A STRATEGY FOR TEACHING SUSTAINABILITY ASSESSMENT

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Abstract: Educating engineers to be active in sustainable development is by no means a trivial task and the challenge has been pursued by several universities and organisations around the world. At DTU MAN research and teaching is focused on engineering management tools. In the section for Quantitative Sustainability Assessment (QSA) the research and teaching is embedded in Life Cycle Assessment (LCA) and Life Cycle Management (LCM) tools. Our vision is that all engineers graduating from DTU are taught a basic knowledge about sustainability and the methods and tools to assess the sustainability of their decisions. Our strategy for the teaching address three target groups and follows two routes.

- One route provides in-depth education for students aiming to specialise in quantitative sustainability assessment. A variety of courses ranging from production level through company level to society level will be offered.
- The second route aims to present concepts of sustainability and potential impacts of the specific technology field as well as methods and tools for specific domains, i.e. nano technology. It is targeted two groups of students at the different technological domains at DTU; those specifically working in innovation and technology development and engineers developing solutions based on existing technologies. The DTU curricula will integrate sustainability assessment in introductory courses at bachelor level, whereas master level courses goes more in detail with the specific sustainability issues for that technology domain and introduces quantitative tools to assess sustainability.

The proposed strategy embeds sustainability throughout the engineering curriculum.

Keywords; Sustainability assessment tools, engineering education, bachelor, master, POPBL

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1. INTRODUCTION

1.1 Sustainability in engineering education

Addressing the presently unsustainable development of the global society, engineering is seen as a part of the problem as well as a part of the solution. Engineers seek to apply the knowledge of science to deliver practical solutions and have to a large extent contributed to the technology development that led us to the current state. However, engineers are also a key to the solution and they need to recognise the context in which the solution is required. The 2002 World Summit on Sustainable Development (WSSD) emphasized the educational objectives of the Millennium Development Goals and proposed the Decade of Education for Sustainable

Development for the period 2005–2014 with UNESCO as the leading agency (Uwasu et al. 2009). In Europe a more recent document targeting the engineering education for sustainable development is the Barcelona declaration from 2004 (Segalas et al. 2009). Additionally also the Royal Academy of Engineering in the UK have published their guiding principles for engineering for sustainable development (Royal Academy of Engineering 2005).

Sustainability has found its way into curricula of many engineering educations around the world ((Perdan et al. 2000, Fenner et al. 2005, Allenby et al. 2009, Onuki and Mino 2009, Quinn et al. 2009, Segalas et al. 2009, Uwasu et al. 2009). A questionnaire survey in the U.S.demonstrated clear evidence that teaching and research in sustainable engineering forms part of the activities of the top 100 engineering programs in the U.S. (Murphy et al. 2009). In the Netherlands, the board of Delft University of Technology adopted an educational plan in 1998 encompassing three interconnected operations aiming at teaching sustainability to all engineers (Peet et al. 2004). In Sweden, the Swedish law for higher education has, since February 2006, included a requirement that all higher education should contribute to promoting sustainable development. Chalmers University of Technology has chosen to strive for an integration of sustainable development into all engineering programmes. Actually, a policy at Chalmers created already in 1985 require that the bachelor curriculum in all engineering programmes should contain compulsory courses of 7.5 ECTS-points[1] concerning environment and sustainable development (Segalas et al. 2009). In Japan an initiative called IR3S (Integrated Research System for Sustainability Science) led by University of Tokyo with Hokkaido University, Kyoto University, Ibaraki University, and Osaka University as the participating universities, have the mission to establish sustainability science by promoting activities in three fields; research, education, and cooperation with industries (Uwasu et al. 2009). The Norwegian University of Science and Technology (NTNU) was very early in offering an education in “industrial ecology” in the mid 1990’s. A number of other NTNU programmes incorporate environmental issues early on as part of their educational offerings. These courses of study offer specializations that are related to sustainable development (NTNU, 2010). The importance of education in sustainability, especially for engineers, is illustrated by the emphasis on this topic around the world.

1.2 Sustainability at Technical University of Denmark (DTU)

DTU have app. 6000 students most of which aim at a master level degree in engineering. At DTU sustainability is embedded implicitly in the teaching strategy, but there is no direct reference to or adoption of a sustainability agenda. It is stated that students must have ”a comprehensive polytechnic approach” which in a more recent interpretation must include sustainability. The research strategy has direct reference to sustainability:”DTU will promote promising fields of research within the technical and the natural sciences, especially based on usefulness to society, relevance to business and sustainability”.

An illustration of the sustainability oriented education activities at DTU is the “groen dyst” (green competition, www.groendyst.dtu.dk) program in June 2010. All engineering student at

[1] ECTS (European Credit Transfer System) describes the workload of a course. 60 ECTS points corresponds to 1 year of full time studies ≈ 1500 hours of student work

DTU have been personally encouraged to enroll with a project (5 ECTS-point) that have a sustainability perspective and to participate in the final conference and competition.

At the QSA (Quantitative Sustainability Assessment) section at DTU MAN we focus our research and teaching on quantitative methods for sustainability assessment and implementation of these. The more qualitative or socio-technical aspects are addressed by other sections at the department. Focus for the remainder of the paper will be on the activities of the QSA section even though activities in sustainability are also on-going in e.g. civil engineering.

2. TEACHING STRATEGY

2.1 Mission and vision

The mission of the QSA section is "To offer education in sustainability assessment methods and tools to all engineer students at DTU. Partly as obligatory parts of introductory courses at all bachelor study lines, partly as electives at all master study lines, and finally as a study line in itself."

The vision of the QSA section is that:

- "All engineers graduating from DTU should be able to administer the sustainability dimension in business and society. They must know what sustainability is and how their decisions as engineers can affect sustainability. Further they should be aware that there are methods and tools to assess the sustainability of their decisions.
- All engineers graduating from DTU with a specialization in innovation and development of technology, systems or products should understand the principles of sustainability assessment and be able to apply tools for sustainability assessment.
- Engineers graduating from DTU should be able to specialize in tools for quantitative sustainability assessment of products, systems, and technologies."

The QSA section strives to be the driving force in implementing the sustainability assessment in research, education and industry creating collaboration broadly at DTU, as well as nationally and internationally.

2.2 Strategy

The QSA section aims to disseminate the knowledge about sustainability assessment partly via teaching in our core area to specialists, and partly through introducing sustainability knowledge and tools to students in other technical fields at DTU. The teaching in sustainability assessment methods and tools thus has three legs targeting different groups of students, see figure 1:

- Teaching in methods and tools for sustainability assessment targeted at the different technological domains at DTU, providing a background knowledge to students pursuing a career in other technical fields

- More in depth education for students aiming to work with the development of technical solutions and therefore wishing a more in depth knowledge of the tools available to assess sustainability of technologies
- Specialized teaching and education in principles and methods for sustainability assessment targeted at the student pursuing a professional career within the field

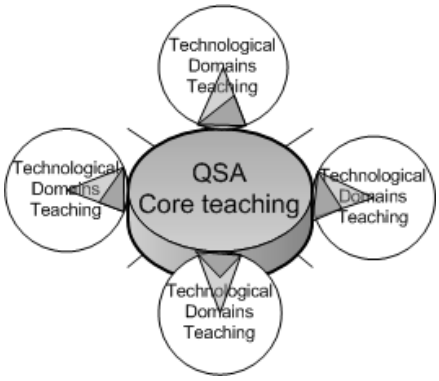

Figure 1: The QSA section's three legged strategy for education encompass education in QSA core competences for engineer specialists in the field and teaching to engineer students in other technical fields (basic knowledge (dark grey triangles) or for innovation and development (light grey triangles)).

This strategy is very much in line with the plans for education in sustainability adopted at Delft University of Technology and at Chalmers University of Technology although not adopted by the top level management at DTU. In Delft the plan encompasses three interconnected operations (Peet et al. 2004):

1. The design of an elementary course "Technology in sustainable development" for all students of DUT;
2. Development of graduation in sustainable development in each faculty and department; and
3. Intertwining of sustainable development in all regular disciplinary courses, in a way corresponding to the nature of each specific course.

Likewise, at Chalmers they are striving to integrate sustainable development into all engineering programs as well as teaching all bachelor students compulsory courses in sustainable development (Lundqvist and Svanstrom 2008, Segalas et al. 2009) the content of which is discussed more thoroughly in (Lundqvist and Svanstrom 2008).

The QSA teaching strategy at DTU aim at creating awareness of sustainability and assessment tools among the engineer students at every bachelor study line (currently 13 different study lines are offered, e.g. biotechnology and electro technology). One component of this is an introductory 5 ECTS point course in sustainability (and tools) which initially will be elective (bachelor degree requires 180 ECTS points of which 45 are elective). The other component involves introductory modules within technical courses at each bachelor study addressing specific sustainability issues. The teaching should be placed early in the study. Every master study line should offer courses including elements of sustainability assessment either in the electives or in the compulsory

courses. Furthermore, a range of courses specializing in sustainability assessment and management will be offered as electives, see also figure 2.

Taking into account that there are 13 bachelor study lines and even more specializations at the master level it can become a huge task if the QSA section is to be responsible for all education in sustainability. The educational plan at Delft University of Technology (educating app. 6 times more students than DTU) address this issue by stating that sustainable development should be integrated into all regular disciplines, i.e. integrating education in sustainable development into core technological/scientific courses. There are quite a few barriers to this approach as described in Peet et al. (2004). One is e.g. a resistance to change curricula because of an already tight programme leaving little space for topics that are not core to the specific subject. "Interdisciplinary work is perceived as important only for applied projects, not for scientific progress as it does not contribute to the conceptual core of the discipline. This creates a barrier for the introduction of sustainable development in the academy, since sustainable development is inherently multidisciplinary" (Peet et al. 2004). Acknowledging such barriers a fully fledged version of our strategy will require adoption and commitment from the top management of DTU before researchers and lecturers from other departments will get involved.

3. TEACHING ACTIVITIES

3.1 Courses offered

At the QSA section we offer a number of courses as illustrated in figure 2, where also courses that are planned are included. As illustrated, emphasis is put on covering all three pillars of sustainability (prosperity, people, and planet). Although our point of origin has been in the environmental life cycle assessment our staff now also covers the social aspects, whereas the economic aspects still depends on cooperation with other institutions.

Each faculty staff will, in addition to their specific expertise, be responsible for the collaboration with one or more technological domains at DTU and for initiating teaching offered at the respective bachelor and master study lines. A typical distribution of teaching for each staff would be 2/3 in specialized courses and 1/3 at other technological domains. The teaching at technological domains should cover more in depth the specific issues relating to that domain, e.g. how much do the specific technologies contribute to sustainability impacts, what activities are most relevant in relation to sustainability (is it the production or the use stage for example, or is it energy consumption or release of toxic chemicals?) in order for the student to better relate the sustainability aspects to the specificities of their own study. At bachelor level one or two modules (4-hour modules) at the first or second semester as well as the elective 5 ECTS point course would be anticipated.

We have successfully been involved in the 1. semester introductory course for manufacturing engineers with 2 modules illustrating the importance of taking in a life cycle perspective in development of products and technologies through teaching a module on sustainability followed by introduction to a simple assessment tool with hands-on experience by the students.

At the master level, cooperation with the civil engineering department has just started and 4 modules are taught by QSA staff at a course on optimization, resources and environment.

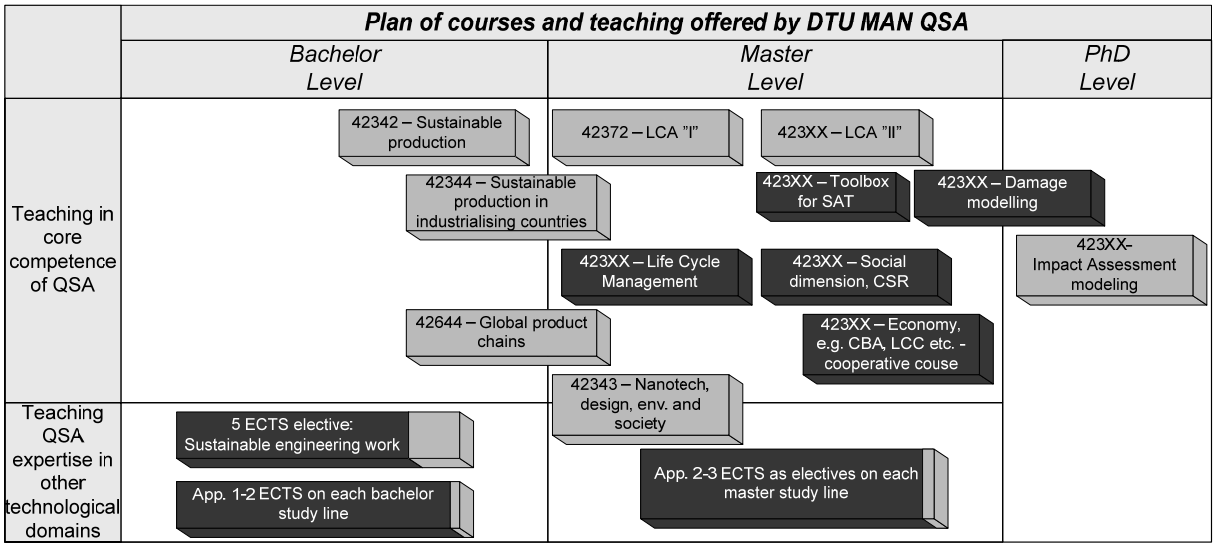

Figure 2: Overview of courses offered (light gray also those with concrete plans) and planned (dark grey) from the QSA section. The succession of the courses is not entirely illustrated and will depend on the interests of the students although there are a few courses that are obligatory in order to proceed with other courses (e.g "LCA I" is obligatory for "LCA II"). The sizes of the boxes do not correspond to the content/size of the course (ECTS points).

A course which has been running for 3 years with a total of app. 30 students is the course "Nanotechnology, design, society and environment" which is based on the sustainability assessment methodology presented in Olsen and Jørgensen (2006). Although not directly in cooperation with researcher from physics and nanotechnology, they have given lectures on the course which has also been followed by a total of app. 10 students from Physics and nanotechnology.

The pedagogical approach in all QSA courses (although not necessarily in single modules in other courses) is problem oriented and project based learning (POPBL). Theory lectures are combined with case based projects and evaluations of the students is by individual assignments as well as by the team based project reports. For example the course on Life Cycle Assessment, which is a 10 ECTS point course followed by app. 50 students per year, has since the course started in the mid 1990's encompassed a case project running throughout the course where the student have worked on a concrete problem for a company.

3.2 Introductory course in sustainability

As previously mentioned an introductory course of 5 ECTS points which is intended to be followed by students from all bachelor study lines is currently being developed. Similar courses

are already running at e.g. University of Limerick (Quinn et al. 2009), Delft University of Techology (Peet et al., 2004) and University of Windsor (Tam 2007) (although a post graduate course). The approach taken by Chalmers University of Technology differs a little since the courses may differ between different study lines (Lundqvist and Svanstrom 2008).

Again we aim to use POPBL taking departure in problems the students find interesting. In this learning by doing approach the students are presented to tools e.g. ecological footprint, simplified life cycle assessment, DfE, CSR-kompass, and CBA. Applying these tools they observe how different choices can influence the sustainability of their solutions. Theory and context will be presented along the course after the students have identified issues they need to learn to understand the sustainability context. A preliminary list of topics is shown in table 2 together with the learning outcomes.

Theories and concepts covered	Learning outcomes (the student will be able to)
• Absolute sustainability vs. relative sustainability • Life cycle perspectives and Cradle-to-Cradle concept • DPSIR (Driving forces – Pressures – Stressors – Impacts – Responses) • Consumer behaviour • Environmental regulation • Actor network analysis • Governance (e.g. actors in sustainability, Marrakesh process etc. WBCSD) • Change management	• Describe the three pillars of sustainability (BT – 1) • Explain that every dimension is multifactorial and that trade-offs exists within and between them (BT-2) • Illustrate how companies can work towards development of sustainable solutions (BT-2) • Describe the product chain perspective (BT-2) • Know and apply different simple tools for sustainability assessment (BT-3) • Explain that assessments involve integrated sensitivity analysis and iterations (BT-2) • Relate critically to the results of the different assessment tools (BT-6) • Master analysis of solution by means of simplified LCA (BT-4) • Master synthesis of solution by ecodesign principles (BT-5)

Table 1: Topics and learning outcomes (Bloom's taxonomy (BT) for cognitive learning (1-Knowledge, 2-Comprehension, 3-Application, 4-Analysis, 5-synthesis and 6-Evaluation))

Overall it is the aim that the students will acquire an understanding of the concept sustainability and the three dimensions of sustainability. They will get an overview of a range of methods and tools for analysis and synthesis of solutions that are sustainable in their whole life cycle and acquire the skills to operate them. And finally they will get an understanding of the engineer's role and responsibility in a sustainable society.

4. CONCLUSION

A teaching strategy for the QSA section at DTU MAN has been presented that is very much in line with the general trends in engineering education in sustainability. Some plans for education are more official being adopted by top management of the universities but nevertheless meets barriers in terms of organizational, academic and engineering culture. These are hurdles that have to be met proactively in the further development and implementation of the teaching strategy

5. REFERENCES

Allenby B., Murphy C.F., Allen D. and Davidson C., 2009. Sustainable engineering education in the United States. *Sustainability Science*, 4:7-15.

Fenner R.A., Ainger C.M., Cruickshank H.J. and Guthrie P.M., 2005. Embedding sustainable development at Cambridge University Engineering Department. *International Journal of Sustainability in Higher Education*, 6:229-241.

Lundqvist U. and Svanstrom M., 2008. Inventory of content in basic courses in environment and sustainable development at Chalmers University of Technology in Sweden. *European Journal of Engineering Education*, 33:355-364.

Murphy C.F., Allen D., Allenby B., Crittenden J., Davidson C.I., Hendrickson C. and Matthews H.S., 2009. Sustainability in Engineering Education and Research at U.S. Universities. *Environmental science & technology*, 43:5558-5564.

NTNU, 2010: Sustainability in engineering education.
Url: http://www.ntnu.no/news/sustainability-in-engineering-education

Olsen S.I. and Jørgensen M.S., 2006. Environmental assessment of micro/nano production in a life cycle perspective. *Materials Research Society Symposium Proceedings*, 895:159-166.

Onuki M. and Mino T., 2009. Sustainability education and a new master's degree, the master of sustainability science: the Graduate Program in Sustainability Science (GPSS) at the University of Tokyo. *Sustainability Science*, 4:55-59.

Peet D.-., Mulder K.F. and Bijma A., 2004. Integrating SD into engineering courses at the Delft University of Technology: The individual interaction method. *International Journal of Sustainability in Higher Education*, 5:278-288.

Perdan S., Azapagic A. and Clift R., 2000. Teaching sustainable development to engineering students. *International Journal of Sustainability in Higher Education*, 1:267-279.

Quinn S., Gaughran W. and Burke S., 2009. Environmental sustainability in engineering education - Quo Vadis? *International Journal of Sustainable Engineering*, 2:143-151.

Royal Academy of Engineering, 2005. Engineering for sustainable development: guiding principles. *The Royal Academy of Engineering*. London, UK.

Segalas J., Ferrer-Balas D., Svanström M., Lundqvist U. and Mulder K.F., 2009. What has to be learnt for sustainability? A comparison of bachelor engineering education competences at three European universities. *Sustainability Science*, 4:17-27.

Tam E.K.L., 2007. Part I - Educating Students in Sustainable Engineering (II) - Developing a Sustainability Course for Graduate Engineering Students and Professionals. *International Journal of Engineering Education*, 23:1133.

Uwasu M., Yabar H., Hara K., Shimoda Y. and Saijo T., 2009. Educational initiative of Osaka University in sustainability science: mobilizing science and technology towards sustainability. *Sustainability Science*, 4:45-53.