INTEGRATION OF EDUCATION FOR SUSTAINABLE DEVELOPMENT IN A MECHANICAL ENGINEERING PROGRAMME

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ABSTRACT

This paper presents and analyzes the integration with progression of education for sustainable development in Chalmers University of Technology's MScEng programme in Mechanical Engineering. The programme has an idea and structure that emphasizes employability, integration of general engineering skills, authentic engineering experiences and focus on holistic view of the complete lifecycle of products and systems. The realization of these aims stress the need of an integrated and adapted sustainable development education for mechanical engineering. To reach this goal, we applied a combined top-down and bottom-up education development process that started with the formulation of programme vision and programme level learning outcomes. Faculty meetings and workshop to formulate the course learning outcomes and to map the programme level outcomes to courses in which the outcomes are satisfied followed this. The strategy became to integrate specific sustainability topics in courses where it is appropriate and to have a separate course in sustainable development to ensure that general aspects of sustainable development are included and that a team of faculty takes full responsibility for this. Design-build-test project courses are shown to be suitable arenas for integrating teaching and learning of sustainable development. Results from a student survey on perceptions of the relevance and quality of sustainability education are accounted for and discussed. Outstanding challenges in the area are identified.

KEYWORDS

Education for sustainable development, mechanical engineering, curriculum, programme development

INTRODUCTION

The mission of a mechanical engineer is to create and operate products and systems that improve safety and quality of life for a growing population. This mission should be achieved using a minimum of resources to ensure we do not limit the possibilities for coming generations to continue to develop their quality of life and safety. The challenges in the next decades are huge; new technologies, systems and solutions for energy supply and transportations are needed, the growing global population requires more efficient use of materials, land and other resources. Mechanical engineers need to take active and leading roles in solving these challenges associated with the transformation to a sustainable society.

Stakeholders and students are expecting engineering programmes to prepare the students for the challenges described above and the education must continuously be developed to meet these needs, see, *e.g.,* Hanning *et al*. [1]. *"Training in engineering and natural sciences is generally sufficient, but social, economic and environmental applications of engineering are poorly provided for"*, argued the Swedish National Agency for Higher Education in a report from the 2005 national evaluation of engineering programmes [2].

These needs are thus being formalized into requirements that are included in national and international requirements on engineering degrees. Specifically within the CDIO context, the CDIO syllabus 2.0 clarifies the position of sustainability in the syllabus, bringing forward topics such as design for sustainability, for sustainable implementation and for sustainable operations [3]. Moreover, the EUR-ACE standards [4] require that a 2^{nd} cycle engineering degree graduate "*demonstrates awareness of the health, safety and legal issues and responsibilities of engineering practice, the impact of engineering solutions in a societal and environmental context, and commit to professional ethics, responsibilities and norms of engineering practice".* As yet another example, the Swedish national degree requirements for the "Civilingenjör" degree (Master of Science in Engineering) ([5], excerpt) state since 2007 that:

"To be awarded the Civilingenjör degree the student should be able to demonstrate:

- *Ability to design and develop products, processes and systems with consideration of human prerequisites and needs and the society's goals for economically, socially and ecologically sustainable development,*
- *Ability to formulate judgements considering relevant scientific, societal and ethical aspects, and demonstrate an awareness of ethical aspects on research and development work,*
- *Insight into the possibilities and limitations of technology, its role in society and the responsibility of humans for its use, including social, economic as well as environmental and occupational health aspects"*

The challenge for educational developers is then to design the education in such a way that the requirements are fulfilled.

Earlier work on the topic of addressing sustainability in CDIO programmes starts with Jeswiet *et al*. [6] who compiled a list of sustainability topics that should be included in a CDIO programme, including lifecycle assessment (LCA), design for environment (DFE) and remanufacturing. Knutson Wedel *et al.* [7] discussed the implementation process of engineering education for sustainable development into CDIO programmes and present and analyze the relation between the concept of sustainable development and the CDIO approach and, in particular, the CDIO syllabus. Silja *et al.* [8] point out that several CDIO standards are very amendable to sustainability education, including Standard Five (Design-build Experiences) and Standard Eight (Active and Experiential Learning). In addition, several authors have presented innovative sustainability project course models that can be included in a CDIO curriculum, for example aiming to develop water sanitation solutions [9] or green design competitions [10]. Few earlier works provide a programme-level perspective on sustainability. A programme-level is essential in order to identify appropriate learning events to include sustainability into, and to develop a progression between such learning events. This perspective is the focus of this paper.

The aim of this paper is thus to bring forward experiences and knowledge on how to develop and integrate a programme specific sustainable development education into a mechanical engineering curriculum. The context is the CDIO-based MScEng programme in mechanical engineering ("the M programme") at Chalmers University of Technology. Specifically, the objectives are to:

- Provide an example of a mechanical engineering curriculum where sustainability is systematically contextualized and integrated,
- Describe the process to develop such a curriculum, applying the CDIO approach,
- Evaluate students' perceptions of the changed education for sustainability and
- Discuss how to increase the awareness of sustainable development amongst mechanical engineering students

The remainder of the paper is structured as follows: We start by describing the current design of the M programme, including its programme learning outcomes and curriculum, and elaborate on how sustainability is addressed in the programme. We then describe the development process of reaching that state. The evaluation section discusses data from recent sustainability courses. A discussion section identifies some outstanding challenges in the area and the paper is wrapped up with a list of conclusions.

EDUCATION FOR SUSTAINABLE DEVELOPMENT IN THE M PROGRAMME

The M programme – sustainability programme learning outcomes

The M programme is a five-year programme divided into two cycles in accordance with the Bologna structure. The first cycle consists of three years of full time studies and corresponds to 180 ECTS and ends with the degree of Bachelor of Science. The second cycle is a two-year (120 ECTS) master programme. After completing both cycles the student is awarded the Swedish engineering degree "Civilingenjör" (MScEng) as well as the degree of Master of Science (MSc).

The M programme aims at developing the knowledge, skills and competence required to participate in and lead the development and design of industrial products, processes and systems for a sustainable society [11]. Sustainable development of products and systems is thus a vital part of the M programme. The programme also prepares for positions in other areas of the society where skills in analysis and processing of complex open-ended problems are of great importance. During the studies, the student shall be able to develop her/his personal skills attitudes that will contribute to professional integrity and to a successful professional life.

The M programme is described in a CDIO-based integrated programme description [11]. A number of the programme level learning outcomes related to sustainability are seen in Table 1. The courses are designed to meet these learning outcomes, and the design of the curriculum in relation to the learning outcomes is displayed in the programme design matrix using a ITU scale (I=introduce, T=teach and U=utilize), see Table 2.

Table 1
The programme learning outcomes related to sustainable development in the M programme

The Master of Science in Mechanical Engineering graduate shall be able to:		
3		Lead and participate in the development of new products, processes and systems using a holistic approach for the entire process: from stating requirements and formulating the concept, to design, manufacturing, operations and phase-out/shut-down. Following a systematic development process that is adapted for the current situation does this. This requires for instance:
	3.6	Select materials with an understanding of how such choices will affect the manufacturing process, product behaviour and environmental impact during the life of the product
	3.7	Compare and evaluate different product solutions with respect to function, environmental impact, production and cost
	3.8	Analyze, design and select production systems and machining processes with consideration to efficiency, work motivation, safety and work environment
	3.9	Describe and estimate the economic, societal and environmental consequences of a product or system through its lifecycle
4		Understand and estimate how human behaviour affects the climate on earth as well as its ecosystems
5		Identify the available energy resources (renewable and non-renewable) and explain how these can be transformed to other energy forms, along with their limitations and environmental impact

Table 2
Excerpt from the programme design matrix. The links between programme learning outcomes and the courses are displayed (I =introduce, T=teach and U=utilize)

Learning outcomes/Courses (mandatory)	**3.6**	**3.7**	**3.8**	**3.9**	**4**	**5**
Introduction to mechanical engineering (project)	I	I			T	I
Strength of materials	I	I				
Materials Science	T					
Machine Elements	U					
Material and Manufacturing Technology	T					
Thermodynamics and Energy Technology						T
Sustainable Product Development	T	T		T	T	T
Integrated Design and Manufacturing (project)		T		U	U	
Industrial Production and Organisation			T			
Engineering Economics		T		T		T

The curriculum

Table 3 and 4 show the M programme’s curriculum for the first cycle. The academic year is divided into four study periods, quarters of eight weeks. The elective courses in Year 3 are shown in Table 4. Courses having learning outcomes related to sustainable development corresponding to at least 1 ECTS are marked gray.

In the second cycle, the M programme students can choose between 15 different master programmes for the degree of “Civilingenjör”, see Table 5. Eight of the 15 approved master programmes are organized in close connection to the first cycle of the M programme. This means that the programme management is responsible for content, level, quality, budget and study environment of both the first and the second cycle. All the approved masters programmes contain integrated sustainability learning experiences. Master programmes shaded in light grey in Table 5 offer substantial advanced development of knowledge in sustainability connected to the programmes’ domains. The M students are also able to choose specifically sustainability-focused programmes as the specialisation of their studies, marked in dark grey in Table 5.

Table 3
The M programme plan for years 1-3

Year 1, Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Programming in Matlab 4.5 ECTS	Calculus in a single variable 7.5 ECTS	Linear algebra 7.5 ECTS	Calculus in several variables 7.5 ECTS
Introductory course in mathematics 7.5 ECTS	CAD 4.5 ECTS	Mechanics and statics 7.5 ECTS	Strength of materials 7.5 ECTS
Introduction to mechanical engineering 7.5 ECTS			
Year 2, Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Mechanics: Dynamics 7.5 ECTS	Machine elements 7.5 ECTS	Thermodynamics and energy technology 7.5 ECTS	Industrial production and organisation 6 ECTS
		Integrated design and manufacturing 7.5 ECTS	
Material science 7.5 ECTS	Material & manufacturing technology 7.5 ECTS	Sustainable product development 4.5 ECTS	Industrial Economics 4.5 ECTS
Year 3, Quarter 1	**Quarter 2**	**Quarter 3**	**Quarter 4**
Mechatronics 7.5 ECTS	Automatic control 7.5 ECTS	Bachelor diploma project 15 ECTS	
Fluid mechanics 7.5 ECTS	Elective 1 7.5 ECTS	Elective 2 7.5 ECTS	Mathematical statistics 7.5 ECTS

Table 4
Elective courses in Year 3 of the M programme

Quarter 2	**Quarter 3**
Energy conversion	Heat transfer
Finite element method	Logistics
Machine design	Materials and process selection
Simulation of production	Object oriented programming
	Sound and vibration
	Transforms and differential equations

Table 5
Master programmes approved for the degree of “Civilingenjör” in Mechanical engineering

Master programmes belonging to the M programme	**Other Master programmes approved by the M programme**
Applied Mechanics	Engineering mathematics
Automotive engineering	Learning and leadership
Industrial ecology	Nuclear engineering
Materials engineering	Quality and operations management
Production engineering	Sound and vibration
Product development	Supply chain management
Naval architecture and oceans engineering	System, control and mechatronics
Sustainable energy systems	

Sustainability learning experiences

Let us now in some more detail discuss the sustainability teaching and learning experiences included in the bachelor part. The basic idea is that sustainable development is integrated into courses when applicable. The main sustainability course is the *Sustainable Product Development* course during the second year.

However, sustainability is included already during the first term in the *Introduction to Mechanical Engineering* course. This course includes lectures on general aspects of sustainability in product development and in the choice of materials for these products. The course also includes a design-build-test project in which the students consider their choice of material for the final product and its impact on the environment. Moreover, during the first year, the *Strength of Materials* course, discusses the role played by "Strength of Materials" in a technological, economical and socially sustainable society: about 80% of all mechanical breakdowns today are estimated to stem from fatigue which can be related to inadequate calculations of the strengths, insufficient knowledge of the phenomena or of other characteristics of the chosen materials. This costs society approximately 4-5% of the yearly GDP. One of the main purposes of knowledge in the strength of materials is to be able to create durable, lean and efficient products. In *Mathematics, Mechanics and Strength of Materials* we focus on computations and simulations and tools for this. These tools are essential to the design of lean products.

In the second year, the *Materials Science* course discusses the choice of materials as well as options for the collecting of waste products. The *Machine Element* course continues the discussion initiated in the *Strength of Materials* and *Materials Science* courses by teaching students how to design durable machines and products for long life, low friction and low energy consumption as well efficient use of material. The following *Sustainable Product Development* course begins with general treatment of the environment and sustainable development focusing on global issues. Analytical tools such as lifecycle analysis and multi criterion analysis are introduced to help determine the effect that products and processes have on the environment. In addition, strategies and methods are treated to help the student gain a view of environmental and sustainability issues that are necessary for the development of future products and processes. In the parallel *Thermodynamics and Energy Technology* course the students are taught the boundary conditions for our society's energy consumption and its connection to the climate issue. Limitations and effects on the environment of different energy sources are discussed as well as ways of minimizing these effects. The *Integrated Design and Manufacturing* project course runs in parallel to the other courses. The solution to an industry problem is developed or reconstructed from idea to prototype. Part of the coursework consists of determining the effect on the environment the product can have from a lifecycle perspective through the use of tools from the Sustainable Product Development course. The basic idea is that students should integrate sustainability considerations to improve their solutions. Also, in the *Industrial Production and Organisation* course, the students are tasked to analyse, design and choose production and manufacturing systems with special consideration taken to efficiency, work motivation, safety and working environment.

The sustainability learning experiences are summarized and classified in Table 2. Further, Table 6 includes examples of learning outcomes that show progression between courses in the programme.

Table 6
Examples of course learning outcomes that show progression between courses in the M programme. The columns include examples of learning outcomes for each course. The rows show learning outcomes that are connected

Introduction to Mechanical Engineering	**Sustainable Product Development**	**Thermodynamics and Energy Technology**	**Integrated Design and Manufacturing**
Describe some basic perspectives for the role of engineers in society ... in connection to environmental issues	Discuss how different environmental values can give different interpretations of environmental issues and how this can have impact on demand, function and need of product design in the role of engineers	-	-
Discuss advantages and problems for the combination of materials, product geometry, joining and manufacturing in the perspective of sustainable development	Describe and use general methods as well as strategies for a sustainable product development	-	-
-	Describe cause effect chains for some known environmental problems	Describe limitations and environmental effects for the use of different energy technologies and fuels	-
-	Perform a basic analysis of the environmental and sustainability impact with the use of life cycle assessment	-	Chart the product life cycle from an environmental perspective

THE CHANGE PROCESS

University-wide strategy and approach

Adopting a ten years perspective of the development of education for sustainability, the first few years the focus was to put sustainability on the agenda. There was an increased interest in sustainability from students, industry and faculties as well as from the management of Chalmers. Results from alumni surveys and interviews with stakeholders stressed the need for improved and extended education for sustainability. Consequently, Chalmers' management developed a strategic framework that guides the integration of sustainability knowledge and skills in its programmes. The framework identifies certain components that should be included in all programmes but an essential element of the strategy is also to connect sustainability education very closely to applications and decision-making in the student's study field, for example mechanical, chemical or civil engineering. This approach aims to ensure the relevance of sustainability education experiences to all fields and to increase student motivation to acquire sustainability knowledge and skills.

The strategic framework comprises four building blocks, as illustrated in Figure 1: fundamental, integrated, advances and sustainability knowledge. The fundamental element typically is implemented in a first or second year course and develops knowledge of some common sustainability topics and definitions along with some domain-specific sustainability concepts. There is thus a common core for all Chalmers students but already here there is some adaptation to the field of study. In the integrated elements, teaching of sustainability takes place inside a disciplinary course or project. Sustainability learning can then be closely connected to learning experiences aiming at mimicking authentic analysis or decision-making

Figure 1. Chalmers strategy for sustainability education

situations in the field, such as materials selection considering performance, lifecycle load and cost constraints. On the master level, all master programmes are required to include learning experiences that further advance the student's sustainability knowledge. This can take place through dedicated courses or integrated learning experiences, or both. Chalmers has further designed its total offering of master programs so that there for each student can select at least one relevant sustainability-specialised master programme. For example, among the 15 master programmes that mechanical engineering students can choose from, two are focused on sustainability: Sustainable Energy Systems and Industrial Ecology.

In order to facilitate for programmes to implement these ideas, a group containing specialists from different disciplines at Chalmers was formed to support faculty and programme managements in the integration of sustainability in courses and programmes. The group conducted series of workshop for programme managements, faculties and student representatives. These workshops included inspiring lectures by specialists and presentations of good practices of course and programme development work at Chalmers. The presentations were followed by discussions in small interdisciplinary groups on how sustainability could be integrated and taught in courses and programmes. This approach successfully put sustainability on the agenda for course and programme developments, created engagement and involvement and increased the general awareness [12].

Programme level

Realizing the education for sustainable development strategy on the programme level involve several challenges. First, we need to formulate specific programme learning outcomes for the particular engineering discipline, *e.g.,* mechanical engineering. Second, we need to create specific courses or/and integrate in existing course and plan for progression. Third, we need to create legitimacy for lecturers as well as students to focus on or include sustainability in courses and projects.

In 2006 an *Energy and Environment course* (7.5 ECTS) was launched in Year 3 of the Mechanical engineering programme. At the same time the integration of sustainability in the programme's courses was mapped. Evaluations of the programme showed that general engineering aspects of sustainability and, in particular, energy related issues such as the climate and impact of different energy sources were covered satisfactorily. Evaluations also showed that sustainability needed to be more distinct integrated with clear learning outcomes and planned for progression. Moreover, the evaluations pointed out that environmental aspects of the use of materials and the environmental impact of the product development process needed to be included in an extended and more distinct fashion. Further, student course evaluations and student interviews pointed out the need for education on tools to estimate the products' environmental impact in the product development projects.

Based on this, the M programme applied a combined top-down and bottom-up education development starting with formulating programme vision and programme level learning outcomes and followed by faculty meetings and workshops to formulate the course learning outcomes and map the programme level outcomes to courses in which the outcomes are satisfied. Education for sustainable development has been a standing item on the programme advisory board meetings and the programme level learning outcomes were outlined at those meetings. The learning outcomes were then presented and scrutinized at the programme faculties meetings. At those meetings the links between the programme learning outcomes and the courses were established and the programme design matrix was filled, *cf*. Table 2.

The strategy became to integrate sustainable development in the courses where it is appropriate and to have a separate, “fundamental” course in sustainable development to ensure that general aspects of sustainable development are included and that a team of lectures takes full responsibility for this. We found that the CDIO approach was beneficial when designing and integrating the education for sustainable development. The existing structure with programme description, programme learning outcomes and programme design matrix was successful and experiences from the integration of general skills such as communication and teamwork were used as a template.

The programme management pinpointed a group of two engaged and committed faculty from two different departments to develop the fundamental course. The separate course was then developed in close cooperation with the programme management to make certain that the students as well as the lectures on the programme understand the relevance of the course and its relation to the rest of the programme. At the same time the education for sustainable development in the *Introduction to Mechanical Engineering* course was increased and focussed on material issues. The energy related sustainability issues were then transferred to the *Thermodynamics and Energy Technology* course.

Because the M programme is CDIO-based there already existed product development courses, or Design-build-test project courses, centred round the realisation of a product. Those courses are natural arenas for teaching, training and practising of general skills and suitable arenas for integrating teaching and training of sustainable development. The fundamental course in sustainable development *Sustainable Product Development* is taught simultaneously and in close cooperation with the second year design-build-test project course *Integrated Design and Manufacturing*. The idea is that the fundamental course should provide tools and methods for sustainable product development that will be used in the design-build-test project to improve the students’ solutions and products. Moreover, lectures and former students of the *Integrated Design and Manufacturing* course fully supported a simultaneously taught course on sustainable product development and had in fact earlier asked for such a course.

To summarize, in the case of the M programme the change has been gradual over several years [7],[13]. It appears at this stage that it has been successful based on student surveys and the input from faculty. According to the model presented by Knoster [14] to lead and manage a complex change, it needs to be consensus, skills, incentives, resources, and an action plan. In the present case the faculties’ workshops were the most important meetings to create consensus. The necessary sustainability skills were established through programme management involving and inviting the Education for Sustainable Development (ESD) group that was active at the university 2006-2009 and by finding faculties with a special interest in the area. The skills necessary to undertake the pedagogical reform were present since many years of CDIO reform has presented many opportunities to gain experience. As mentioned, incentives were given both by the national degree requirements, the vision of the university and also the CDIO process, which alls highlighted the importance of skills and the societal context of engineering. Resources were, as usual, not abundant, but there were some financial support to develop courses and to engage the ESD group. The most important, however, was the action plan developed by the M programme advisory board (who discussed to gain consensus) and the use of the CDIO model to implement this plan.

EVALUATION AND RESULTS

The renewed education for sustainability is being evaluated. Some of the first course evaluations are reviewed below. A survey was included in the course evaluation of the *Sustainable Product Development* course. The response rate was 54 % (138 students). We can notice that after this course, over 80 % of the 2nd year M students regard sustainability to be an important competence for professional Mechanical engineers, see Figure 2. *"I liked the course and its content was relevant",* read one free text comment. The percentage of students that regard sustainability to be of no importance has decreased significantly compared to previous years 10-15%. The majority of the M students consider that the programme's strategy to integrate sustainability is successful and that it facilitates learning and provides a better understanding. See Figure 3. Moreover, the questionnaire reveals that the 2nd year M students consider the M programme to provide them with competences in sustainability that are relevant for their profession, see Figure 4: *"I have an interest in the environment and the course was a good fit in both private and professional aspects*".

These results from the questionnaire are very promising and encouraging, in particular considering that the students are in the middle of their five-years education. Clearly, the M students have a genuine interest in sustainability and they regard sustainability to be an important and relevant competence for their careers as mechanical engineers, see also [1]. Moreover, the students claim that the programme provides the relevant competences and that they have received a fairly clear picture of what competences regarding sustainability that mechanical engineers need, see Figure 5.

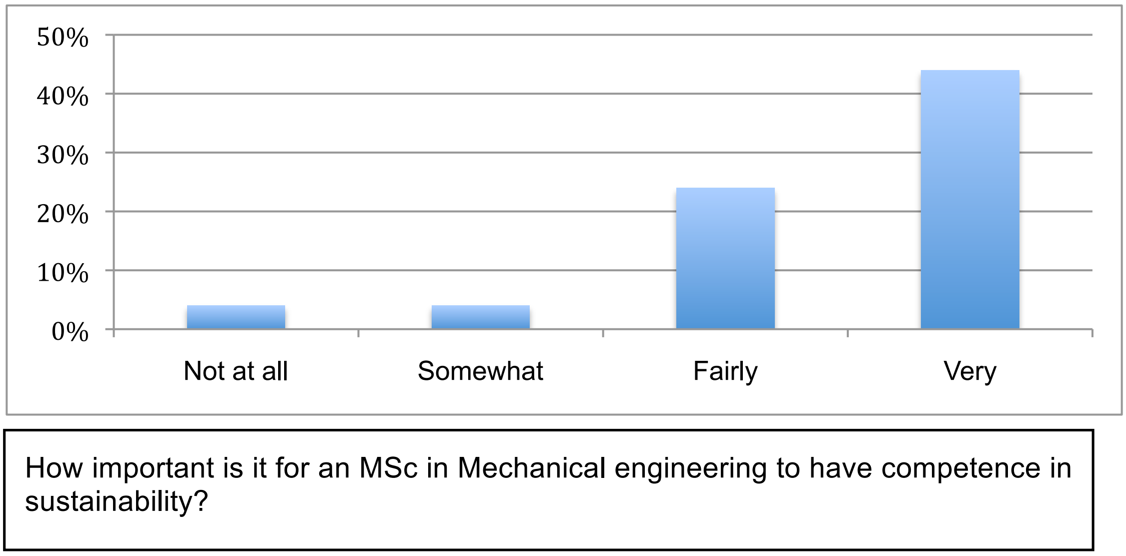
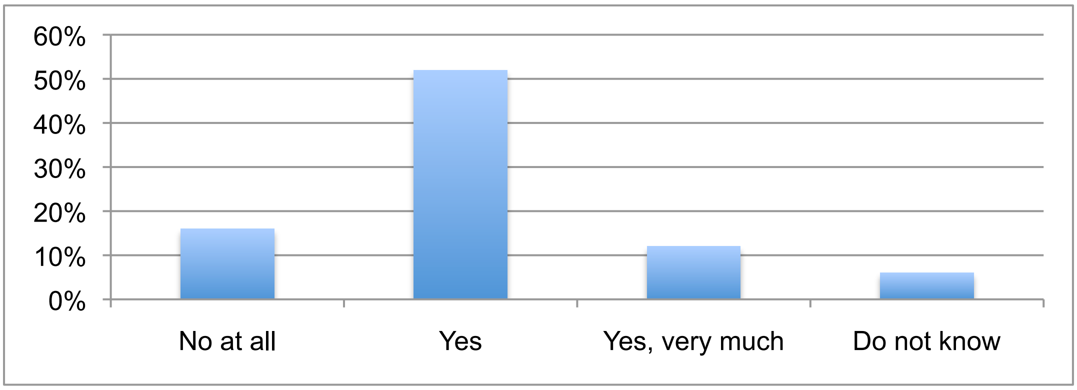
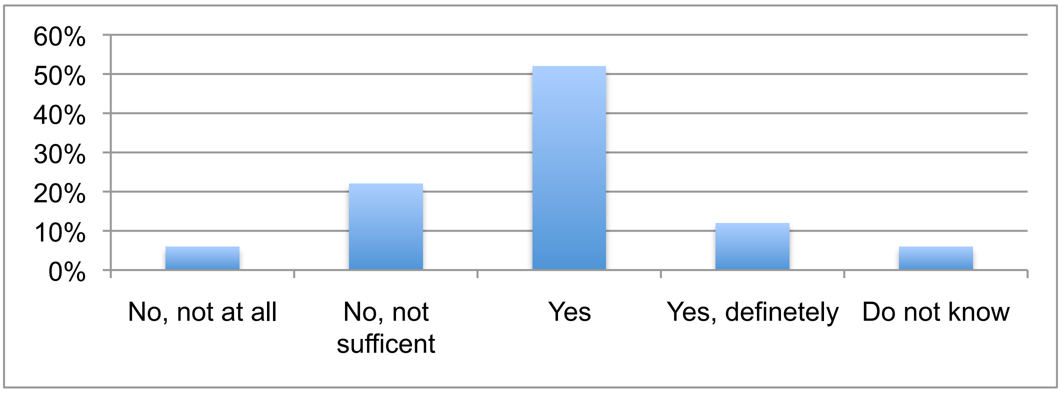


Figure 2. Results from course evaluation in *Sustainable Product Development* course



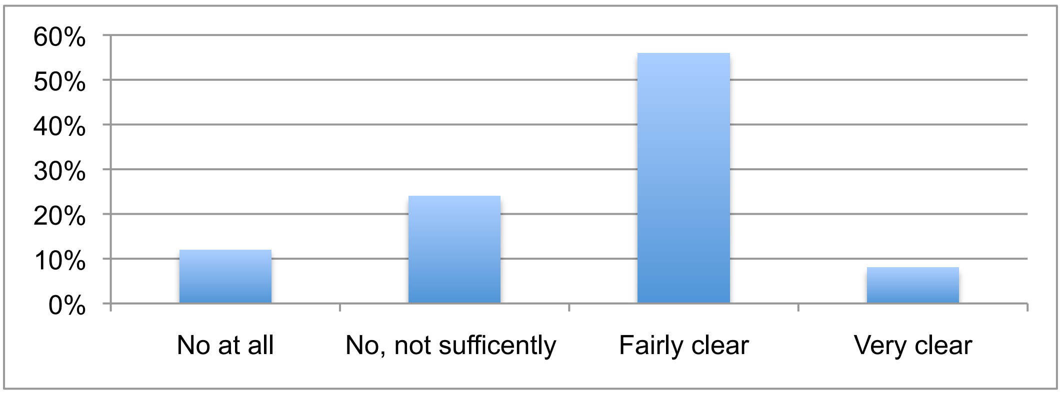
Has it facilitated your learning that sustainability has entered several courses?

Figure 3. Results from course evaluation in *Sustainable Product Development* course



Have the Mechanical engineering programme provided you with competences regarding sustainability that you believe are relevant in your career as Mechanical engineer?

Figure 4. Results from course evaluation in *Sustainable Product Development* course



Did you get a clear picture of what expertise in sustainable development a mechanical engineer needs?

Figure 5. Results from course evaluation in *Sustainable Product Development* course

Faculty teaching in the *Integrated Design and Manufacturing* project course (taught in parallel with the *Sustainable Product Development* course) verify the general picture of M students' interest in sustainability and claim that the students include aspects of sustainability in their reasoning to a higher extent compared to previous years. Since the project course is still running and the students have not finalized their products it is to early to discuss possible effects on the environmental impacts of the developed solutions and products.

The results of the students in the *Sustainable Product Development* course were extremely good, 99 % of the students passed the course and the mean grade was 4.3 where grade 5 is the highest. Such results are unusual for mandatory courses in the M-programme at Chalmers. The lectures were very pleased with the students' efforts and the cooperation with lectures of the course taught in parallel.

However, despite these favourable data, the students ranked *Sustainable Product Development* course low. The average overall satisfaction with the course given by the students in the course questionnaire was low, 2.7 out of 5. The low overall satisfaction may partly be due to that the course was given for the first time, some administrative information was late and students missed old exams etc. But more important, students argued that the level and the content of the course were too basic. They maintained that the course was not challenging enough and that the contributions to their competences and skills in sustainability were minor. Moreover, the students asked for a more clear focus on the product development process and the corresponding environmental impacts. *"I would have appreciated more on tools to analyze the environmental impact of different materials and processes etc. The Thermodynamics and Energy Technology course covered this much better."* At the same time the students are, so far, generally satisfied with the integrated elements of sustainability in the other courses: *"I have learnt very little from this course but courses such as Thermodynamics and Energy Technology, Material Science and Machine Elements have given me useful (sustainability) competences and skills".*

The criticism by the student will be taken seriously and there are obvious possibilities for improvement of the *Sustainable Product Development* course and continue to transfer focus towards estimations of environmental impacts from the products created and designed during the Design-test-build projects.

DISCUSSION

From the course evaluation responses, it is apparent that the integrated approach has been successful in some ways, especially concerning the awareness of the relevance of specific sustainability knowledge in the mechanical engineering. However, the results also point to areas that need to be carefully considered. Let us point out a few key challenges:

Improved previous knowledge and dynamic progression. It is a common amongst engineering faculty to complain about students' entry-level knowledge and skills, in particular with respect to mathematics knowledge and hands-on mechanical skills. However, with respect to sustainability, the opposite situation seems to be at hand. Current students know, due to inclusion in elementary and high school curricula, and in the general public debate much more about the subject that students did, say ten years ago. This is reflected the responses to the course evaluation: *"I think the course was too easy, I did not have study at all to pass the course".* University educators need to understand what the current students bring in terms of previous knowledge and consciously build their courses on that platform. There is also a cascading effect to consider: If new students bring more advanced knowledge to our basic courses, we should take advantage of that in those courses, but we also need to change our advanced courses to take advantage of the revised basic courses.

In summary, a dynamic approach to sustainability learning progression is needed. Continuous change is a factor and a challenge, but in this case with the positive situation of taking advantage of improved pre-knowledge.

Challenges to the programme ethos. Edwardsson Stiwne and Roxå [15] discuss what they call "programme ethos", as the idea of what an educational programme stands for and argue that in addition to what is explicitly stated, there are many unspoken elements in the ethos, which are carried by students and faculty. If a change proposal challenges the unspoken ethos, it will be difficult to introduce and sustain. In the engineering context, part of the unspoken ethos has to do with the difficulty and workload of the engineering education. To be admitted to the programme and completing your studies reflects high ambitions and a sense of achievement when you are finished. Edwardsson Stiwne and Roxå point out argue that this is positive when applying for jobs and for self-confidence. However, a course that does not comply with this ethos runs the risk of devaluing the subject in the students' perceptions. Again we quote the students who stated: *"I think the course was too easy, I did not have study at all to pass the course". Another student wrote: "An important subject but unclear approach and too little fact-based information made the course fuzzy".* While these viewpoints can be problematised in terms of being "right" it seems to be a reality, and subjects which are perceived this way continue to be considered as something that lies outside of the core of the education and is thus less important. The question becomes to what extent sustainability education should be aligned with the dominating practices of engineering education and to what extent a different approach should be applied. If so, a considerable amount of effort needs to be put into motivating why the differences are necessary. And this task is not the sole responsibility of the faculty responsible for a single sustainability course. Rather, the programme manager and the faculty collective need to embrace the cultural change.

CONCLUSIONS

Sustainability should be addressed in many courses in a mechanical engineering programme. A suitable strategy includes at least one fundamental sustainability course and a systematic approach to integrated sustainability in many other courses. A program-level perspective is important to maintain links to overall programme learning outcomes and to ensure progression.

An open process for developing and implementing sustainability elements was applied in Chalmers M programme. The combined top-down and bottom-up approach created arenas at different levels for development work which gave the possibilities for programme management to communicate and discuss the programme level vision and gave ample room for individual involvement and engagement. The CDIO framework with an integrated programme description, the tools for creating an integrated curriculum and inherent Design-build-test learning experiences was found to facilitate the process substantially.

In the reformed curriculum, sustainability elements are pervasive and adapted to context. It is shown that this has increased students' awareness of the topic and clarified their view of what specific sustainability competence that is applicable and relevant in their field. The integrative approach facilitates learning of sustainability topics by connecting them closely to professional engineering tasks, such as decision-making in design projects.

The work described here is the first steps towards an integrated and domain-specific sustainability education for mechanical engineering at Chalmers. The strategy described here will be used in a continuous development setting to improve and extend the education.

Many challenges still remain, though, including to:

- Adapt sustainability goals and contents to the increasing level of pre-knowledge and understanding that current students bring from high school. This is in contrast to the common situation where teachers are challenged by weaker pre-knowledge, *e.g.,* in mathematics and with respect to hands-on mechanical skills.
- Consider if and how to bring the sustainability courses closer to the ethos and pedagogy of engineering programmes, which typically is characterized by high ambitions, a high workload and tough exams. When a course deviates from this ethos, it runs the risk of being criticized by students just for being taught in a different style. Awareness of this risk and an appropriate strategy to deal with it is essential.

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