, the project assignment 'Product Analyses and Redesign' is carried out in collaboration with companies donating products for analysis including the context of use. A redesign is carried out based on potentials identified in the analysis phase and here the students learn, that redesign also means redesigning the complete network of players involved in the product.

The third semester theme is 'Engineering construction'. This semester the students learn to carry out a complex design based on given specifications. The focus is on mutually coupled design assignments within the domains of mechanics, electronics and software. This includes selecting components and using them ac-cording to functional demands within the three domains and ensuring their mutual interaction. The project assignment 'Mechatronics design' includes a detailed conceptual design based on given specifications i.e. a product with a mechanical-, electronic and software content that further-more builds on knowledge, skills and methods learned in the integrated subjects like electronics and objects.

The fourth semester theme is 'Workspace design'. The core of the semester is a project with a company or an organization. The students themselves plan and execute an analysis of a given workspace and related work processes. Reflections on choice of methods and tools in the design process constitute a significant part of the project.

The fifth semester theme is Innovation and sustainability. The semester focuses on environmental- and resource issues connected to the development, production and disposal of products and systems. Importance is placed on methods to describe, assess and improve environ-mental and resource issues in a life cycle and a product chain perspective. Social and socio-economic aspects of sustainability are covered as well. The project assignment 'Product service systems' includes identification, analysis and assessment of a product and it's system's environmental aspects and resource consumption, including reflections on the planning of design processes.

The last semester in the bachelor program include the 'Bachelor project'. This semester is the conclusion of the bachelor part of design & innovation. This project is supported by a course in scenarios and concepts which furthermore ask the students to reflect and report on the conclusions of former project assignments.

Projects and coordination

Project oriented work is the continuum of the design & innovation education. A chain of projects with a progression of challenges in various dimensions constitutes the spine of the syllabus. The basic idea is to combine 'learning by doing' with a structured learning sequence emphasizing elements of practice necessary to obtain specific competences in the three key areas.

Understanding and mastering working with design synthesis requires elements of apprenticeship relations to the professional. The student must experience the professional in action to experience value based assessments and utilize this dialogue in connection with one's own creations. The learning process is thus primarily based on interaction and experience.

All through the thematic semesters, the multidisciplinary approach are taught through project assignments and by giving the students extensive training in the innovative process. Core to the semesters integrating project assignment is the coordination of courses and topics among the team of design teachers. The coordination may be one of the crucial elements contributing to make the course work and project function as a coherent and appealing program for the students.

Study lines at the masters level

The bachelors program of 3 years is providing one main line of progress and content for almost ¾ of the activities leaving the rest for students own interests to pick courses from the modular course program of a large number of technical disciplines as a complement to the design education. In contrast the masters program of 2 years is offering a larger variety of possible study lines each of which offers a certain orientation of the core design activities still providing a further progression in the students learning. The core elements comprise of a set of courses improving the knowledge and skills of the students in the fields of product design, user interfacing, industrial design, materials knowledge and an advanced project assignment demanding rather finished concepts or results from the products, services or systems that the students focus their design competences on. I parallel the students follow technical domain courses in a few field to reach a deeper understanding of the technologies and methods from these fields. Through this combination the candidates have a combination of a technical engineering specialization and their deep understanding of the field from having worked with design activities reaching the implementation stage.

In the framework of design & innovation four study lines are offered. They all share the common base of the master's but each offers the opportunity for a different focus:

- Prototypes and production
- Eco-design and sustainable transitions
- User involvement and co-design
- Workspace and systems design
- Design and innovation management

Each study line can be combined with a 'global semester' that has focus on 'people-centered' design building intercultural competences and related to local developing issues in either newly industrialized or developing countries.

Combining education and research

The starting point for the development of a new engineering curriculum in design & innovation was based on the work of a group of ten devoted and experienced teachers of engineering design and social science subjects based in the departments of 'Mechanical Engineering' and 'Manufacturing Engineering and Management'. It took more than one year to construct this new curriculum. Though the education was constructed at an already existing and old engineering university, the basic idea was to re-design the complete curriculum including the core engineering and natural science curriculum to create a coherent new education. The students seem to have embraced the new curriculum and the number of students' abandoning the education is very low.

The research program in design & innovation subsequently was developed by basically the same cross disciplinary team but also involving a network of Danish university-based research environments. Through research workshops where people from industry and university researchers and teachers meet and exchange experiences from practice and theory concerning innovation in product development a range of new research problems have been defined.

HAS THE PROGRAM DELIVERED A NEW TYPE OF ENGINEERS?

After successful operation of the design & innovation educational program since 2002, and having the first students graduating, the team behind the education found a need for having an evaluation being carried out of the program aiming at exploring whether the students through the 5 years ended up with a profile as heterogeneous engineers, e.g. having obtained competences within the fields of 1) reflective technological engineering competences, 2) creative, synthesis oriented competences and 3) innovative, socio-technical competences.

The evaluation was designed comprising of three phases: 1) workshops with graduates, teachers and censors, 2) a telephone survey of graduates and representatives of the graduates' employers and 3) qualitative interviews with censors, teachers, graduates and students. The outcome of the evaluation is reported in [23,24,25]. In this section the outcome of the evaluation and thus the challenging of reforming engineering educations are discussed.

Challenges identified through the evaluation

In the first phase of the evaluation three workshops were facilitated by the evaluators with graduates, teachers and censors affiliated to the design & innovation program. Based on these workshops, it was clear that the education meets its objective of providing the candidates with heterogeneous design competencies as specified within the three fields illustrated in the presentation of the program. Concerning study efficiency and flow the education also demonstrates the importance of providing a coordinated curriculum that motivates the students to follow plans and timelines. With respect to drop out rates and extended study time the education is among the best performers at DTU. But this is still a side effect of the planned curriculum as the principles were foremost introduced to reach the levels of integrated competences in design engineering.

However, the education also faces some challenges in relation to the priorities made in the curriculum construction. Since the education is designed with thematic semesters it provides less room for optional courses than more open, modular programs at DTU where the courses may be placed more freely. Applying a multidisciplinary approach in the education, e.g. teaching the students to shift between using technical, creative and socio-technical competences also raises a challenge in accordance to the graduates own self-understanding (identity) as engineers. The workshops as well as the telephone survey and qualitative interviews revealed that the students and the graduates experienced difficulties in defining their competences precisely when meeting their first potential employers. This was a result of breaking out of the established patterns of engineering disciplines and programs. When having experienced their first jobs and assignments this problem of identity seem to vanish in the comparison with other engineers and professionals in comparing their practical ability to carry out project tasks.

Related to this, it turned out to be a challenge for the graduates to ensure that they would fit into existing job profiles and practices. Phrased as the need for a conventional 'hook' into technical disciplines and production planning this was another problem relating to the importance of convincing employers of the new type of design engineers. This was in particular mentioned by the censors and the representative from the industry, however, it reflects a complexity, since emphasizing a need for a technical ‘hook’ might be a left-over from the traditional way of thinking engineering, where engineers had a more conventional science based profile. In practical terms this problem has not shown to be of detrimental importance since the design engineering graduates have had lower initial unemployment rates than graduates from other programs. As a consequence the curriculum has been changed improving the student’s skills in bringing their design from a conceptual state into production preparation.

The other aspect of the need for technological competences is related to the way most engineering disciplines are taught. Most courses in technical sciences are focusing on theoretical models and optimization while their use as object of design in more complex constructions is given low priority. This often makes it difficult to combine different technical disciplines even though this would be ideal for a design engineer.

Employment patterns and motivations

To gain an understanding of the graduates’ careers, e.g. patterns, workplaces and applied competences, the second phase of the evaluation was a telephone survey of all graduates and selected representatives of employers. Out of a total of 78 graduates, 72 were interviewed, equal to a respond rate of 92%. In addition 14 representatives of employers were interviewed, aiming at exploring the graduates’ competences. The representatives of employers were among other issues asked what had motivated their decision of employing a design & innovation engineer. To this question they responded that they were on the look-out for engineers with a specific profile and competences meeting the following requirements.

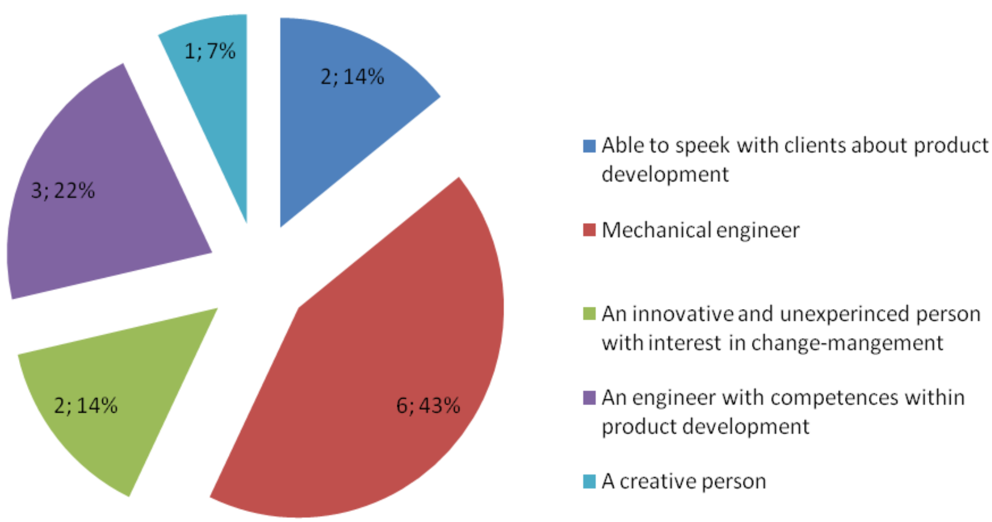

Figure 2. The representatives from industry’s motivation for employing D&I engineers.

Important insight into the characteristic of the design & innovation engineers was drawn by the representatives of employers. They emphasized that the graduates have strong competences in relation to generating concepts, working and approaching problem-solving in an open and creative way and yet in a very structured way. They are very user-oriented, while still maintaining focus on the product or the technological system to be developed, as well as the graduates upholds a strong culture for teamwork.

In general the evaluation concludes that the graduated design & innovation engineers succeed in upholding competences making them heterogeneous engineers, which also is illustrated in the different job functions they obtain. All the interviewed graduated design & innovation engineers reflect on their education as having been interesting, challenging, and relevant for their present job function. Further, the representatives of the employers seem satisfied with the education, even though they in some cases requested needs for specific competences, such as more insights into plastic materials etc. Interestingly while the censors' requests more technical competences, the graduated engineers as well as the students mentioned that the priority of weighing creative and socio-technical competences in line with technical competences is what makes the education interesting and unique compared to the more traditional engineering educations.

CDIO AND THE DESIGN & INNOVATION PROGRAM

Even though the design & innovation education at DTU in many respects seem to be modelled by using the CDIO principles as the outset there are some crucial differences in some very important dimensions. Besides the historic fact that the education at DTU was developed independently from CDIO the differences open for some important dilemmas concerning the future of engineering education.

One important conclusion from the evaluation of the design & innovation education is, that the priority of weighting creative and socio-technical competences in line with technical competences is what makes the education interesting and unique for industry and other employers compared to the more traditional engineering educations. When comparing the disciplinary composition with the visions and ideas of CDIO a very fundamental difference shows since the technical competences are given the main priority combined with an add-on of communicative and interpersonal skills. In the listed priorities of the CDIO syllabus 'technical knowledge and reasoning' is given the first priority followed by 'personal and professional skills and attributes' and 'interpersonal skills: teamwork and communication' which is a rather conventional way of providing an important add-on of skills and attitudes to the very basic technical knowledge. First as the fourth priority 'Conceiving, Designing, Implementing and Operating systems' in the enterprise and social context' show in a rather general way without specifying what knowledge might be needed to reach these competences [26,p.55-56].

The priorities of this list are seen as fundamental as stated in the following:

> *The CDIO Syllabus is a list of knowledge, skills, and attitudes rationalized against the norms of contemporary engineering practice, comprehensive of all known skills lists, and reviewed by experts in many fields. The principal value of the Syllabus is that it can be applied across a variety of programs and can serve as a model for all programs to derive specific learning outcomes.* [26,p.49].

When going a little more into details with the content of the four acronym letters the following defining table is found:

Conceive	Defining customers needs, considering technology, enterprise strategy and regulations, and developing

	conceptual, technical and business plans.
Design	Focusing on creating the design; the plans, drawings, and algorithms that describe what product, process or system to be implemented
Implementation	Refers to the transformation of the design into the product, including hardware manufacturing, software coding, testing and validation.
Operate	Uses the implemented product, process or system to deliver the intended value, including maintaining, evolving, recycling, and retiring the system

Figure 3. The Four elements of the CDIO concept [6,p.8].

The dilemma related to these elements is that they seem to neglect the socio-technical competences as well as competences to work with synthesis as also demonstrated in the following definition of the CDIO goals:

> *Master a deeper working knowledge of technical fundamentals defined by: Engineering education should always emphasize the technical fundamentals …deep working knowledge and conceptual understanding is emphasized to strengthen the learning of technical fundamentals …In a CDIO program, the goal is to engage students in constructing their own knowledge, confronting their own misconceptions". . Instead the CDIO concept with its three overall goals seems to be enrolled in a classical techno-science discourse, emphasizing the 'technical fundamentals'.* [6,p.20]

While in the DTU program the phase of conceiving the problems and demands that can be identified in the use context of designs of products, services or systems has been given a very high priority in accordance with the earlier stated imbalance in engineering education between (socio-technical) problem identification and (technology-driven) problem solving [17] not much can be found elaborating of the meaning of 'Conceiving' in CDIO. In fact this 'letter' has only been given a few lines in the complete book outlining the principles, goals and standards. In the listed priorities of the syllabus point 4.3 detailing what is meant by *conceiving* includes: 'setting systems goals and requirements; defining function, concept and architecture; modeling of systems and ensuring goals can be met; project management' [26,p.56]. At another place *conceive* is understood as 'interaction and understanding the needs of others' [6,p.28]. Nicely followed up by this general statement:

> *In a CDIO program, experiences in conceiving, designing, implementing and operating are woven into the curriculum, particularly in the introductory and concluding project courses.* [6,p.28]

This underpins that the focus in CDIO still is on engineering as a self-contained and complete discipline of both knowledge and skills implying that no other types of knowledge is given a similar status.

Another difference in approach relates to the content of semesters and the hierarchy of the topics included in the education and how they are placed in the progression of semesters. The basic structure of CDIO is illustrated in the following figure.

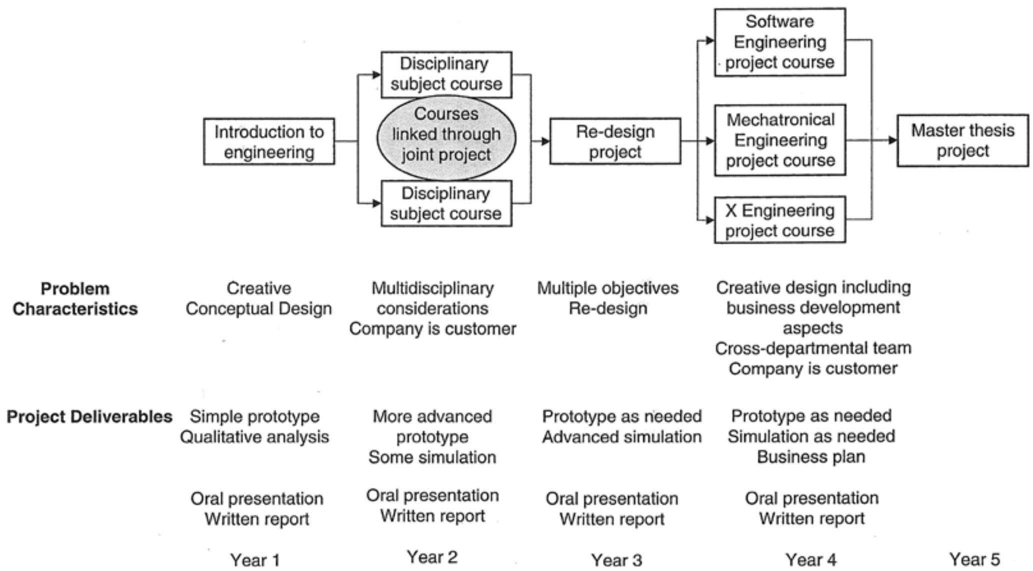

Figure 5.Semester plan – integration of design-implement in the curriculum [27,p.108].

Though the semester plan shows that design problems are part of the learning outcome it does not state this as something needing support form theoretical knowledge or skills as the topics included are mainly courses in technical subjects as outlined in the following:

> *Introductory first-year courses usually include basic design-implement experiences. These early experiences have significant positive effects on first-year students. Students are introduced to structured engineering problem-solving with opportunities to apply fundamental engineering principles. In addition, they learn to work in teams and communicate their progress and results.* [27,p.106]

While the program at DTU has seen it as important to create a mindset of including user perspectives at the very first semester not missing the technical and natural science competences the practical vision of CDIO still has a strong emphasis on technical knowledge:

> *Early introduction to disciplinary knowledge is effective in building students' enthusiasm for engineering.* [27,p.106]

The technical focus is followed also in the outlines of the following years emphasizing design as the production of technical artifacts leaving the needed knowledge implicit and to the readers own ideas:

> *... advanced design-implement experiences are usually planned for 3rd- or 4th-year students … Advanced design-implement experiences are technically challenging in all phases of the project. The work includes design and implementation of student-developed components, as well integration, testing, verification and validation in conjunction with commercially available components or those developed by other students".* [27,p.106]

When it comes to the organizational skills of operating also very few details are given. This leaves the CDIO conceptual framework in a dilemma of having introduced very much needed new pedagogical methods and team work assignments into engineering education but not providing a deep discussion on the type of knowledge, identity and skills needed to meet future demands.

APPLYING A MULTIDISCIPLINARY APPROACH IN ENGINEERING EDUCATIONS

The role of engineers in technology and innovation is often taken for granted. Even in future-oriented reports on engineering, there is a tendency to expect problem-solving abilities in societal and environmental issues from engineering, without challenging contemporary foundations of engineering curricula. Innovations during the last decade are leading to changes that may make the role of engineering less central in the future. Policy and management attempts to govern innovation processes have also broadened the scope and shifted the focus from technological development and breakthroughs to a broader focus on market demands, strategic issues, and the use of technologies. [28,p.233]

Lessons from designing the design & innovation education program, point towards a need for new mechanisms of coordination in the curriculum as well as a need for cross-disciplinary cooperation. The creation of successful reforms in engineering education does not result from introducing new projects or problem-based learning processes in the classroom alone. There is a need to understand the isolated and often scattered character of individual disciplines and introduce measures that support the teams building and continued cooperation among teachers to overcome the isolation of individual courses and disciplinary approaches.

Even though the design & innovation education at DTU is a success both of the perspectives of the involved actors as well as seen from the perspectives of DTU, applying a multidisciplinary approach to engineering educations is a challenge, since the education continuously needs to consider and reverse the teaching and curricula ensuring the education keeps positioning itself in the forefront of innovation. Some of the challenges the evaluation of the design & innovation education points towards are 1) how to keep ensuring a progression in the students competences, 2) are the education to put more emphasis on opportunities for specialization, 3) how to ensure opportunities for in-depth studies while maintaining a wish of educating heterogenic engineers.

Applying a multidisciplinary approach in engineering education requires that the role of knowledge in learning and the creation of engineering identity implies a need to overcome the taken-for-granted approaches in curriculum development emphasising the role core science-based disciplines instead of the domain competences needed from field of practice [28,p.235]. In this respect does CDIO not meet the challenges from the domain of engineering design – there is still much room for improvement and some ideas and experiences can be found in the design & innovation program at DTU.

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