SUPPORTING ENGINEERING INNOVATION AND DESIGN BY A MULTIDISCIPLINARY MASTER'S PROGRAM

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ABSTRACT

The aim of this paper is to reflect on lessons learned from a master's program with a multidisciplinary approach. The rapidly developing technology and specialization in society, business, industry and labor puts a demand on education to provide specialist skills in various technical fields. Paradoxically, the increasing complexity also demands skills from different disciplines, such as understanding human capabilities to handle technically complex systems and adapting technology to the design of organizational and individual working conditions in different workplaces and businesses. Therefore, knowledge and experience from engineers often need to be combined with skills and experience from the domain of behavioral and health scientists in order to obtain good usability and system performance. It is not, however, an easy task to combine experiences from different domains of expertise, as diverse traditions are deeply institutionalized by different approaches and research platforms and not easily adapted and integrated within engineering faculty. The master's program reported on in this paper is an example of promoting a multidisciplinary approach contributing to an effective CDIO implementation. The design of the master's program includes a combination of courses from a number of scientific disciplines with teachers who represent different theoretical areas, practical skills and in addition a careful mix of examination forms. Furthermore, the students' different backgrounds and learning traditions as engineers, behavioral and health scientists create a platform with excellent opportunities to learn from each other in order to develop new and innovative ways of thinking and approaching design and business development. It also offers opportunities to experience and reflect on the cultural contradictions between educational disciplines and practice.

KEYWORDS

Humans, technology and organization, ergonomics, systems thinking, pedagogics

INTRODUCTION

The rapidly developing technology and specialization in society, business, industry and labor puts demand on education to provide specialist skills in various technical fields. Paradoxically, the increasing complexity also demands skills from different disciplines, such as understanding human capabilities to handle technically complex systems and adapting technology to the design of organizational and individual working conditions in different workplaces and businesses.

It is however a challenge to integrate knowledge from various areas of expertise in faculty as the CDIO standards also reflects [1].

The goal of engineering education includes innovative development and design of products, systems, workplaces, etc. and how to lead others, all of which refer to the CDIO components, *Conceive, Design, Implement and Operate* [1]. To achieve this and to meet the demand to close the gap between engineering practice, knowledge and skills in engineering need to be combined with knowledge and skills from other domains to reach a holistic view as pointed out in the CDIO standards [1] and earlier studies [2, 3]. However, it is not an easy task to combine faculty skills and experiences from diverse areas of expertise, as different traditions are deeply institutionalized by diverse educational approaches and research platforms. Consequently researchers/teachers as well as students in different disciplines, in this case the engineering domain, benefit from learning, better understanding and interacting with other areas of expertise to be equipped to contribute to successful and sustainable production systems and good usability in product design [4, 5]. This is also emphasized in the CDIO standards program philosophy, curriculum development, experiences, methods of teaching and learning, assessment and evaluation [6].

The aim of this paper is to present lessons learned from developing, managing, teaching and examining a master's program with a multidisciplinary approach. A number of aspects of the CDIO standards are discussed as well as challenges and benefits from the program. They include philosophy of the program, program design and curriculum, faculty teaching skills, interaction and pedagogical approach, and examination and continuous program evaluation.

The term “multidisciplinary” is defined from a curriculum point of view embracing the composition and content of courses as well as the pedagogical approach. This approach encourages an ”interdisciplinary” interaction process between the students representing different disciplinary backgrounds. This process has the potential to create "something new" in terms of broadening the students’ perception and application in their future professional activities [5].

Experiences from two of the main teachers including the role of the program coordinator are integrated in the paragraphs below, in which the above aspects of the CDIO components are discussed. Experiences from students are presented under a separate paragraph later in the paper. This is followed by lessons learned and conclusions.

PHILOSOPHY OF THE PROGRAM

As the complexity in operations and development of activities in production and product development systems increases so does the demand on interaction of human, technological and organizational interfaces. At the same time the societal demands for sustainable work systems increase [6]. This indicates the importance of addressing contextual factors and the characteristics of the human-machine interaction in the actual organizational setting to enhance usability of technological products and production systems [7]. The master in *Ergonomics and Human-Technology-Organization (HTO)* reported on in this paper is based on this awareness and the implications for applying the basic CDIO principles *Conceiving-Designing-Implementing-Operating* through the developed standards [1].

Ergonomics is a multidisciplinary field. There are many definitions of ergonomics such as “the study of human abilities and characteristics which affect the design of equipment, systems and

jobs. It is an interdisciplinary activity based on engineering, psychology, anatomy, physiology and organizational studies. Its aims are to improve efficiency, safety and operator well-being" [8]. The International Ergonomics Association extends its relevance to any system with which the humans interact [9]:

> *"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance."*

The concept of humans, technology and organization (HTO) has since the 80's been used as an acronym to highlight that a business develops successfully only if one takes into account the interaction between all three system components human, technology and organization [10].

The master's program described in this paper is an example of promoting a multidisciplinary approach by integrating the domains of engineering with behavioral and health science. This is represented by the teachers' and students' backgrounds. We believe that it is advantageous to combine teachers with different disciplinary backgrounds but with the same core values – in this case, HTO and ergonomics – in order to stimulate innovative Conceiving, Designing, Implementing and Operating in the engineering education [1]. This is also illustrated in the experiences from teachers and students below.

The students consist of younger students coming directly from their Bachelor studies as well as students who have worked for several years. This latter group includes specialists in certain fields, consultants, self-employed people, teachers, representatives for Swedish authorities within occupational health and safety, etc. The students' varied backgrounds regarding education, profession, experiences and age create an exciting and dynamic learning environment creating opportunities for knowledge bridging between the students and their experiences from practice. This is partly a challenge for teachers, but teachers also benefit from this as it broadens their knowledge and application areas. Sometimes students with a high level of skill and experience in a specific domain fitting into the curricula are able to contribute in the teaching.

PROGRAM DESIGN AND CURRICULUM

The design of the master's program and curriculum is based on the philosophy of multidisciplinary knowledge and skills. This is reflected in the course design and integration with different teaching and learning approaches e.g. interpersonal learning with multidisciplinary connections in group works but also personal reflections, critical thinking, problem solving, product design and systems thinking individually as well as in seminars following the recommendation in the CDIO standards 2 and 3. The introductory HTO course plays an important role in framing and integrating the other courses by emphasizing the interaction between the human, technology and organization and the reciprocal effect between these components and system efficiency. All courses are evaluated orally as well as written regarding fulfillment of learning outcomes, pedagogics, scheduling, course material, examination forms, etc. on a graded 1-5 scale where 5 is the highest rank. The ranking is generally high with an average of 4-5. The program is also regularly evaluated by the Swedish National Agency for Higher Education. The latest evaluation conducted in 2006 reports that "the education is good and considered by the assessors as a model for how a breadth master's program should be structured." The theoretical courses were judged to have a high throughput but not thesis degrees [11]. This has since then been addressed by

introducing a separate project course for planning the degree project.

PROGRAM CONTENT AND SCHEDULE

The first year courses are:

1. Humans, Technology, Organization, 6 credits
2. Research Methods and Study Design, 6 credits
3. Cognitive Ergonomics, 6 credits
4. Organization, Change Management and Work Environment Legislation, 6 credits
5. Physical Ergonomics, 6 credits

Each course lasts five to six weeks with some overlap between the courses, see Table 1. The program is a mix of tele-studying and ten course meetings during two to three days each. During the course meetings there are lectures, seminars, discussions and different types of examination activities depending on the learning goals. Except for individual studies the tele-studying time between the course meetings includes group and hand-in tasks.

The students may choose to study the master's program in one or two years. When studying for two years, the first year includes the five courses listed above. During the second year, the students carry out a project work and their final degree project in ergonomics. Those students who fulfill their master's program in one year carry out the project work and final degree project in parallel with the other courses.

Table 1. Distribution and Overlap of Courses for Half-Time Students

Courses	Aug		Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Jun	
1st year																						
HTO																						
Method																						
Cogn Erg																						
Org																						
Phys Erg																						
2nd year																						
Proj work																						
Degree proj																						

The program begins with the course *Human-Technology-Organization*, which also serves as a uniting theme throughout the program to stress the application of the HTO-perspective in the other courses. The main content of the course consists of ergonomics and HTO concepts, their background and development; systems perspectives; and practical applications based on a systems approach from different viewpoints. The course is divided into two parts, a first part in which the students analyze own cases and apply HTO models and a second part in which the systems perspective is deepened through analyses and reflections on additional cases.

The course in *Research Methods and Study Design* includes epistemology, scientific and methodological paradigms, data collection techniques, analysis of data, the research process, and writing of scientific reports. Examples from real case studies representing HTO applications are used to stimulate reflection of different methodological approaches.

In the course *Cognitive Ergonomics*, the students learn about human information processing to enhance usability in design of human-machine interfaces; how allocation of functions influences the interaction between humans and the machine and systems performance including automation. Labs and case studies from real world settings are used for analyses and discussions.

The course in *Organization, Change Management and Work Environment Legislation* includes work organizational theories from the engineering as well as human behavioral perspectives; development theories within work organizations; leadership; change strategies; design of the work organization, and work environment legislation.

The course *Physical Ergonomics* includes application of knowledge about human physical capacity, limitations in work situations; the influence of human and work interaction on quality and effectiveness in the work system; the causes and prevention of musculoskeletal problems. This course includes a number of situated labs on workload including mathematical calculations.

The second year consists of a *Project Course* and the *Degree Project*. In the project course representing 15 credits, the students improve their ability in professional written and oral communication; critical examination and discussion of other project works; and planning of a project task, preparing them for the degree project. In the degree project, finally, the students perform an independent degree project corresponding to 15 credits. In the project the students demonstrate their ability to perform independent project work. Some perform their degree project within existing research projects, others perform advanced investigations in private or public organizations.

Many students have already been active in an occupation for some time and find it difficult to get enough time off for studying, which means that they might get their degree somewhat later than predicted. They also, in many cases, have a family to take care of that from time to time interfere with the studies. We have tried, however, to adjust the curricula to fit these circumstances, e.g. by adapting examination schedules. Besides, the introduction of the project course that prepares the students very well for the final degree project has significantly increased the number of completed degree projects.

The program was originally developed for part-time students and only a handful of students per class earlier chose to read full-time. The last few years, however, an increasing number of students chose to study full-time partly because more students come directly from a bachelor degree and some chose to read this master as part of their five-year M.Sc. in technology. Today, about half of the 30 admitted students every second year are full-time students and it is not possible to arrange special scheduling for such a large group.

Curricula set-up for full-time students can pose a challenge as they begin their degree project before all theoretical courses are completed. Depending on the disciplinary background of the students the knowledge and pre-understanding vary. However, we have now after some years of course evaluations found better ways to introduce and schedule the courses, which most students find satisfying according to the course evaluations.

FACULTY TEACHING SKILLS, INTERACTION AND PEDAGOGICAL APPROACH

The program is led and continuously developed by a group of three teachers at three collaborating engineering schools and they have collaborated in this master's program since 2007. Their research interests cover complementary multidisciplinary areas by embracing mechanical

engineering, physiological ergonomics, cognitive science, human factors, work organization, group dynamics, and industrial management and engineering. Further, their multidisciplinary research has fostered a broad competence which matches the CDIO requirements regarding competence on a personal and interpersonal level in relation to product design and system building.

In each run of the program, the students appoint three representatives, one from each educational background. The main teachers have regular dialogues with these students and work continuously with improvements.

The pedagogical approach in class includes a high level of students' active interaction in dialogues, discussions, oral presentations and seminars. For group work, the student group size (3-4 persons) makes it possible to monitor each individual's learning. The course evaluations confirm the analysis we do as teachers in the program, namely that the pedagogical approach works well. It also reflects the recommendations in particularly CDIO standard 7.

The coordinating role is important as a central and necessary function to handle the diversity of courses and students as well as coordinating the three universities, although this is done in collaboration with the other two main teachers. Being two of the teachers we benefit from our different backgrounds when collaborating in teaching in each other's courses.

EXAMINATION AND CONTINUOUS PROGRAM EVALUATION

A variety of different assessment methods and examination forms are used in the master's program in order to match different learning outcomes and address disciplinary knowledge, as well as personal, interpersonal, product and system building kills" as described in standard 2 and elaborated on in standard 11. They represent individual and group performances as well as oral and written exams, see Table 2.

Table 2. Examination Forms Distributed Across Courses

Examination forms / Courses	Written exam	Seminar	Labs	Individual and group hand-in task	Project report	Oral presentation	Opposition
HTO	X	X		X		X	
Method	X	X				X	
Cogn Erg	X	X	X	X		X	X
Org	X	X	X			X	
Phys Erg	X		X	X		X	
Proj work		X	X	X	X	X	X
Degree proj					X	X	X

Except for assessing the students' theoretical knowledge, much focus is put on encouraging an interdisciplinary collaboration in group work etc. To encourage creative interdisciplinary group processes, we have strived to mix groups with equal numbers of students from the three main educational backgrounds; engineering, behavioral sciences and healthcare science. As teachers we encourage students to discuss assignments from their own disciplinary background as well

as benefiting from discussing other perspectives. As teachers we also problematize case study discussions and written essay assignments from different educational backgrounds to further stimulate the students' benefit from working in a multidisciplinary environment. In other words, assignments are designed in a way that forces students to reflect on what they learn with regard to a multidisciplinary approach.

THE ENGINEERING STUDENTS' EXPERIENCES

In a current questionnaire to investigate the engineering students' view of the program, they state that the master's program in ergonomics and HTO has contributed to their development of a broader view as well as deeper understanding of how other people may regard situations, events and phenomena. Some students stated that:

> *"The master's program has provided deeper understanding on how other people may see things from another perspective and a systems thinking that I have not encountered throughout my education in engineering. I regard the ability to see the whole as a competence, both in my professional and my personal life."*

> *"From an engineering perspective I see an enormous advantage to be able to pay attention to H, T and O in a system, to see that there is not any scape goat in a problem. It is all about interaction."*

> *"The technical part is central to us. It is rewarding to learn how the other parts interplay and the context of technology."*

The engineering students also commented on the different backgrounds of the students in class. The other students contributed to the development of the engineering students' understanding of other people' views and they gave concrete examples in class and group work. Some students pointed out:

> *"I think this has improved my ability in cross-functional work which is very good for future working life in a company. Then there might be people with different educations in the group and different departments that shall co-operate towards an overall aim, but they may have different foci and perspectives in the same way as we had in class."*

> *"Group discussions in such a context with our diverse backgrounds are incredible rewarding."*

> *"I perceived the multidisciplinary group of students as very rewarding, especially during our many group work sessions when we really could use our different competencies and experiences. Many times these co-operations challenged my pre-understanding and values. Learning did not only take place in the formal educational situations but continued during the coffee break, during the evening dinner and at the hostel when brushing my teeth."*

Furthermore, the students referred to implications of their developed holistic view in relation to future engineering work in designing innovative products and/or systems:

> *"The better picture of reality, the more sustainable products/organizations/workers can we get, and that is exactly what this education has given me – a better comprehensive view."*

"I think the master's program is relevant for engineers who want to work in an R&D-department or with design of technical products. Furthermore, I think that engineers who are interested in production would have great use of this knowledge, and also those who want to work with organizational design!"

LESSONS LEARNED

The aim of this paper was to present lessons learned from developing, managing, teaching and examining a master's program with a multidisciplinary approach.

Regarding the development and managing of the master's program there are some lessons learned to highlight. First, the main teachers' complementary educational and research orientation as well as their work life experience have been very important for developing a successful interdisciplinary education suitable for the heterogeneous student group with different disciplinary backgrounds. Second, the close collaboration between the main responsible teachers as well as between the teachers and the students has facilitated the process of developing and managing the masters' program. The collaboration with the students was supported by course evaluations as well as continuous discussions with the students throughout the program. This made is possible to e.g. adapt the program to fit both full-time and part-time students.

Lessons learned concerning teaching and the pedagogical approach is the importance of a conscious overlapping between the courses which is the result of the teachers' close collaboration throughout the program as well as participation in each other's courses. Furthermore, the application of "blended learning" with a combination of different modes of teaching and styles of learning [12] proved to be highly appreciated by the students. This was executed through a combination of online and face to face approaches. Furthermore, dialogue and reflection was promoted through seminars, oral presentations with following discussions, case analyses from real situation provided by teachers and students, and a continuous integration with theory.

The multidisciplinary approach was also reflected in the assessment and examination of the students. Throughout the program different examination forms have been applied depending on the subject and learning outcomes. Along with the development of the program, there has been a continuous reflection and improvement of the examination forms, which now include traditional written exams (with or without literature), written home examinations, development and discussion of student posters, seminars reflecting on literature, etc.

The field of ergonomics and HTO is multidisciplinary, which requires interdisciplinary collaboration between the students to reach good solutions. The heterogeneous group of students is both a challenge and a benefit depending on how the educational program is adapted and the potential dynamics in the student group is utilized. One challenge mentioned earlier concerned the poor throughput of degree projects for the part-time students who worked along with the studies. This was solved through the introduction of a project course for the initial planning of the degree project. Working with students with a professional background thus resulted in challenges but at the same time offering abundant opportunities to share experiences and resulting in multifaceted views on topics and phenomena discussed in class. It also offers opportunities to experience and reflect on the cultural contradictions between education and practice.

CONCLUSIONS

This paper has presented some experiences and reflections from developing, managing, teaching and examining a master's program with a multidisciplinary HTO approach. The multidisciplinary approach contributes to an effective dealing with the CDIO components in engineering education. The design of the master's program and the students' different learning traditions as engineers, behavioral psychologists, social scientists and ergonomists, create a platform with excellent opportunities for both students and teachers to learn from each other. This contributes to the engineering students' development of new and innovative ways of thinking and approaching design and business development as well as the teachers' continuous development of the master's program. Furthermore, the multidisciplinary approach offers opportunities to experience and reflect on the cultural contradictions between educational disciplines and practice.

Faculty as well as student representatives constitute multiple professions, which we believe is a successful concept that encourages creativity, innovation and collaboration across professional boundaries. This is increasingly important in order to avoid sub-optimization and instead promote systems thinking and interaction between disciplines in order to promote productive and healthy work and production systems. Thus, we can conclude that this master program is one example of how a multidisciplinary approach can facilitate the integration of the CDIO standards.

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