RENEWAL OF A LOCAL CONCEPT FOR ENGINEERING EDUCATION INCLUDING CDIO

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ABSTRACT

The education concept of School of Engineering (JTH) in Jönköping, Sweden was established in the mid 1990-ies and included a view that apart from a strong core of technology, each engineering curricula should include education in leadership, entrepreneurship, finance, environmental demands as well as relevant engineering skills and practice. Moreover, it should also emphasize aspects like international orientation, industry contacts and employability. This proved to be a fruitful idea both internally for quality development and externally for marketing the school to possible students. After about 15 years JTH had grown into one of the leading undergraduate engineering schools in Sweden and CDIO principles were to a large extent implemented in all its curricula at bachelors' level. At this stage it was decided that the concept should be updated to continue to fulfill its purpose. This paper describes the first part of the renewal process of development in terms of its organizing as well as the influences that were taken into consideration concerning education of professional engineers. The resulting structure and content of the new concept to be implemented during the coming two years are outlined. The new concept is now supposed to include both undergraduate (3 years) and master programs (2 years). The new concept is based on a core of the technology taught and additional course modules that are supposed to add knowledge, skills and acquaintance knowledge to the curricula. The technical education will be built up by basic science, advanced science, niche and system knowledge. The developed modules should bring the complementary subjects in a form and way that make them better integrated in the curricula. Moreover, a course called Off-campus integration theory and practice is introduced, bringing more depth of skill and acquaintance with the industry into the curricula.

KEYWORDS

Engineering education concept, professional education, engineering skill, course modules, curricula development

INTRODUCTION

The bachelor degree engineering education in Sweden dates back only about 20 years. In order to create a structure for the new 3-year engineering educations (from a Swedish horizon) the dean of the School of Engineering mandated a committee 1995 led by a senior professor from one of the well-established universities to develop and describe a three years engineering education [1]. The result of this work was a structure for the technical part of the engineering education ranging from basic engineering mathematics over basic technical courses to the third year specialized technical courses. The basic idea with this structure was to provide a guidance for designing the programs so that a proper and beneficial progress in technical knowledge and methods was guaranteed. In addition to this, however, the committee suggested that the education should incorporate a separate stream of educational elements that were not technology but other elements necessary for a good engineering curriculum. Such elements were for example basic knowledge in leadership, corporate finance and environmental aspects but also things like helicopter view, results orientation and employability. This result can be compared with for example pp. 11-12 and table 1, p 47 in Rethinking Engineering Education: The CDIO Approach [2] which express similar thoughts.

Table 1. Evident shortcomings of graduating engineers with respect to skills and abilities [4] , referenced in [2]

Most important abilities with respect to employment	**Greatest deficits with respect to education**
Work effectively as a team	Business approach
Analyze information	Management skills
Communicate effectively	Project management methods
Gather information	Methods for quality assurance
Self-learning	Ability to communicate effectively
	Knowledge of marketing principles
	Sense of ethical and professional responsibilities

The result of this process was implemented as the education concept of School of Engineering. The concept can be viewed as a general program idea [3], a strategic as well as an operative description on mandatory parts of all engineering educations at JTH to meet the demands of key stakeholders, the societal context and pedagogical advances. The operationalization of the concept included a course in *Organization, leadership and change*, a course in *Industrial Management and Entrepreneurship* dealing with basic economics, a course called *Engineering methodology* including among other things report writing, ethical dilemmas, and basic investigations to be done in a host company (guaranteed to all students) as well as a smaller course in *Sustainable technology*. In total these courses stood for about 15 % of the credits in the entire curricula. In addition to the courses, the concept included such issues as organizing student influence and influence of employers of engineers as well as international student exchange etc.

During the 2000-ies three additional occurrences changed the picture. The Swedish Higher Education Ordinance was thoroughly revised and the goals set for each level of education were divided under three headings: knowledge and understanding, skills and abilities and values and attitude (my translation) [5]. The changes also meant that all curricula for higher education in Sweden had to be revised.

The second important change for JTH was the decision to join the CDIO initiative 2006 and as the first university in Sweden to include all engineering curricula at undergraduate (bachelor) and graduate (master) level. The first step of implementation was performed during 2006 including revising all syllabi and curricula.

Moreover, Sweden joined the Bologna process in order to simplify the exchange and movement of students between different countries. The pattern of a three year undergraduate and a two year graduate engineering education came into force in 2007 and apart from the length of the educations, learning outcomes were introduced to describe what students should have achieved. The European Credit Transfer System was also introduced where one year of full time studies corresponds to 60 academic credits [6].

During these years (1995-2011) JTH grew from being a small educator of engineers at bachelor level (11th in size in Sweden in the beginning of this century) to being one of the top three at this level. The school also attracts students from a geographically much wider area than any other undergraduate engineering school. One of the success factors according to the marketing department has been the education concept. This has made it easier to interest students for the education and the quality of the school. The school also has been highly ranked among Swedish engineering educators by different organizations.

A number of problems had occurred over the years in fulfilling the concept. The fast increasing body of technical knowledge to be handled within the curriculum shape problems. The tension regarding the course concept volume (15 %), advocated by education management, and the body of disciplinary knowledge, advocated by discipline faculty always to be too small, continued to be viable. This tension has been observed by other researchers as well [7] and the problem is addressed in the CDIO context using the idea of the integrated curriculum as a means for handling the problem better than before, see chapter 2 and 4 in Rethinking Engineering Education [2].

The shaping of an integrated curriculum for the engineering educations using the concept related courses did not succeed for all programs. The courses *Organization, leadership and change* and *Industrial Management and Entrepreneurship* were more often used for balancing the work load in some of the programs, either by program chair or by students. For a single student they could thus occur somewhere in the program with very few links to other courses.

Moreover, the *Sustainable technology* course was considered to be difficult to relate to specific programs and the specific technology area taught in the programs and it thus became too general for the students. Lastly, the *Engineering methodology* course was a low intensity course ranging over a whole year, half of it taught in the first year, second semester, and the rest in the second year, third semester and in total including six visits to a specific company. Both faculty and students considered this course to be difficult to manage and to understand when running although graduated students often considered it to be of great value. The criticism, in spite of large development efforts and large improvements, remained however strong.

Since the education concept was believed to contribute strongly to the trade mark of JTH, the basic idea of the education concept was evaluated through a survey among the faculty. The result showed that the concept idea as well as its basic content had a strong support among the personnel. It was thus decided to perform a revision and a development of the concept. A committee was formed which the author was heading. The committee encompassed four teachers, the head of marketing at the school and three students. The mission was to:

- Modernize, update and suggest a concept that could be implemented more effectively
- Adapt the concept for both external and internal communication.
- Find and suggest new and better ways of organizing, implementing and developing engineering education according to the basic ideas behind the existing concept.

The committee work was mainly performed during the spring semester 2011 and the committee report was delivered in August. The content then lay the ground for management to formulate the new concept and to schedule the implementation process.

The aim with this paper is to report on the work and findings of the first stages of the development process, the conceive-design stages. The paper describes the basic influences behind the development in terms of its content and organizing as well as the content and structure of the suggested new concept.

The two last stages of the development process, implement and operate, that follow are not considered in this paper.

PROCESS OF DEVELOPMENT

The committee met during eight meetings starting from January 2011 and finishing in June 2011. The work was performed as discussion meetings where the different aspects of the old as well as the renewed concept was penetrated. The author served as discussion leader, secretary and also wrote the final report proposing a new structure and content of the concept. The members of the committee contributed with their experiences from teaching, working as engineers (all faculty participating in the committee had more than three years of experience from working as mechanical, electrical or building engineers outside the academia) and working in different manager positions in the School. The students were from two programs, one from building engineering and two from industrial engineering and management. The students were mandated from the students union.

During the meetings, the report was successively developed and its content discussed. The report was based on the work during the meetings as well as on literature on engineering education and technology. A whole-day seminar for all personnel, was held in May when the committee had findings to present and later the final report was sent out for comments and feedback before it was published.

BASIC CONSIDERATIONS

When revising a general structure for engineering education two basic definitions were found to be of relevance for the work. The first one was what defines technology, the subject area to be taught and being the core of engineering education. Both its delimitations and how it was structured for educational purposes were issues to be examined. Second, roughly it can be said that the product of an engineering education is an engineer, or at least the services provided to assist students to develop engineering skills and it was thus considered to be of interest what defines an engineer and engineering work.

What is technology?

Often, technology is defined in a routine fashion as applied natural sciences or more specific, applied physics for common societal benefit. This definition is however questioned by many. In the late 1990-ies, a large investigation was made in Sweden concerning engineering education. Some of the following comments have their origin from the reports of this investigation.

Hult [8] meant that the technology is defined by the way it is taught. The base for technology is however technical science which differs from natural science. Technical science concentrates on understanding and describing characteristics of designed technical systems and encompasses a structure with axioms, theorems, propositions, architecture and system view in order to reach or explain the characteristics of technical systems. Dahlbom [9] further argued that we do not live in nature anymore but in a world of designed artifacts. In order not to build a false picture, we need to base our education, not on natural sciences but on “artifact sciences”, which are design sciences directed into other phenomena than what is found in nature. This will imply that how the artifacts are regarded by the user, their benefits to society as well as the user quality will be more focused and the question of what good technology is must be considered. The transition into the information society and an increasing number of services built into the technology accentuates the necessity to define technology from a user’s perspective.

Interesting, most conceptual definitions of technology in literature are found in the social sciences and in philosophy. It seems that the need for defining technology have been more prevalent among researchers that try to describe the influence of technology on society, work, organization and overall human life. Depending on the area different authors have studied, the definitions were adapted to the contextual conditions of the study. See for example Goodman and Sproull: Technology and Organizations [10] where each of the contributing authors have more or less their own definition. A significant change was when technology became computerized. Even before, the technical systems often were complex, difficult to overview and understand but mostly observable directly or by using different instruments. In such environments, humans can more easily develop mental models to understand the built-in cause-effect relationships and thereby also control the technology. When dealing with computerized technology, however, the situation became completely different. The technology now behaves according to programmed instructions, which can be changed without any outer signs. Moreover, it is also possible to change the technology itself while it is used and with this also the conditions for using it. This new situation is more complex, difficult to overview, it does not lend itself to easy understanding of cause-effect relationships and it poses completely different cognitive demands when the technology shall be used. To handle computerized technology, entirely different reasoning and ability to handle logical procedures is demanded where intention is partly separated from action. To understand the benefits and the influence of new (computerized) technology there is a need for understanding how people use and utilize it in their situated daily lives (technology-in-practice) instead of solely looking at the functional abilities of the technology [11].

This reasoning also emphasizes the need for understanding technology in terms of technical systems. There is a need for understanding, not only the cogwheel but also the gearbox, not only the transistor but also the integrated circuit or the computer. There are also a lot of technical systems that include societal aspects like the electrical power system from power plants over the power grid to the electrical bulb or the transportation system including the different types of cars, road system, bridges, tunnels as well as the fuel support including oil wells, refineries, ships and gas stations. Here, the coupling between technology, society and human becomes very clear as well as the need for including the systems view on technology in the education.

Within CDIO, technology as such is not explicitly defined, it is taken for granted and my interpretation is that the working definition is close to the definition by Hult referred to above [8]. The structure of technology is basically defined under the heading of technical knowledge and reasoning and contains underlying science, core engineering fundamentals, advanced engineering fundamentals and systems engineering [2].

The conclusion of this was that there is a need to define the technology for which an education curricula is designed. What does it build on? What are the most important technological systems that the future engineers must understand and work with? What type of future work will the engineer meet? What do the perceptions of the use of the technology look like? What societal benefits is the technology supposed to shape? This conclusion is also related to the integrated program descriptions and more specifically the program purpose proposed by Malmqvist et al. [3]. Interestingly, in the literature dealing with technical education it is very rare to find references to the “outside” world of technology as the scientists that provide an external perspective on technology like the sociologists mentioned above [10].

How to define engineering work?

To educate engineers, we must build an idea of what characterizes engineering work and engineers, the professionals that are supposed to design the technology of the future. Schön [12] included engineering in the professions that builds on three basic components, originally defined by Schein and Kommers [13].

1. One component which is the basic science that the practice is based on and develops from.
2. One component which is the applied science or engineering that serves as the base for daily analysis, diagnosis and problem solving.
3. One component that is the skill and the attitude which relates to performance and the service provided to the client by using the other two components in professional practice.

This division is general for many academic professions and reoccur in similar structures. It is important to note that these components are not independent of order but are described so that you first learn the underlying science, thereafter its applications and finally the practiced skill. Schön [12] do not stop there, he also argues that in the professional action, the problems professionals (engineers) encounter can normally not be found in textbooks as prescribed solutions, but has to be solved in a way which Schön calls reflection-in-action. The problem-solving process is then characterized by the engineer doing research in the practical context, creating a local theory for the specific case to solve the problem. In this process, goals and means are intertwined and are interactively redefined as the problem-solving process proceed. Thinking and doing cannot be separated but leads in a reasoning way towards decision and action. By this process, the implementation to a large extent will be built-in in the investigation of the problem.

The Norwegian philosopher Johannessen [14] reasoned in a similar way. He defined propositional knowledge as the part of our knowledge that can be expressed in propositions or rules and supported empirically or proved. The propositional knowledge corresponds to the first two components in Schein and Kommers [13] definition. The last component was however further developed by Johannessen to include both a skill in using statements and acquaintance with the conditions that the statements say something about. Johannessen further meant that the skill and the acquaintance are the bases for the propositional knowledge, which means that the interactive process described by Schön [12] also can be viewed in a larger context. In a professional skill the relation between propositional knowledge and acquaintance with contextual conditions is integrated and should not be viewed as two separated qualities of knowledge but as different aspects of the same knowledge where the acquaintance gives life to the abstract concepts of propositional knowledge [15].

From this theoretical reasoning we can draw some conclusions concerning an engineering education. We need basic technical science, we need applied technical science and we need to train skills in applying this theoretical knowledge to relevant problems collected from reality. Moreover, we must find ways to include development of acquaintance with both the technology itself but also with the contextual conditions in which the technology is supposed to be used. The need to put technology into a specific context was a reoccurring theme in the anthology "What is an engineer" [16]. The importance of an engineer possessing fundamental technical knowledge that do not lose its actuality, being able to integrate knowledge from different areas, to have a holistic view, to know when a solution is good enough are some examples that were emphasized in the anthology.

The definition of engineering skills suggested by the faculty board of technical and natural sciences at Uppsala university can serve as an operationalization of what can be called engineering skills and as a summary of the discussion above [17]. Engineering skills can then be characterized by:

– The ability to develop good enough solutions to complex technical problems within given limits of cost and time by collecting and applying necessary knowledge.
– The ability to apply a holistic view, that is the ability to see how the technical problem and its solution are parts of a larger system and from this view, assess and prioritize the own work.

What should be added to this is a more clear stance concerning the use of technology, the effects of technology on (other) human's work and on society. Our suggestion was thus to add:

– To be able to evaluate and prioritize different technical solutions from sustainability and user perspectives concerning social, financial and ecological issues and concerning the ability of humans to interact with the (new) technology.

With this as a background and together with the experiences from the current education, the following description was the suggestion for a renewed conceptual design of the engineering education at the School of Engineering at Jönköping University.

SUGGESTION FOR THE CONCEPTUAL DESIGN OF ENGINEERING EDUCATIONS AT JTH

The aim of the school should be that the final product, the graduated engineer, should have accomplished an education that can be compared with the best engineering educations in the world in the respective area. The student should be well prepared for a professional career in an international context and have a good communicative ability. The education should be characterized by a balance between technical depth, technical width, technical niche knowledge and the application of those.

Pedagogical base

The different parts of the education should combine into a whole through integration and progression where the succession between theory and application practice leads towards the graduation. To strengthen the connections between the different parts of the education, co-operation between different subjects and teachers in courses is necessary and projects and problem-based teaching are suitable and vital parts of the education. This is also in compliance with the view that is found within CDIO and that is considerably deepened in the initiative.

Technology

Technology is naturally the all dominating part of the education, built by mathematics, fundamental and advanced technical science and applied technical science in the area of technology chosen. There is a difference between advanced courses that specialize in a certain technical core, sustainable over time, and niche courses with high actuality but less sustainability (for example in using a specific software) concerning their knowledge content. The latter are important for profiling the graduated engineer and for leading to the first employment. Applied mathematics is "the" method in large parts of a technical education. There are however fields of technology that need other methodological knowledge, this might also be a part of the technical theory.

Another important issue for linking the parts of a program together is the existence of system knowledge in the courses, so that the properties of technical entities are taught and not only the properties of technical details. Here it is important to point out that system knowledge also embraces multidisciplinary and interdisciplinary views encompassing humans and different parts of the society.

The theory parts of the technical education must be completed with training the ability to use the theory, to develop the technical skill. In this, the ability to verbally describe the technology and its application is included. Moreover, the acquaintance with the field of technology must be trained in order to understand, to take part of, to develop and to communicate praxis within the chosen field. As a part of building engineering skill and acquaintance, a new course involving training at campus but with the main body performed in companies or organizations off campus was suggested. The course should encompass real problem-solving in engineering tasks in a real environment. The course is supposed to be a part of the progression in the curricula and is called "*Offcampus integrating theory and practice*". All this was considered necessary to reach and succeed in realizing the conceive-design-implement-operate chain in the education.

Engineering skill – broadening of perspectives

A basic idea in the concept is that the technology need to be complemented by parts of the education that widens the students' knowledge and provides insights, theoretical bases and skills that enhance the students' abilities to work as an engineer. Today, these ideas is also a part of the legal demands on engineering educations in Sweden, and some researchers have advocated that providing a coupling between technology and humanities is necessary for attracting students to engineering educations in the long term [18].

Sustainable development

A large part of the widening of the education is supposed to be related to sustainable development, which was formulated in three perspectives: social, financial and ecological sustainability. All these three perspectives can be realized at the individual level, at the organizational level or at societal level. In social sustainability, work, health, living, culture, participation and democracy are issues to be included.

Financial sustainability includes individual economy, business administration and finance as well as society related economy. The notion of life cycle cost is central. Within financial sustainability issues like business conditions, basic financial theory, business plans, cost management, marketing are at hand. Ecological sustainability was defined as the effects of products and processes on and usage of natural resources and how these effects can be reduced or removed. This part was assumed to be entirely integrated in the technology part of the educations and should be examined according to defined intended learning outcomes.

Communication and scientific writing

An important part of the additional competences for an engineer is the ability to present findings and results, both orally and in professional reports. Moreover, basic skills in investigation and research methodology and literature search is absolutely necessary.

SUMMARY OF THE DIFFERENT COMPULSORY PARTS OF THE CONCEPT

Table 2 summarizes the different course-related parts that were decided to be included in the concept, both in terms of its content and its volume in credits. Each curricula must include the course modules in the table. Course modules means that each subject must be taught in chunks of at least 3 credits in order to avoid that the content will be too much dispersed to be recognizable and testable in examinations. At the same time, the choice of course modules open opportunities for A course however cannot be smaller than 6 credits which means that at least two modules must be integrated to form a course.

The course module subjects decides the content of what should be included and integrated in each curricula. Given credits are a minimum, the management of each program can decide whether there should be more credits relating to the subject. Each of these subjects are then to be broken down into separate intended learning outcomes. The separate column means that this module introduce the subject theoretically and should be taught by a teacher, specialized in the subject, for example Group dynamics should be taught by an organization psychologist and the module is to be clearly distinguishable in the course. This means that there has to be an integrative collaboration between technology teachers and teachers responsible for modules in courses, thereby setting role models for cooperation.

Table 2. The distribution of course modules to be included and integrated in each curricula

	Undergraduate (Bachelor) 180 credits/3 years			**Graduate (Master) 120 credits/2 years**		
	Credits			Credits		
Course module subjects	Sepa-rate	Inte-grated	Tech. skill	Sepa-rate	Inte-grated	Tech. skill
Offcampus integrating theory and practice			12			9
Leadership and project management	3	3			3	
Group dynamics	3			3		
Business adm. and entrepreneurship	3	3				
Business planning and marketing	3					
Presentation and report writing	3					
Research methods	3	3		3	3	
Sustainable development		9			6	
Sum	**18**	**18**	**12**	**6**	**12**	**9**

The modules in the integrated column indicates that the subject is integrated in a technology course, examined against intended learning outcomes but that these outcomes can be combined with technical issues. The off-campus course is considered to be a part of the technical core of the education, especially directed towards developing skill and acquaintance.

Apart from this content suggestion, the new concept will include a number of organization changes to support both the shift from conceptual courses to modules but also to better relate responsibilities and functions to the renewed concept. We are now in the middle of the implement-operate process and the new curricula will be used from fall semester 2013.

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