From environmental concerns to sustainability

– Learning sustainability in a Robotics engineering education

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1 INTRODUCTION

At Aalborg University the learning method in the engineering educations is PBL. In the first semester the students have a 10+5 ECTS semester projects supported by three 5ECTS courses. They work in project groups with 6-7 members. These groups are used both for semester projects but also for exercises related to courses, see figure 1.

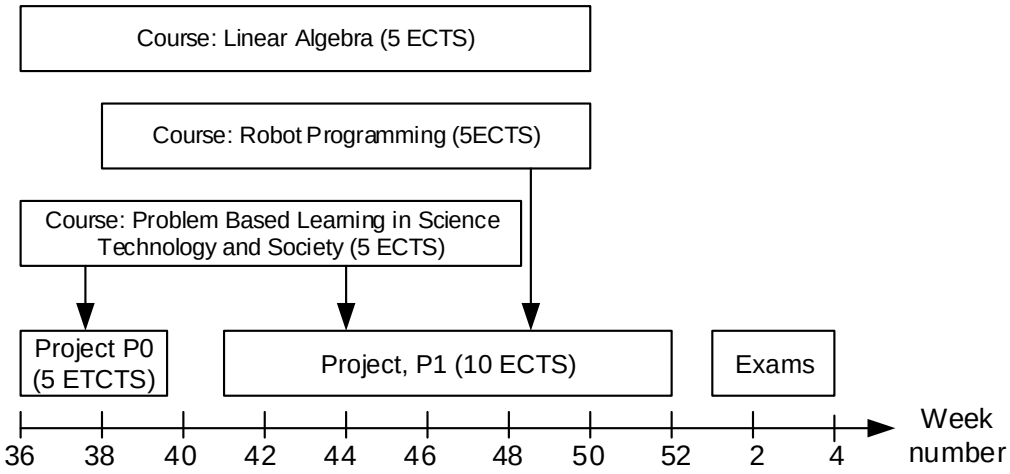

Fig. 1. Structure of first semester Robotics [1].

In the PV-course in fall 2015 it was decided to teach sustainability with a more active learning approach by introducing the concept in a workshop and facilitating that the students apply sustainability concepts in their semester projects. The workshop is a part of a course in Problem Based Learning in Science Technology and Society (PV) that support the students' project-work and collaborative learning.

1.1 Learning sustainability in a PBL environment

Deep learning is dependent on a student's level of engagement with the topic [2]. Deep learning is motivated with an intention to understand, and not just pas an assessment task [3]. Thus it is essential to provide a learning environment where students develop a personal interest in sustainability. This can be done by making sustainability relevant for the individual student and have varied learning styles.

Active learning approaches such as problem based learning increase students learning outcomes regarding sustainability in engineering education [4]. It is however essential for learning sustainability that it is interest-led and interest can be stimulated by placing emphasis on contextual interpretation more than curriculum content [5].

Integration of non-technical issues such as sustainability into engineering curricula is facilitated by a problem-oriented rather than a subject-oriented approach. In the problem analysis it is an important element to understand the sustainability implications of the technologies and this gets less focus in a technical subject-oriented approach, where the focus is on efficient technological solutions. In other words problem orientation address both problem identification and innovative problem solving that allows for sustainability issues to be addressed [6]. By including sustainability in the problem analysis, it is included in the product requirements but also included in the technology assessment of the developed solutions.

Sustainable development education draws upon many disciplines and is grounded in interdisciplinary research and processes [7]. It focus on the interaction between social and ecological systems and this requires an understanding of its interdisciplinary. Problem-based learning helps the students to develop this understanding when they apply their knowledge in different ways [7]. Students not only need technical knowledge to generate effective engineering solutions; they need to understand the sustainability impact of their decisions and final solutions [8].

The Robotics students at Aalborg University develop a mobile robotic solution in their semester project, based on a predefined technological platform. They are free to choose the kind of problem they want to analyze and develop a solution for, and they develop a product specification based on their problem analysis. This means that the students have the freedom to analyze a broad range of functional parameters and efficiency measures they want to address in the projects, and sustainability can be one of these.

The aim of this article is to analyze how engineering students understanding of sustainability changes when they are taught sustainability as a part of an active learning environment, and how they apply this knowledge in relation to their semester projects.

2 METHOD

There are 69 international first semester students in the Robotics program that is the case selected for this study. The students comes from all over Europe, but there is a majority of students from Denmark and Eastern Europe.

In fall 2016 a new approach to teaching sustainability is introduced, namely a half-day sustainability workshop as a part of a course. This workshop is followed up by discussions on sustainability a month later in the project groups in order to facilitate engagement by the students within the topic.

2.1 Action research

The authors teach the students, and this introduce an action oriented research approach. Through this approach it is possible to compare the results from this year's learning outcome with previous experiences where sustainability were addressed in traditional classroom lectures, and not integrated in the semester projects.

Another advantage of the action oriented approach is that the authors are able to follow the discussions in the project groups throughout the semester, and also have access to the semester reports that the student groups write.

There are three main elements in the student-teacher interaction regarding sustainability

- Workshop on sustainability
- Feed-back and discussions of assignments related to semester project
- Participation in status seminar

2.2 Written material

Four types of written output from the students addressing sustainability is analysed, namely:

- Their initial individual reflections on sustainability, written as the first part of the workshop on sustainability.
- The results of group exercises during and after the workshop
- The semester project reports
- The individual reflections on sustainability in the exam of the course

This approach provides us with three data set that represent different levels of reflections by the students. Having the initial individual reflections makes it possible to assessing how the students perceive sustainability and how this changes. The results of the group exercises shows how the discussions changes the perceptions of the students. The semester projects gives insight into application and deeper learning of sustainability in their semester projects and finally the individual reflections in the exam shows us how each student understand and apply sustainability.

3 LEARNING SUSTAINABILITY – RESULTS

The semester projects is a PBL project with the theme "Reality and Models" where the robotics students program robots that move around humans. The students analyze the "context" of the robots and use this to set technical product requirements for how the robot moves around humans.

3.1 Initial individual reflections of sustainability

A half day workshop is the first of a number of encounters with sustainability in the 2nd semester of Robotics. After the workshop the students work with understanding sustainability in the content of their semester projects and reflect on this in their final exams.

In the beginning of the workshop the students individually answered three questions (See the left side row in *Table 1*). The idea is to map the initial awareness of sustainability issues among the students in order to understand if this developed through the workshop and the semester in general.

Table 1: Initial questions and categories of answers (50 answers). The percentages reveals the content of the answers that the students provide (assessed by the authors)

	Includes environmental perspectives	Includes social perspectives	Includes economic perspectives
What is sustainability.	96 %	8%	12%
How is sustainability relevant for a robotic engineer.	80%	4%	16%
How is sustainability relevant for your semester projects.	60%	0%	12%

The answers received on these assignments revealed that the predominant imperative for the students understanding of sustainability is the environmental, and especially climate impact and energy consumptions were predominant. Most of those that addresses economic sustainability related to the importance of having a product that is economically competitive on the market.

As to how sustainability is of relevance for a robotic engineer energy usage, material usage and lifetime of the technology were the dominant answers, supplemented with a few students answering that robots can offer solutions to environmental problems. The few that addressed social perspectives relates to health and safety when working close to robots. The economic perspectives included relates to pay-back time of a robotics solution implemented in an industrial setting.

For the final question, namely how sustainability is of relevance to semester projects the environmental focus mainly relates to resource consumption (including energy) and the few that address economic perspectives relates to the costs of the technology.

3.2 Group exercises during and after the workshop

In the workshop three imperatives of sustainable development are presented, the ecological, the social, and the economic and they are applied as a framework for study of concrete applications. The presentation of these imperatives takes around 10 minutes and links the sustainability concepts to robotics solutions.

The next student assignments is to link sustainability to the semester projects (in their semester groups) and afterwards in mixed groups discuss how sustainability is relevant for robotics in general, see *Table 2*.

These discussions are intended to facilitate perspectives of sustainability that are found of interests to the students in stead of reading or hearing about the theme. This is also facilitated by letting the students discuss with students that have a different perception than their own, by mixing nationalities.
Table 2: Discussion topics and categories of answers from group assignments (10 group answers)

	Includes environmental perspectives	Includes social perspectives	Includes economic perspectives
How is sustainability relevant for your semester project	90 %	80%	60%
How is sustainability relevant for robotics.	90%	90%	70%

In the written results of the two assignments, it is clear that they to a larger degree have included social and economic considerations as well. The environmental perspectives have become more specific than in the first assignment, and now includes elements like stand-by consumption, power supply, non-renewable materials, end of life discussions and extended lifetime.

As a part of the social imperative, the students include man-machine interaction, health- and safety, robots replacing humans and ethics related to robots in operation.

The economic imperative is mainly addressed by the students by including reduces production costs due to effective robotics solutions, life time costs of the technology including reduced costs for salaries for the humans the robot replaces and finally production costs of the robots.

The students were then asked to prioritize the sustainability-issues that they had identified. This was difficult for the students as they value the three imperatives differently and most groups never agreed on how to prioritize them. Their own explanation is, that they can agree upon what sustainability is, but their priority seem dependent on their nationality and the sustainability issues they value individually.

According to the students these discussions among different nationalities have helped the students to understand the context of the technical problems that they work with, as one of the groups wrote in the assignment:

"*We have realized that a good solution to a robotics problem is not just a matter of a technical efficient solutions, it has to include the surroundings where it has to operate as well*"

These types of reflections have made the students more aware of the importance of sustainability, and even though they do not have methods to "calculate"

sustainability, they include it as an important theme for their solutions to the problems in their semester projects.

After this workshop the students worked with sustainability as one of the themes in the semester projects. Below two examples of how sustainability is included in the semester projects are given.

Example 1: Social robots
A semester groups developed a solution for a social robot that assist people with frontal lope damages. This group focused on social sustainability in their problem analysis and interviewed caretakers, observed people with frontal lope damages and discussed human-robot interactions.

Example 2: Little Fetcher Robot
A semester group developed a solution for a little fetcher robot that fetch parts to be assembled and transport finished assembled goods to the next operation in a production environment. They addressed energy consumption of the robot, the potential savings in salaries and health and safety implications of working with the robot. The group also addresses the technological development in industrial production in Denmark where production costs are reduced by implementing robotic solutions that makes the industries more competitive on a global market by decoupling expenditures from labor costs.

The semester projects had more focus on sustainability than previous years, and this might be facilitated by the increased focus on active learning regarding sustainability.

3.3 Individual reflections from exam question

The final course exam included an assignment where the individual student explains how sustainability is relevant to his/her P1 project, this exam is situated after the students have handed in their semester projects, see figure 1.

The answers revealed that most students are able to reflect upon how sustainability are of relevance for their semester projects and they understand all three imperatives of sustainability (less than 15% of the students only addressed one or two of the imperatives).

It seem that the active learning environment where the students have worked with sustainability in a problem oriented projects have facilitated the learning regarding sustainability.

The answers to the exam revealed that the international environment with students from all over Europe influence the perceptions of sustainability. One example is that the Danish students mainly address occupational health and safety among workers that interact with robots, whereas some other nationalities focus on social acceptance of robots as a part of the production in companies. Based on the available data it is not possible to analyze what other parameters than nationalities, such as the collaboration in the group, that influenced their perceptions.

4 DISCUSSION

In the beginning of the semester the students, that all have a technical background, express frustrations of not being able to “calculate” sustainability impacts in their projects. They therefore tend to focus on energy consumption, health and safety

statistics and similar quantitative measures. Sustainability is grounded in interdisciplinary research and processes [7], and it is a complex issue for the students to grasp the interaction between social, ecological and technical systems.

It is however interesting that as the semester progress and the students become more familiar with sustainability and its implication their focus changes and especially the social impacts of the solutions are integrated in the projects. In the technology assessments in the end of the semester projects, both social, environmental and economic discussions are included. This is similar to the findings of Warbourton [5] , namely that the active learning environment where students reflect upon and implement sustainability into their semester projects in a PBL environment facilitates a deeper learning of sustainability.

Previous studies have shown that the international students at the Robotics education find it hard to understand why they have to work in projects based on problems and not just develop technical solutions [1]. The discussions on sustainability have helped the students to understand the importance of analyzing the problems that they are trying to solve. What they experience is that the analysis of the problem are essential for removing the focus on their own perception of a “good solution” to the perception of the users and the societal implication of implementing the technology.

The themes that students feel ill equipped to apply in their work are generally perceived as less important than those they feel equipped to apply [9]. Problem analysis are one of the themes that the students feels ill equipped to handle in the beginning of their 1st semester. It seems from this analysis that addressing sustainability in a workshop, and letting the groups work actively with sustainability have increased their focus on the topic (compared to previous with traditional lectures) and this might be an indication of a deep learning, where the students feel equipped to address sustainability in their project work.

The deep learning regarding sustainability is of a holistic (global) style where pictures of the whole task is created (comprehension learning) and not a serialist (step by step) learning style focusing on details and processes. The next question is then how to provide students with the tools to critically evaluate their solutions based on e.g. limits to resource availability and environmental impact, valuation of environmental asset and social equity.

5 CONCLUSION

The engineering students expand their understanding of sustainability through the first semester. They go from a more traditional focus on the environmental imperative addressing issues that can be calculated and measured to more nuanced discussions of the social implication of technologies and economic considerations in relation to implementing technologies. This development have not been seen previous years where the students were taught in a more traditional way with lectures and assignments. The students understanding of sustainability changes when they are taught sustainability as a part of an active learning environment, where they apply the knowledge in relation to their semester projects.

The students’ nationality are reflected in their understanding of sustainability, and this shows that they reflect on sustainability in their own national context not just the context of the semester projects. Through the workshop in sustainability and the

following group discussions that relate sustainability to semester projects the engineering students widen their understanding of sustainability due to these national differences. These discussion does however not make them agree on what is important within e.g. the social imperative of sustainability, but make them aware that there are differences among the nationalities. As a part of this they broaden their understanding of technological “context” as they understand the importance of where the technologies are applied. To understand sustainability it is encouraged that the students mix nationalities in the groups.

In the final course exam the students reveal a far more nuanced view on sustainability that have previously been the case, and this might be due to the focus on contextual interpretation and deep learning more than a curriculum taught in traditional lectures and examined in individual assignments, where the focus can be on passing the assessment task more than learning sustainability. For future research, it will be interesting to include information of e.g. gender and work life experience in the analysis of how students perceive sustainability, and how they apply sustainability in their semester projects.

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