Sustainability in engineering education from a programme perspective

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INTRODUCTION

During the last 20 years, the amount of research on higher education and sustainability has increased in the literature, with many published books, journal issues and conference papers addressing this topic. Several countries have formulated learning outcomes for sustainability in engineering education [1][2][3]. This means that sustainability is an element in the accreditation process in many countries, and one would expect that Australian, Swedish and American universities

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would have developed strategies for implementing sustainability in different disciplines accordingly.

1 BACKGROUND

The sustainability literature that follows contains various perspectives; the most dominant cluster of articles focuses on “best practice” within higher education [4][5][6][7][8][9]. The examples come from universities all over the world, but particularly from Australia, Europe and the US, and cover several subject areas. Sharing experiences from practice is an extremely important approach for fostering inspiration and ideas for changing the curriculum. However, it does not necessarily contribute to a more general understanding of what to change and how to change it. Most of these examples concern stand-alone courses, which is basically what Sterling [10] calls an add-on strategy.

There has been an ongoing conversation about combining the learning of sustainability in education with social learning, thus addressing the need for more complex and interdisciplinary knowledge and education [11][12]. The approach adopted here combines learning theories with social learning theories and represents an alternative to the overwhelming amount of “best practice” examples; however, this approach may not be very specific for defining concrete strategies for implementation. Likewise, there are contributions on system thinking from an STS perspective to stress the need for developing an interdisciplinary understanding of sustainability and the context within which it will work [13].

A recent study on the presence of sustainability in the formal curriculum was conducted at an engineering faculty, which had explicitly formulated aims for sustainability; however, the results indicated that a very low percentage of the formal engineering curricula had adapted explicit learning outcomes in this area. More precisely, 57% of the educational programs did not mention a single element relevant to the overall concept of sustainability [14]. However, this does not necessarily indicate that 57% of the studies did not provide students with an opportunity to acquire knowledge, skills and competences about sustainability, as classroom practice and students’ learning might differ from the official curriculum descriptions.

Some learning outcomes for sustainability were defined as affective learning outcomes (attitudes, values and behaviours), but the lack of focus on students’ needs and the restrictions experienced by academic staff in their educational programs made these learning outcomes absent in most of practice. Consequently, these learning outcomes were reduced to a hidden curriculum or left to students’ individual learning [15].

There have been a few studies that have indicated that students’ learning and approach to sustainability are important factors in a curriculum change. Nicolaou and Conlon [16] emphasised that engineering students do not understand the complexity of sustainability and instead focus on environmental issues. Other studies have analysed students’ learning outcomes and showed great knowledge gaps among final year engineering students regarding environmental tools, legislation, policies, technologies and sustainable development. They also suggested that students’ understanding of the complexity of sustainable development was poor, and that this understanding was not aligned with what academic staff had intended their students to learn [16][17][18]. This study indicates that students’ interest in all sustainability concepts might be low; therefore, it would be interesting to study their interest from initial enrolment in engineering education to graduation.

1.1 Research Question

In this article, we present results from a Danish research program (PROCEED) funded by the Danish National Research Council. The PROCEED project has conducted a longitudinal study of engineering students' approach to sustainability and professional identity. The first survey was deployed to all engineering students enrolled in 2010, a second survey was given in May 2011 to the same group of students and later surveys will follow. Here, we present results on students' interest in sustainability, where their interest is represented through a series of sustainability items. Previous studies led us to expect an equally low interest in the environmental, social and economic aspects of sustainability [19][20]. Based on the literature review and our assumptions, we were interested in studying the students' interest in sustainability at enrolment and whether there were differences between various engineering programmes.

2 METHODOLOGY

The analyses in this paper were based on a questionnaire conducted on Danish engineering students in the autumn of 2010 just after their enrolment. The questionnaire was web-administered using SurveyXact and reached all Danish engineering students in eight engineering education institutions offering a total of 104 different engineering programmes. The response rate was 46% (1,675 respondents out of 3,630 enrolled students. The respondents were representative of all Danish Engineering students in terms of age and gender [21].

Table 1. Sustainability index construction and reliability test overview.

Survey Question	Response categories	Item clusters based on factor analysis	Constructed index	Cronbach's alpha N
Question 10 Please rate your interest in the fields listed below?	*Question 10*: Very interested; Somewhat interested; Not interested;	• Working environment • Ethics • Human rights • Engineering projects in developing countries	Factor 1 Social aspects of sustainability	0.58 N=1,419
		• Modelling • Technology transfer • The interplay between different technological systems	Factor 2 Systemic aspects of sustainability	0.68 N=1,347
		• Theory of science • Biofuel • Climate change • Air pollution	Factor 3 Environmental aspects of sustainability	0.72 N=1,477
		• Global division of labour • Innovation • Intercultural communication Entrepreneurship • Growth strategies	Factor 4 Economic aspects of sustainability	0.63 N=1,341

In this paper, we concentrate primarily on question 10: interest in a series of sustainability items. Based on a literature study, we identified 18 individual questionnaire items for assessing students' interest and knowledge within contextual engineering knowledge of sustainability. These items were a mix of sustainability indicators, contextual engineering items and existing curriculum elements like theory of science.
We conducted a factor analysis of the 18 items to identify the correlation between the different items, which resulted in five clusters. As the fifth cluster was without meaning, the items that it contained, i.e. "engineering projects for developing countries," "research communication" and "global division of labour," were included in factor 4 since they also appeared there. We decided to delete "research communication" as it was weak and forced the item "engineering projects in developing countries" into four clusters. The factor analysis therefore identified four clusters that we characterised as:

1. Factor 1: Social aspects of sustainability,
2. Factor 2: Systemic aspects of sustainability,
3. Factor 3: Environmental aspects of sustainability,
4. Factor 4: Economic aspects of sustainability.

For each of the four factors, Cronbach's alpha test was run. Table 1 presents the results from the factor analysis and the Cronbach's alpha tests on question 10. Furthermore, the entire cohort of engineering students 2010 is enrolled in 104 different engineering programs at five different engineering institutions in Denmark. The 104 engineering programmes were organised into 14 main categories that were pre-defined based on content [21].

3 FINDINGS

3.1 The constructed indices

The factor analysis resulted in four constructed indices for student interest. These four indices add to the understanding of sustainability as the analysis revealed four clustered aspects of sustainability. Compared to Brundtland's report [22], our data analysis indicated a fourth cluster, which we have called the systemic aspects of sustainability. The systemic aspect represents three dimensions: abstraction by modelling and theory of science, north-south dimension by technology transfer and design dimension by how different technology systems play together. As such, these are all important aspects of sustainable development, but in the curriculum they are not necessarily taught within a sustainable content context. The question was asked in the survey such that students could answer this item without having sustainability in mind. The items in this construct can be interpreted partly as engineering methods such as modeling, but the construct has an inner cognitive logic, as addressing technology systems would automatically involve a more abstract modelling approach. The explicit social contextual aspects of engineering are in factor 1 on the social aspects of sustainability, and in factor 4 on the economic aspects, while the environmental aspects are in factor 3.

3.2 Students' interest in sustainability

The results indicate that engineering students at the time of university enrolment have different interests in the four dimensions (Figure 1). The social dimension scored the lowest, followed by the environmental dimension. On the other hand, the systemic and economic dimensions of sustainability scored the highest. These results are surprising as we expected a more equal distribution of interest among the various items, and as the participants were all engineering students, maybe even a greater interest for environmental items than for other aspects of sustainability. Therefore, we wanted to see if there were any differences among students' interest at a programme level.

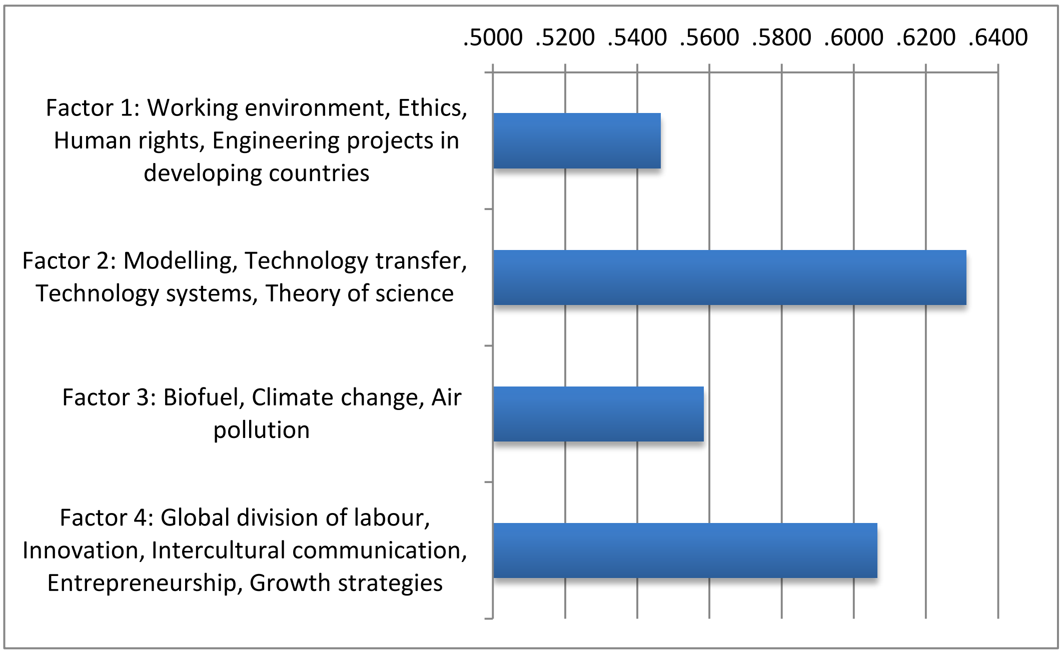

Figure 1. Students' interest in four sustainability indices.

3.3 Students' interest in sustainability at a programme level

As engineering is a wide concept that covers subjects ranging from abstract design education to electronics and mechanics, we wanted to see how the students within various engineering programmes would respond to the questionnaire. Figure 2 presents data of the four indices per program cluster. The results indicate that there are huge differences in the interest of engineering students by programme of enrolment in Danish engineering institutions.

A comparison of the engineering students' highest levels of interest at the programme level within the indexes showed that:

- Engineering students from environmental engineering, health and medical technology, planning and design were most interested in the social aspects of sustainability.
- Engineering students from mechanical, electrical, energy, computer and software and hybrid programmes were interested in the systemic aspects.
- Engineering students from biotechnology, chemical, environmental and energy were interested in the environmental aspects.
- Engineering students from design and in particular from business and innovation were interested in the economic aspects of sustainability.

- Students from building and civil engineering and industrial production did not seem to express a priority among the four indices.

These results indicate that the interest and motivation for learning about sustainable subjects come from very different angles.

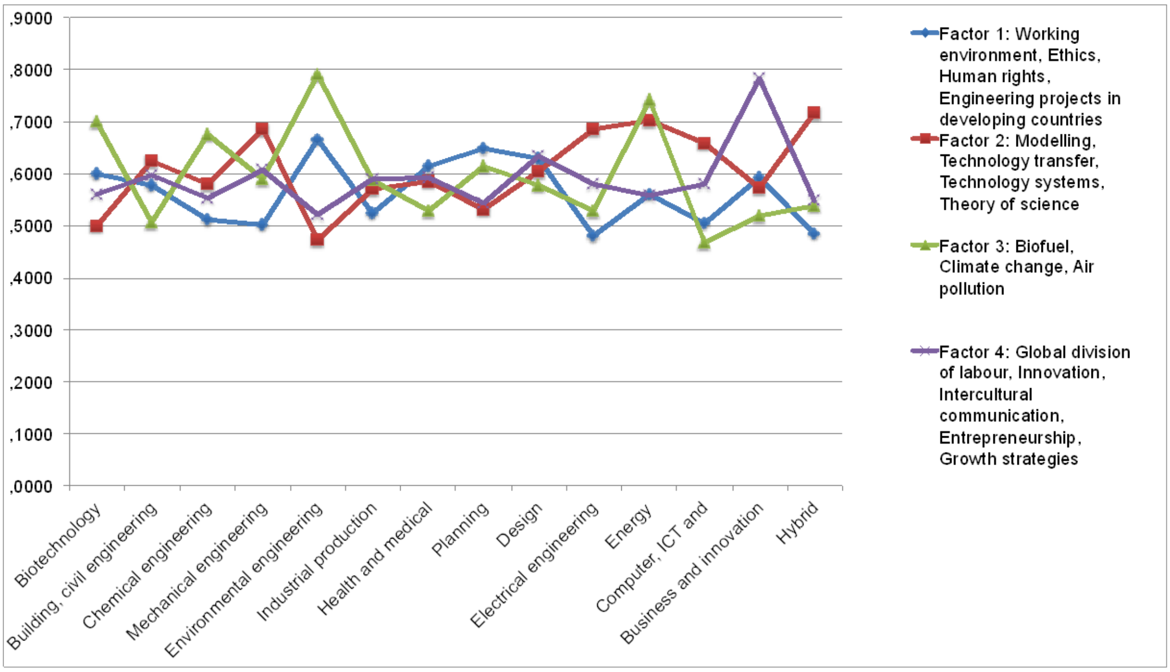

Figure 2. Students' interest in four sustainability indices and engineering programs.

There are notable results from the data of student interest by programme. Students in biotechnology, chemical engineering and environmental engineering gave a high score to environmental aspects of sustainability, but a low score to systemic aspects. This is in contrast to students in energy, who gave a high score to both systemic and environmental aspects.

4 DISCUSSION

The PROCEED study collected a lot of data on students' learning and attitudes of factors relevant to engineering education. In this article, we only concentrated on their interest in a series of sustainability items.

The study found that newly enrolled students were generally most interested in systemic and economic aspects of sustainability, followed by environmental and social aspects. This result was surprising, as we expected to a higher score on environmental aspects compared to the others. Furthermore, we found explicit differences on a programme level, which reinforce the importance of analysing engineering students' approach to contextual knowledge and/or sustainability by programme since their interests may greatly differ from one another based on their academic subjects.

The results at this stage raise interesting issues for the developing the engineering education curriculum, especially questions on how to integrate sustainability into it. The use of different strategies appears to be necessary, depending on whether biotechnology, chemistry or environmental engineering is being addressed or whether the more traditional engineering programmes such as mechanical, electrical computer science or hybrid programmes (Nano) are at issue. The former group demonstrated a high level of interest in environmental aspects, whereas the latter was more attracted to the systemic dimension. The curriculum would interest the students in the first group if it started out with environmental issues and then linked to other aspects, whereas students in the latter group would find a discussion of the systemic aspects to be more accessible.

These findings provide information to educators so that they could take their students' perceptions into consideration when developing a curriculum. Moreover, the results encourage a more visible integration of all aspects of sustainability, but also enough flexibility to customise the content to students by discipline. In particular, it would be important to develop the systemic aspect, which is of great interest to students and would be a point of access to a broader contextual understanding of sustainability in engineering education.

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