Sustainability in Design Engineering Education; Experiences in Northern Europe

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Abstract

In recent years, the implementation of sustainability into the curricula of engineering has become increasingly important. This paper focuses on the experiences of integrating sustainability in Design Engineering education in the academic bachelor programs at Delft University of Technology in The Netherlands, at the University College of West-Flanders in Belgium, and at the Norwegian University of Science and Technology. The different approaches are described and discussed.

This paper aims to share insights and lessons learned in how to accomplish true integration of sustainability in bachelor course curricula of Industrial Design Engineering .

Key words: *Design Engineering Education, Sustainability Education, Course development, Sustainable Product Innovation*

1. Introduction

In recent years, the implementation of sustainability into (industrial) design engineering curricula has become increasingly important. Design engineers can play an important role in the transition process towards a sustainable world. With an overpopulated planet, hungry for electricity and resources sustainability will be one of the biggest challenges for (design) engineers in the future.

In December 2002 the United Nations General Assembly adopted a resolution declaring a "Decade of Education for Sustainable Development" to begin on January 1, 2005 [1,2]. The United Nations Economic Commission for Europe has produced an implementation plan based on this, called Strategy for Education for Sustainable Development [3]. Other dedicated initiatives include the peer-reviewed International Journal of Sustainability in Higher Education (since 2000), and the biannual Engineering Education in Sustainable Development conference (since 2002). This shows that the topic is increasingly gaining attention. However, literature and other documented experiences and examples integrating sustainability specifically into Design Engineering education are rare.

2. Aim of the paper

Sustainability in Design Engineering Education has moved rapidly the last few years in the Industrial Design Engineering (IDE) courses described in this paper; from traditional eco-design to sustainable design, from an environmental to a sustainable context, from a single existing course into a large proportion of courses, from 'product design' to 'product life cycle design' and from factual knowledge to contextual implementation. This largely reflects the transitions in sustainable product design research as discussed by Boks & McAloone [12].
This paper describes and compares the different approaches for integrating sustainability in bachelor-level Design Engineering education at three North European Industrial Design curricula: Delft University of Technology in The Netherlands (section 2), the University College of West-Flanders in Belgium (section 3) and the Norwegian University of Science and Technology (section 4). The paper aims to reflect on the form, content, learning goals and evaluation systems of the chosen frameworks. An assessment of strengths and weaknesses of the current set-up is given at the end of each section. The paper concludes with an outlook based on the main insights gained from the three institutions. Lessons learned by the writers of this paper are addressed and shared as experience to base future course building on.

3. Delft University of Technology

3.1. Organization and program

The IDE bachelor program in Delft enrolls over 300 new students per year. For these students the high school math and science track is a prerequisite. There is no separate admission exam. There is a section *Design for Sustainability* (DfS). It consists of roughly 5 fte faculty members and about a dozen PhD candidates.

In the previous version of the bachelor program, a single sustainability course was included in the second

year based on a mechanical and chemical engineering background. Over the years gradually business-oriented topics such as green marketing and communication were included. It was followed by a design course that integrated sustainability with other design considerations. For a description of the old program, as well as master-level courses in the Delft program, see [4]. In the last program revision this was changed by integrating sustainability into several courses.

3.2. Sustainability in bachelor level courses

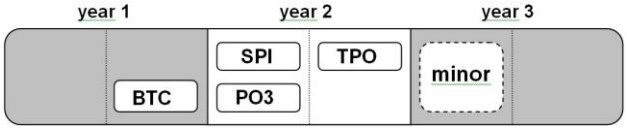

Figure 1. The Industrial Design Engineering bachelor program at Delft University of Technology.

The courses in the current bachelor program:

Business, Culture & Technology (BCT) is a first year course of 7.5 ECTS. The course covers the force field in which companies innovate. The sustainability part of the course covers the forces exerted on a company (through legislation, pressure groups, consumers) on a company to commit to sustainable innovation. The course is coordinated by faculty members from the Product Innovation Management department. Faculty members of the DfS section supply several lectures to the course. Half of the grade of this course is based on a written exam, of which one third is about sustainability.

Strategic Product Innovation (SPI) is a second year course of 7.5 ECTS. The course covers the selection of the future direction for a certain firm given a solid understanding of several strategic considerations. Through an internal and external analysis, students learn the strengths and weaknesses of the company and the opportunities and threats in the market. Based on that information, a strategy for the future is developed. Based on this future strategy, a choice for the market and a positioning and product strategy is developed. Sustainability is an explicit consideration in the internal and external analysis. Several lectures are given by faculty members of the DfS section. Next to regular coaching, specific sustainability experts are available to the student groups. There is a multiple choice exam connected to the course that includes several sustainability-related questions. The questions are drafted by the DfS section.

Product Design Project 3 (PO3) is a second year course of 7.5 ECTS. The course challenges students to apply the acquired skills from previous courses in a design exercise for an SME company in need for innovation. The design exercise mainly covers the front-end of the New Product Development process. Students work in groups and are challenged to incorporate sustainability in every stage of their process. This course builds on the design course described in [5]. The course is coordinated by faculty members from all departments. Faculty members of the DfS section are available to students as 'sustainability consultants' and give an introductory lecture. Prior to the course coaches are trained in how students can address sustainability.

Technical Product Optimization (TPO) is a second year course of 7.5 ECTS. The course provides students with a range of tools that can be used to improve the product. These tools include mold-flow and design-for-assembly. In this course students are also introduced to Life Cycle Assessment (LCA). The placement of LCA, after sustainability has already been addressed in several previous courses, was made in the hope that the previous courses would create a 'need to know' feeling among students. The course is run by faculty members of the Design Engineering department. A one week practical assignment is given to students to analyze a given product with an LCA software tool. Subsequently students are to give a short presentation, in a session with 4 or 5 other groups. Both the computer session and the presentations are coached by DfS faculty members and student assistants.

In the fifth semester students have to select a **Minor** of 30 ECTS. One Minor theme is 'sustainable design". As the sustainable design minor is not a compulsory part of the bachelor program it is not elaborated on here.

3.3. Strengths of the current set-up

- Sustainability is now linked both to engineering subject and strategic subjects;
- Through the links to other courses, sustainability is placed more in perspective to other design aspects;
- Sustainability is presented more on equal footing with other design aspects such as ergonomics;
- Being spread over multiple courses makes sustainability present in every year, which improves knowledge transfer;
- Being spread over multiple courses spreads the teaching load over the entire academic year.

3.4. Weaknesses of the current set-up

- Sustainability is no longer a must-pass subject, as it does not have its own specific course anymore;
- In several courses where sustainability is addressed the actual coaching and/or grading is done by non-sustainability-expert faculty members;
- Adjusting to the host course, makes sustainability into a fragmented subject, endangering overlap as well as uncovered aspects;

– Adjusting to the host course may cause the sequence of sustainability subjects to become illogical.

4. University College of West-Flanders

4.1. Organization and program

HOWEST (University College of West-Flanders) in Belgium is an University College with 22 professional bachelor and 7 academic bachelor/master programs. A strong interaction with the small and medium sized enterprises in Flanders pushes HOWEST to offer demand driven applied research and service to society. In its strategic plan for 2008-2016 it describes the permanent attention for a sustainable campus and the essential integration of competences within a trans-disciplinary context. The most important challenge for the next decade is implementing sustainability in education curricula using trans-disciplinary projects, combining real-life industrial cases with multidisciplinary student teams.

In Belgium, University Colleges are still in the Bologna reformation process towards a sustainable, transparent and quality-driven European education system. For the applied (industrial) engineering degree, a transitional BA-MA arrangement is made into a 3 + 1 structure. The reformation process into a fully 3 + 2 structure should be finished by 2012. This allows HOWEST to fully rethink the integration of sustainability into the education program with emphasis on the sustainability of the product design, ethics and awareness of the implications to the environment and business related eco-decision strategies.

A unique 3 + 1 bachelor-master program is Master of Industrial Sciences, Industrial Design Engineering (IDE), focusing on a technological, market-driven and/or human-social demand that is transformed into a product or service. Founded in 1995, IDE enrolls more than 50 academic and 70 professional bachelors each year. The IDE program in HOWEST combines engineering skills with creativity, product design and entrepreneurship. 45% of the curriculum consists of general scientific engineering courses, 55% is dedicated to domain specific industrial design courses.

4.2. Sustainability in bachelor level courses

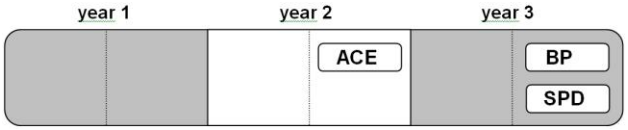

Figure 2. The Industrial Design Engineering bachelor program at HOWEST.

In the 4th semester, a 6 ECTS general engineering course is **Applied Chemistry and Environmental science** (ACE). This course is a basic environmental science and applied chemistry course where students are introduced to environmental problems and insight in the 'big picture' of sustainability. The factor 'chemistry' in social and industrial subjects and environmental problems is discussed in the lectures. The course focuses on the ecological pillar of sustainability without losing the context. Preferably exercises are based on real life examples.

In semester 6 the **Bachelor Project** (BP) is an international module of 6 ECTS (workshop + follow up). The first part of this course is a 10-day Erasmus Intensive Program (IP) workshop entitled "Green products through a multicolored approach" [6,7]. The IP brings together engineering students of different countries (Belgium, UK, Portugal, Italy, The Netherlands, France) and of several disciplines (electronic, mechanic, ICT, industrial design and environmental sciences) and different cultures (south versus north of Europe). Student teams search for green solutions for an industrial product or process introduced by a multinational or Flemish SME. The focus of this project lays on 'real life' sustainable product innovation in an industrial context. Morning seminars about sustainability and other relevant topics (e.g innovation, project management, methodology) are given by external experts, IDE faculty members and guest professors. In the afternoon workshops, these techniques are implemented on industrial innovation cases. All professors of the different partners are seated in a multidisciplinary consult board, coaching the students. On several moments feedback is given by the industrial partners. In the end, the student teams give a presentation and deliver a final report. Grading is done by the participating professors and industrial partners. The second part of this course starts after this 10-day IP. Students work further on their project on an individual base taken the feedback of the jury into account.

Parallel in the same semester, a specialized course in **Design for Sustainability (DfS)** (6 ECTS) is organized. This course is divided in a theory part (2 ECTS) and a design project (4 ECTS). The theory part is a continuation of the theory in the international module and is going more into depth. It also includes more business related issues like organization, communication, leadership, strategic product portfolio, scenario building. In the design project students have to design a product-life-cycle. They work around a central theme (e.g. C2C, Base of the Pyramid), in close cooperation with an external client. The client can be an industrial partner but also a NGO or non-profit organization. In this design project students translate the theory and generic insights in a specific case. Students learn in this project that

sustainability is often a cultural problem where solutions are context dependent. Both parts are coordinated by the same IDE faculty members. This gives a good interaction between the theory and the design project. The theory is traditionally given in several lectures, with room for group discussions and exercises. The grading of this course is based on a written exam. Students work together in small groups for the design project. 70% of the grade is based on the weekly consults and the process during the semester. The other 30% is given on the final result at the end of the project by the coordinators and the external client.

4.3. Strengths of the current set-up

- The IP is an inspiring environment where sustainable product innovation is happening in a real business context with a multidisciplinary international team.
- Attempts are made to educate all students as T-shaped engineers [8,9], combining domain-specific and general domain-independent knowledge and skills, which is a key factor for sustainability.
- The course "Design for Sustainability" is a must-pass in the curriculum. Students cannot start the master thesis without succeeding in this course
- Courses are not set up as a knowledge transfer, but as a combination of information, innovation, inspiration, involvement and intention.
- Close collaboration between students and companies in design projects stimulates awareness on sustainable product innovation in business.

4.4. Weaknesses of the current set-up

- There is a strong focus on Planet and Profit. Social issues receive far less attention;
- Most supervisors of the design projects are not environmental specialists and have no (professional) background in sustainability issues;
- Sustainability is currently not a separate topic in the evaluation criteria of design projects;
- In general engineering courses, the point of view of the professor is modifying whether there will be a link to sustainability or not. Sustainability is not explicit translated in the learning goals.
- Sustainability is not mentioned as a separate topic in the mission statement of HOWEST. There is no medium or long term action plan.

5. Norwegian University of Science and Technology

5.1. Organization and program

NTNU's Department of Product Design, which is part of the Faculty of Engineering Science and Technology, offers both a 2-year and a 5-year master program in Product Design Engineering. In recent years between 100 and 150 students each year have this program as their first choice in the Norwegian higher education application system, out of which ca. 25-30 students are selected to start in the first year. In their 4th year these are joined by ca. 5-10 students that follow the 2 year master program. Within the Faculty of Engineering Science and Technology, which is NTNU's largest with more than 600-800 new students yearly, the Department of Design has the highest high school grade-point-average requirements to get in; the study program is very popular.

The Department of Product Design is a relatively small institute with less than 10 full time staff members. One full time and one part time staff member have design for sustainability as their main expertise. In addition, 2-3 PhD students and Postdocs research design for sustainability related topics and may act as supervisor or guest lecturer. The sustainability education activities have a connection with NTNU's Industrial Ecology Program, which is one of the oldest and largest of it kind globally. In this program, professors from a wide range of backgrounds jointly offer an international master program. The existence of this program significantly contributed in the fact that NTNU ended first in the most recent survey on engineering education for sustainable development in European higher education [10]. Every year, the Sustainable Product Design course at NTNU hosts several students from the Industrial Ecology International Master Program. In addition, exchange students from all over NTNU take the course as an elective, doubling the number of participants, resulting in a 50/50 division of students with and without a design background.

5.2. Sustainability in bachelor level courses

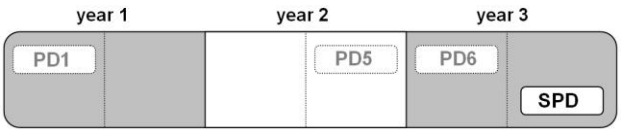

Figure 3. The Industrial Design Engineering bachelor program at NTNU.

Within the study program, sustainable product design education is concentrated in the 6th semester of the 5 year Masters program. Apart from a brief introduction in the first semester, the 7.5 ECTS Sustainable Product Design course taught in this semester is the first course where sustainability issues are the explicit focus of the course. Partly due to student and industry interest, sustainability is increasingly also an explicit topic in the next three semesters (4th and 5th year), where courses largely consist

of group and individual project work, with a considerable amount of freedom to choose in which area of product design to specialise. In recent years an estimated total of 15-20% of the individual and group assignment topics have a specific sustainability interest. Increasingly also other bachelor courses adopt sustainability elements, but rather as a theme for application than with a theoretical focus; examples are the disassembly of a car in the 3rd year PD5 Mechatronics course, environmentally friendly packaging in the PD1 Introduction course, and water-saving shower and waste management systems in the PD4 Form and Function course. However, the themes for these PD courses change from year to year, and therefore may or may not include a sustainability theme.

Over the past years, the sustainable product design course has been coordinated by several teachers, using several approaches and assignment variations, including product analysis and essays. In its current set up, the backbone of the course consists of a series of plenary lectures that can roughly be divided in 6 main topics:

- Historical developments and relevance of sustainable product design
- Environmental Product Analysis
- Environmental Product Improvement
- Implementation of Life Cycle Thinking in industry
- Green Marketing and Communication
- Design for Sustainable Behavior

Additionally, lectures (including guest lectures) may address topics like sustainable energy technologies, product service systems and sustainable design and architecture. The entire course has a distinct focus on developing, and reflecting on, the students' own attitude and engagement towards sustainability issues in their future academic or industrial profession. Group discussions play an important role in that.

Course assignments consist of two main elements: a comparative product analysis, and the subsequent development of an eco board game. For the product analysis assignment, students receive a budget of up to 100 Euro which is to be spent on buying products with similar functionality. These products need to be analyzed and compared on basis of a range of characteristics, including physical functionality, cost of ownership, aesthetics, user-friendliness, durability, and environmental impact. This way, students gain experience in identifying a variety of design dilemmas, many of which include environmental considerations. Examples of dilemmas are to find out if ultra-cheap consumer electronics are less durable than premium brands, if large flashy toys appeal more to children, and if high power consumption vacuums carpets or high-pressure washes cars better. These insights on various dilemmas create input for the development of eco board games, where students, based on a self-chosen theme and target audience, are challenged to educate this audience on sustainability themes [11]. The open-endness of this assignment has resulted in a broad range of games and game intents, with two main variations: board games that build on design dilemmas and strategies, and card-like games that build on creating awareness, using trivia and interpretation questions.

In the individual third assignment students write a letter to a company, reflecting on its (communication of) design for sustainability efforts, such as performance measurement, integration of life cycle thinking, and green marketing and communication strategies.

5.3. Strengths of the current set-up

- Sustainability is discussed in relation to all aspects of product design and development, focusing on interactions and dilemmas;
- The course material is not intended to be moralistic but used to develop students' own engagement toward sustainability issues;
- Through the presence of a large number of exchange students in the course, students interact with colleagues from a variety of backgrounds;
- The course assignments provide an inspiring context for creative application of knowledge gathered through lectures, but also invite to self study;
- The course interests a significant number of students to take up sustainability focused individual courses in the last two study years, with or without industry participation.

5.4. Weaknesses of the current set-up

- Integration of life cycle thinking is not yet a standard element of all courses in the study program;
- There is only little focus on using sustainable design methodology in the actual development and design of artefacts; students gain little to no expertise in applying material and construction knowledge in actual product design;
- Application of obtained knowledge and insights becomes possible only in the 4th and 5th year, which mostly consists of individual projects meaning that students can choose to ignore the acquired knowledge and insights.
- Open-ended course assignments provide considerable initial frustrations with the students as they find it hard to image what their end result will be. This is not necessarily a bad thing (even a good learning experience) but it requires intensive individual and group tutoring, which is sometimes difficult to organize given the limited (specialized) staff available;

6. Conclusions and Insights

This paper has described and analyzed the integration of sustainability into the academic IDE bachelor programs in DUT, HOWEST and NTNU. This exercise has, implicitly or explicitly, lead to the formulation of a number of insights that may be important to consider in other sustainability integration processes:

Evaluation

- When integrated in other courses, ensure that sustainability skills and knowledge are tested explicitly;
- Integrate sustainability as a standard evaluation criterion for bachelor thesis projects;

Coaching

- Try to ensure expert faculty members are in the course. Otherwise train coaches and graders extensively,

Course development

- Try to retain a specific sustainability course, if only as an elective, that allows to present 'the big picture'. This can be either at the start or end of an integrated program.

Teaching Method

- Sustainability is often more about how you think than what you know. Try to give the students something more than just a transfer of knowledge. Stimulate them to develop a critical mind, inspire them.
- Link theory to design projects. Let students apply generic insights in specific cases. Theory without practice has less value.
- Try to work with real life business cases. Sustainable innovation under client constraints is far more interesting. Trans-disciplinary projects in collaboration with research and industry gives the best results.
- For most people it's easier to believe in quality than in sustainability. Quality is often a good starting point for integrating sustainability.

Further discussion is needed as to what aspects of design for sustainability are elementary and essential, and which one can be regarded as optional and specialist. For example, do all industrial design students need to know about photovoltaic or fuel cell technology in more than just the most basic terms?

On a final note: the increasing multidisciplinary of design for sustainability (including social science aspects, alternative energy technologies, corporate social responsibility principles, etc. [12] makes that dedicated sustainability courses easily become cramped with a lot of introductions without going into depth on any of them. Integration of sustainability themes in other courses can be good solution for that, as pointed out in this paper.

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