Abstract

In the past decades, education for sustainable development (ESD) has obtained increasing recognition as a general subject in higher education (HE). Institutions worldwide have had attention to the integration of sustainability into the curricula, and on the conceptual level problem based learning (PBL) has been put forward as a promising pedagogical model and emerged as an opportunity to implement sustainability successfully. Due to the almost forty years of experience in PBL, a case study was carried out at Aalborg University, Denmark to excerpt their experience of integrating sustainability in a problem based learning environment. Three electronics engineering project modules were selected as example and empirically supported by constructed interviews with staff and document analysis of selected material. The findings were analysed with a systems approach and presented with reference to three difference factors: input, throughput and output factors; whereas reflections on the study is presented in the final part. It is found that the PBL practices in the modules comprehend the integration of sustainability in engineering education without compensating technical and engineering competencies as the core contents.

Keywords: Sustainability in Engineering Education; Education for Sustainable Development; Problem based learning;

1. Introduction

In Denmark, problem based learning was founded in the early 1970s by institutionalizing the problem and project pedagogies in two universities, Roskilde University Centre in 1972 and Aalborg University in 1974 (de Graaff and Kolmos, 2007). Learning by doing and experimental learning were two of the central principles (de Graaff and Kolmos, 2007), and the students were to work in collaboration with teachers and others to explore and solve a problem in close relation to the social reality in which it exists (Berthelsen et al., 1977). Thereby, the societal context was a key consideration from the very beginning, drawing from (Mills, 1959) among others and his visions of social imagination.

As such the path to integrate sustainability was established, but it was not before the Brundtland Commission, chaired by Gro Harlem Brundtland, published their famous report “Our common future” (Brundtland Commission, 1987) in the late 1980s that a sustainability discourse was developing at the Aalborg campus. In the 1990s sustainability started to show explicitly in curricula. One of the more comprehensive initiatives were taken by the former study director Mona Dahms, being responsible for a gathered first year of all educational programs at the Faculty of Engineering and Science. In this first year, students were working in inter-disciplinary groups on projects for sustainability. This example still stands as the most throughout integration of sustainability at AAU. Today sustainability is integrated as a patchwork of practices across faculty, whereas management is now determined to gather and develop these practices in order to secure ESD in all programmes.

In this paper, we present a piece of this patchwork of practices at the Faculty of Engineering and Science Aalborg University, to exemplify the integration of sustainability in a problem based learning environment. The case study example is related to engineering education and more specifically electronics. In the following we elaborate on the case, the methodology and the results, whereas we in the concluding part point to reflection that can be of general interests for institutions working with ESD in a PBL environment.

2. Case description – three project modules in electronics and IT

In this paper, three project modules are presented as an example of progression of ESD practices in the Study programme of Electronics and IT. The three project modules emerged as the outcomes from program inventory, which the inventory was designed to identify a module that integrates sustainability. In the inventory process, each of the modules were thoroughly examined on the learning contents such as module objectives and expected learning outcomes i.e. knowledge, skills, and competencies. The project modules are offered for first year student in the first semester and second semester and structured as Problem and Project based Learning activities. Typically, the phases of a project module are that the students, within the frame of a pre-defined project unit theme, formulate an initiating problem (sometimes based on a catalogue of project proposals), then they move to problem analysis and based on that they formulate a narrower problem within pre-defined disciplinary boundaries.

* Tel.: +45-5265 9679 (Denmark)
E-mail address: mahyudin@plan.aau.dk (Denmark), mahyuddin@utm.my (Malaysia)
Taking the point of departure in this problem formulation and a methodological framework, they solve this problem and assess the proposed solution taking results of the problem analysis into consideration.

In this case the three project modules are as follows:

a. Technological project work (P0 - approx. 5 weeks)
   This module is offered to provide students with an insight in a problem based learning environment and at the same time introduce basic concepts and applications in electronics and IT. The problem presented here is rather narrow within a technical frame of mind.

b. Basic Electronic Systems (P1- approx. 10 weeks)
   This module is structured to provide a platform for enabling students to be socialized into the electronics and IT-related engineering disciplines. Theoretical and practical work is combined, taking point of departure in a problem derived from a community or business context. This problem will be analysed by decomposing the problem in sub-problems in order to select and formulate a technical problem that can be solved by using the theories and methods of microprocessor-based systems. The solution has to be an electronic system, incorporating a programmable computer and being able to react to and/or control parts of its outside environment via selected actuators and sensors.

c. Dynamic Electronic Systems (P2)
   In this course students will be through theoretical as well as practical work, based on a selected problem that will acquire knowledge within the electronic and IT related engineering discipline. However, here the students also have to use relevant methods within the field of Science, Technology and Society (STS), that demonstrate that they can contextualize a technical problem including relevant social contexts. Again, the problem will be analysed through decomposition into sub-problems, but in this case the context of the problem in analysed more in depth, which have implication on the formulation of the technical problem. In any case this technical problem has to be solved using electronic systems interacting with the surrounding environment. The final solution will then be evaluated at the end based on evaluation criteria’s derived from the technical as well as the contextual analysis.

3. Methodology

In their works, Rompelman and de Graaff have presented the possibilities to analyse the existing world and synthesize ‘a new world’ with a systems approach, and they also have explored the concept of system approach in an educational context (Rompelman and de Graaff, 2006). The systems approach in this paper categorizes students in the center of the teaching and learning process. Whereby, the other variables such as course contents are categorized as input factors; abilities, knowledge and skills are considered as output factors; and facilitation and teaching are considered as throughput factors. The reflections on the whole process are then seen as a feedback to re-design the system, see Figure 1.

![Figure 1. A systems approach for analysing engineering curricula](image-url)

In the same paradigm, Creemers and Scheerens have used an input-process-output approach, rather specific termed as a context-input-process-output based approach in educational effectiveness research (Creemers and Scheerens, 1994). The system approach in their study instead seem to put the educations in the centre, as the inputs are considered to be students’ background including personal and financial resources, the context is related to educational contexts of schools and socio-economic context, the process or throughput are considered to be the factors within the school, and the outputs are students’ achievements and educational attainment.

In this paper, we lean towards the system approach introduced by (Rompelman and de Graaff, 2006) as the focus is on the educational practice, all though inspired by (Creemers and Scheerens, 1994) to take into consideration broader institutional input factors. Two main data collection techniques were used for this analysis: document analysis and interview sessions. First of all,
documented evidence such as electronic and electrical engineering curricula, course/module outlines, students’ assignments and students’ project reports was collected. The key words related ESD (i.e. sustainable development, sustainability, environmental perspective, social/culture perspectives, sustainable technology, green technology) were used to identify the manifestation of the integration in the document analysis. Secondly, four interviews were planned and carried out with teachers, coordinators of the modules and ESD experts. The data were collected from September to December 2012. The interview sessions were structured to identify intangible forms of integration yet not documented and beyond what could be read in the available documents.

4. Results - Factors of integration

In the following we will present three salient “factors” to analyse the way sustainability has been integrated in the programmes of Electronics and IT. Together with the Danish qualification framework, the written statements in the curriculum related to the three project modules in focus, constitutes the input factors. As throughput factors we consider formulation of objectives/requirements, facilitation and team activities during the project period, and finally as output factor, we have considered students learning outcomes represented by project reports.

4.1. Input factors

Input factors are considered as the input for the students in the teaching and learning process environment. The input consisting of all kind of variables related to the structure of program i.e. the electronic and electrical engineering curricula and courses/modules outlines and teaching materials. Besides that, the institutional context of the program structure is also considered as an important input factor, here represented by the Danish qualifications framework.

4.1.1. Documented in Danish qualifications framework

The Danish qualifications framework aims to make the degree structure in Denmark for higher education programs nationally and internationally clarified and transparent. The qualifications framework also describes the desired outcomes and competencies in such a way that it can steer curricula planning. The importance of the qualifications framework is underlined by the inclusion of stakeholders representing universities, non-university programs, students, Danish Evaluation Institute, Danish Centre for Assessment of Foreign Qualifications and employers.

In general, the Danish qualification framework was established based on a model that encompasses i) Competency profiles, ii) Competency goals and iii) Formal aspects. The competence profiles are provided to specify the variety of competencies needed and three types of competencies are defined being i) intellectual, ii) professional and academic and iii) practical.

Intellectual competencies point to general process competencies for intellectual development; being neither specified as disciplinary nor program oriented, e.g. communications skills, self-learning, analytical and abstract thinking (The Danish Bologna follow up group’s QF working party, 2003). By this time on the Bachelor level, students have to be able to identify their own learning needs and organise their own learning in different learning environments (Ministry for Science, Technology and Innovation, 2009). This goes well together with PBL and its emphasis on exemplary learning as well as meta-learning.

On the contrary professional and academic competencies are related to a specific discipline or programmes, whereas practical competencies are specifically aimed to the fulfilment of job functions e.g. professional ethics and responsibility (The Danish Bologna follow up group’s QF working party, 2003). Even at the bachelor level, the qualification framework state that engineering students must be able to handle complex and development-oriented situations in study or work contexts, and furthermore that they must be able to independently participate in discipline-specific as well as interdisciplinary collaboration with a professional approach (Ministry for Science, Technology and Innovation, 2009). Taking the increasing complexity of technological systems into considerations as well as the increasing focus on environmental management and corporate social responsibility in business, the qualification framework creates an important platform for integrating sustainability in engineering education.

4.1.2. Sustainability related learning objectives in the written curricula for the three modules

All though the Danish Qualification framework provides a platform for integrating sustainability it is not a premise for accreditation that sustainability is explicitly mentioned in the written curricula. This is however the case for the curricula for electronics in relation to the first year as shown in the analysis of the learning objectives, related to the following three project modules.

In the project module entitled Technological project work (P0), the overall objective enables students to describe and apply typical elements of a problem-based project, manage the learning process and provide reflections on this process. The relation to ESD is that the students should be enabled to describe the problem in a holistic perspective.

In the following project module, Basic Electronic System (P1), the course learning outcomes were constructed to provide students with knowledge, skills and competencies related to both electronic system and ESD. At the end of the course, students is expected to understand the basics of electronic systems, but this also includes interaction with the outside world and identification of relevant contextual perspectives including technological as well as societal aspects. The students is also
expected to identify requirements for technical solutions based on these contextual perspectives, and furthermore show their ability to manage a project include planning, structuring, implementation and evaluation. In addition, it is stressed that the students have to take point of departure in a problem having societal or vocational relevance.

The last project module on the first year, Dynamic Electronic Systems (P2) is offered at the second semester for electronic engineering students. The module is, besides progress in the understanding of electronic systems, specifically designed to integrate knowledge related to the field of Science, Technology and Society (STS) supported by a subject at the first semester. Students have to obtain adequate skills to analyse and solve a technical-scientific problem taking technological, environmental and also social aspects into consideration in the problem analysis as well as in the assessment of the social and environmental consequences of the proposed solution. Specifically user involvement, stakeholder analysis and analysis of environment regulations are mentioned as areas of interest. In the process of solving the problem, students also have to sharpen their abilities to construct comprehensive models to be used in design, implementation and test of an overall system to assure that the requirements and the desired specifications are met.

### 4.1.3. Project proposals

As a third input factor, the facilitators provide students with project proposals designed to the learning objectives in the curricula. It is however possible for students to contribute themselves with a project proposal. Project proposals outline the problem-field and the related possibilities to contextualise and develop technical competence within this field. In most practices, the project proposals are constructed in an open way, so the students themselves are formulating the initiating problem and problem formulation.

This input factor could be the most vital element for the efforts to provide education about sustainability in electronic engineering education, as previously highlighted in the introduction, sustainability could in fact be an overarching theme and the project proposals could be developed to capture different aspects of sustainability in relation to the disciplinary field of work. For instance, there was a P1 project, executed by the second semester of electronics engineering students and the project was designed to deal with pupils with disabilities.

In the electronic and IT programme, the proposal can be entirely funded by industries or companies, or the proposal can be prepared specifically for education purposes. Teachers will normally prepare the proposal and present it among a committee or peers including all teaching staff at the semester. The approved proposal will be collected and offered to the students to choose. The students are thereby occasionally triggered with a proposal in relation to sustainability.

### 4.2. Throughput factors

In the following analysis the throughput factors are analysed in two sections related to i) the student directed team work and ii) the influence by teachers in the facilitation of students’ project work by questioning students, discussions at group/class meetings as well as feedback to students on their writings. These teacher behavioural factors are positively related with student achievement (Brophy and Good, 1986).

#### 4.2.1. Project activities

Throughput factors in terms of project activities have considerable impact on the integration of sustainability in electronic engineering curriculum to maintain the momentum and manifest ESD as a process and not only an input or outputs of engineering projects. The study has identified three possible activities along the process of developing the project or finding a solution that integrates sustainability, that is i) the identification and analysis of problems, ii) product design and test iii) product evaluation.

Early in the process of identifying problems, the students’ start out with an open problem and the further analysis of the problem include an explicit focus on the social as well as environmental aspects of the problem. Some of the problems, either proposed by the teacher or students, demand at least a site visit and discussions with stakeholders. During such processes, students will have opportunities to identify related issues regarding the technical problems as well as the related non-technical social and environmental aspects. They also have to develop instruments for collecting data such as interview guidelines and questions for interview sessions with the stakeholders; and in the design of these instruments an explicit focus on sustainability is evident.

Later in the process of designing the possible solution to the now well-defined problem, a specification of the demands to the products can be made based on the conclusion of the problem analysis. All though students often delimit the project by a narrow problem formulation calling for pure technical developments – the students then are aware of the more contextual factors coming into play in real life product development, where departments of environmental and/or health and safety often are involved. In that way they learn how to be specialist in a team and at the same time have enough inter-disciplinary knowledge from cross-departmental collaboration.

In the same line of reasoning, students are, in the last part of the project, asked to make overall assessment of the products impacts on environment as well as society at large. In this phase more strategic management tools as SWOT analysis (assessing
the strengths, weaknesses, opportunities and threats) or screening tools (e.g. in relation to environmental assessments) often are in play.

4.2.2. Facilitation

One of the cardinal features of PBL is that the students are at the centre of the learning process, and have to take responsibility for their own learning. The teacher is not telling students what to do, but instead guide them along the process of learning with reference to the learning objectives. Unlike the traditional methods of learning, where teachers usually has full control of learning process and contents, teachers in a PBL environment takes the role as facilitator (Kolmos et al., 2008).

The role of facilitator in a PBL environment is to keep students on track in their projects, so they progress in alignment with the intended learning outcomes. Therefor for the facilitator to make sure that sustainability is integrated in the project work, there have to be a clear reference to the curricula. On the other hand, if the learning objectives do not point to the integration of sustainability, this sometimes unintentionally occurs in the process, due to nature of the chosen problem, which is closely related to the field of interest of students. Based on the learning objectives or student’s interest, the facilitator will provide some insight and maybe put some more emphasis on sustainability in the project facilitation.

However, the integration of sustainability challenge the facilitators to have a clear understanding of the subject and as one of the criteria’s for accreditation of HE in Denmark is that the teaching has to be research based, this calls for an inter-disciplinary team of teachers. In this specific case, teachers from the Department of Development and Planning contribute with researchers working in the field of sustainability science and Science, Technology and Society (STS). These researchers are involved in a course module at the first semester, and co-supervise the groups in the project module in the second semester.

In the case where sustainability is integrated in the project modules, the facilitators play important roles in motivating the students and help students to open up to other lines of thinking. This sometimes happens, when the facilitators question the conditions of the project or provide suggestions to integrate economic, social or environmental concerns. This often leads to discussions of the role of sustainability in the project and the ways to integrate sustainability in the project without compensating technical competences. This directive approach (with reference to the learning objectives in the study regulations) combined with a collaborative approach is very much depended on students’ motivation, performances and ability to achieve the course learning objectives.

In other cases, students had opportunities to meet external personnel such as engineers and managers from companies to make a network and collaboration on developing their projects. To get in contact with various stakeholders and meet with the target groups or users of the products was a great experience for students to understand their problems and to develop their project. In this way students also have the opportunity to experience, that sustainability plays a role in real life innovation of electronic products.

4.3. Output factors

In a systemic approach, output factors of teaching and learning process are referred to the students’ learning outcomes such as basic skills, other cognitive outcomes and non-cognitive measures (Centra and Potter, 1980) or abilities, knowledge, skills and competences (Rompelman and de Graaff, 2006). In this paper, it is assumed that students’ project report can be analysed as representations of students learning outcomes. Six reports are analysed, two from each module, to exemplify the progression in the integration of sustainability in the first semester of study (P0 and P1) and in the second semester of study (P2).

4.3.1. Students’ reports in P0 – getting a sense of electronics and PBL

The analysis of two P0 reports showed that the students have reached the intended learning objectives in relation to PBL and basic knowledge in the field of electronics. The students all had the same project proposal, where they had to develop a robot by use of LEGO mindstorms® (see example in figure 2), that was able to cope with some challenges put forward by the facilitators e.g. carrying items or follow a predefined route. Being able to build something and enter into competitions with each other motivated the groups. However, due to the very fixed technical challenge, it is very hard to find any evidence that the students in fact have had a holistic perspective on their project as intended in the learning objectives.

4.3.2. Students’ reports in P1 – the social responsibility project

In the P1 project reports, sustainability solutions are the target, but at the same time reflections or relations to sustainability are not explicit in the report.

In one project, students proposed stimulation tools for pupils with sight and hearing disabilities. Due to pupils’ disabilities, it is vital that the tools have cardinal features such as interaction and strong responses to the user. The strong responses could be in the form of light, sound and vibration. In addition to that the students have to present ideas of activities that combine physical activity with social elements and learning to stimulate the pupils at Centre for Deaf blindness and Hearing Loss, CDH. The project also included i) A study of possibilities for stimulating sight and hearing disabilities based on interviews with employees
at CDH and selection of ideas to project development, ii) Preparation of technical specifications for the system iii) Design and construction of a laboratory model, and iv) A testing and assessment product.

The other project considers assistive technology for people with sight disabilities in order for them to manage everyday life. In the project, the students made interviews with representatives from the Danish society for the sight disabled, to point to the most important challenges in the everyday life of blind people, get an overview of the assistive tool already at hand and what demand they this organisation have for assistive technology. Based on that, an interface instrument was developed to help blind people in their use of public transport.

By focusing on the assistive technology, these two projects can be considered as social responsible projects. Furthermore, the real life social problem is carefully analysed by involving the target group and use their input for product design. However, there is no explicit reference to aspects of economic or environmental sustainability; and there is no real trace of sustainability in the approach to the problem analysis and problem solving.

4.3.3. Students’ reports in P2 – integration of sustainability

Students report at P2 is clearly influence by the increased and more specific integration of sustainability in the learning objectives and the presence of a co-supervisor with special attention and competences in relation to STS and ESD.

In one of the reports social sustainability play a role in the purpose of the project that is to improve traffic safety by intelligent headphones identifying and amplifying signals of danger. Other projects working with intelligent headphones have instead been targeted at the quality of working environments by reducing noise problems. This is an example of the same product type and basically the same technical learning outcomes related to different types of problems related to different contexts. In the analysis of traffic safety problems the students draw open statistics of traffic accidents and they develop a survey instrument to investigate different types of distraction problems in traffic. Furthermore students measured the amount of noise in traffic and developed a prototype. In the final part of the project, they made overall assessments of the environmental impact from the hardware and estimated the price.

The other report analysed from P2 have the objective of making a small satellite, which can be used for educational purposes at high school level. Interviews are made with high school teachers and pupils in order to develop an educational set-up around the satellite. Interestingly, student estimated the environmental impact from the satellites as a part of their problem analysis – and thereby before they develop their prototype. They calculate the CO2 emissions to send up a satellite and found that the emission of sending up one approx. equals 1.25 km of car driving. Besides environmental regulation is discussed referring to the WEEE directive (on Waste from electrical and electronic equipment) and the RoHS directive (Restriction of Hazardous Substances). Based on these and more technical consideration a prototype of a satellite is developed.

5. Reflections and final remarks – feedback to create new input to ESD

Even though the qualification framework creates an important platform for arguing that sustainability should play a role in HE, it is not a criterion for accreditation that sustainability is explicitly addressed in the curricula. In a PBL environment this is however crucial, as the learning objectives in the curricula is the frame of reference when guiding students in their learning process. However, bottom up initiatives are also important drives e.g. by staff proposing projects with sustainability focus or students choosing to integrate sustainability in their projects.

However, sustainability cannot be prescribed – it has to be lived, and as such be a part of the project activities and facilitation. Interviews with staff together with analysis of students report points to the conclusion that students do need to be facilitated to maintain the focus on sustainability and at the same time find a way to cope with this relatively complex subject in relation to a specific context without compensating core technical competences. Choosing sustainability in relation to the problem field e.g. by assistive technology for hearing disabled, is one way to integrate sustainability, but from this does not necessarily follow and comprehensive and holistic perspective in the design and implementation of the product. On the other hand the ability to make overall assessments of the environmental, economic and social impacts from a technology should be developed at some time in the curricula, and here the strategy at Aalborg University has been to make sure that co-supervision is provided in the field of STS and ESD. Due to the strong collaboration in the supervisor team, this might also be an indirect training of staff and raise the awareness of sustainability in research environments where this is not considered as the core discipline.

Sustainability has to be included and the aims or goals must be aligned in all three factors therefore the sustainability can be effectively addresses along with the teaching and learning process. The cases have showed that the sustainability was partly in the written learning objectives, dedicatedly discourse in the project activities or facilitation and documented in the project reports. However, there is still a room for improvement where the alignment of the three factors needs to be part of overall assessments. So that, the teachers as well as the students have opportunities to reflect and make improvements in any part of the learning process that insufficiently address the sustainability. We also find out that even though students have showed their abilities to reflect their projects in the perspective of sustainability which commonly documented as a part of the project background and end-of-pipe analyses of project. There was a lack of reflection on sustainability perspective along the process of project development or realization.

However the case-example from Aalborg University shows that, it is in fact possible to integrate ESD without compensating technical and engineering competencies as the core contents. This is however due to a very structured project model, where
students gradually work from an initiating and very open problem, through a process analysis phase, whereas they have gained a comprehensive understanding of the problem to narrow this problem to a technical problem to be solve, but still being aware of the limitation of their technical perspectives in a business as well as in a broader societal context. Engineers are not necessarily to become environmental managers or sustainability scientists; but they have to know how to bridge and collaborate interdisciplinarily in their future profession in order to design sustainable sound solutions. We hope that this paper have provided some insight of the possibilities of making our engineering students ready to take on this responsibility.

References

Brophy, J. and Good, T.L. (1986). Teacher behaviour and student achievement. In M.C. Wittrock (Ed.), Handbook of research on teaching (pp. 328-375). New York:MacMillan
The Danish Bologna follow up group’s QF working party, (2003). Towards a Danish “Qualifications Framework” for higher education. (pp. 13-15)