# Educating engineers for Sustainable development

# – a work based approach

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## ABSTRACT

In this paper, we explore the potentials of designing engineering education activities for sustainability development based on how environmental concerns are integrated into product development processes in a company context. First we draw on a case study from the Danish company Grundfos Management A/S and based on their experience with product development practice and competence development of product developers, we propose a set of competences to be addressed in engineering education for sustainable development (EESD). Furthermore, we use the problem based learning philosophy as a base for proposing a framework for transferring the experiences from professional practice to an educational setting. The conclusion is that professional practice can serve as a valuable source of inspiration to design EESD activities; however to foster EESD beyond company level, broader ethical reflections on science, technology and society are needed.

## INTRODUCTION

In 2001 Stephen Sterling phrased the problem of Education in terms of sustainability very precisely by stating: *“We are educated by and large to ‘compete and consume’ rather than to ‘care and conserve’”* [1: 21]. What is needed, Sterling argued as soon as in 1996, is a change in educational paradigm from a modernist perspective emphasising education for environmental management to a postmodernist perspective on education for sustainability encouraging a deeper response to sustainability, which is more people/eco-centred than growth-centred and indicates a more critical and holistic approach to education for sustainability [2].

Fifteen years have passed and during that time the need for Education for Sustainable Development (ESD) has been strongly emphasised internationally; not least by The United Nations Decade of Education for Sustainable Development (2005-2014) [3] and the growing number of Regional Centres of expertise for education for sustainable development [4]. However, still, the contour of the new paradigm is blurred posing challenges to educational researchers and designers all over the world.

In relation to engineering education, technology can be seen as both a part of the problem and a part of the solution to enhance sustainable development. If technology is seen as a part of the problem; the challenge is to prevent the environmental, economical and social impacts in the different stages of the life cycle of the technology. If technology on the other hand is seen as a part of the solution; sustainability is considered to be one of the main targets of technological development. In either case, engineers play key roles – 1) as designers and maintainers of systems to monitor the performance; and 2) as designers of sustainable sound technological solutions. Whereas the first is likely to be supported by what Sterling (2001) has termed as an add-on strategy to ESD e.g. by adding a new programme (e.g. environmental management) [1]; the second role of engineers in SD demand a more integrated strategy; e.g. integrating sustainability in engineering education at large. Furthermore, if the post-modern turn is to be taken seriously, engineers should perceive themselves as agents in a sustainable society.

As an educational designer, one way to cope with these challenges is to seek inspiration at different sites in a life long learning perspective e.g. ESD activities at pre-school, school or high school level; from ESD activities at other engineering educations, from SD practice at the work place. In this paper, we will focus on the latter, based on a study of the integration of environmental considerations in product development processes at the Danish company Grundfos A/S. With this point of departure, we propose a set of competences to be addressed in engineering education for sustainable development (EESD). Furthermore, we will use the problem based learning philosophy as a base for proposing a possible framework for ESD by transferring the experiences from professional practice to an educational setting. From that point, we will finally discuss the strengths and limitations of using work based approaches to design EESD.

In the following, key competences for environmental innovation and experiences of work- based learning are based on a recent case study of the Danish Pump Manufactory Grundfos, prepared by Myrdal (2010) [5]. The case study took place during 2007 and 2008, staying at the company for 129 days in total. The activities were: participation and observation of daily practices in both the environmental department and product development; participation in 79 meetings; observant in one eco-design workshop; co-designing and facilitating another eco-design workshop; and last but not least 18 qualitative interviews with product developers and environmental coordinators were conducted. [5]

After presenting the experiences from the case study, the Aalborg PBL model will be used as a point of departure for exemplifying a work and problem based design of an EESD module.

## KEY COMPETENCES FOR ENVIRONMENTAL INNOVATION

In the following, a process of integrating environmental considerations is outlined based on a case study at the Danish Pump Manufactory Grundfos. Where nothing else is noted this outline is based on [5]. In this context however, the focus is on key competences of the product developers for environmental innovation.

Grundfos has three development processes: 1) Concept development; 2) Technology development; and 3) Product development, also called the DP-process. DP stands for Decision Point. The processes and the feedback mechanisms are illustrated in Figure 1.





Figure 1. On the left, an illustration of the connection between the three development processes [5, page 111]; and on the right, an illustration of the feedback mechanisms between the processes (based on [5]).

In **technology development** the relevant technologies are developed to support either concept development or product development projects. The need for development of specific technologies often emerges in either concept or product development. The project teams are typically small (1-4 members) and the knowledge acquisition is rather person dependent, which means that it relies on personal experience and network relations.

At Grundfos the environmental considerations in the technological development phase has been guided by an “impact” perspective. Optimising the practice based on what is proved to be the most considerable environmental impacts. In this case, the focus is on energy efficiency based on results from Life Cycle Assessments (LCAs) performed on a selection of Grundfos’ products. The result in the technology development process is that there is roughly no focus on other environmental or sustainable aspects in the daily work because there seems to be no reason to focus on anything else than this hotspot. Thereby, there is a need for a broader environmental competence, as an *awareness of the diversity of environmental impacts of technology* might point to other potentials for improvements – not because of the strength of the impact – but because of the potential for change.

The purpose of the **concept development** process is to investigate and develop ideas and transform them into product concepts based on an iterative process of idea analysis and concept clarification. In concept development, there is an emphasis on creating a creative environment, freeing the mind from “state of the art” procedures, tools and designs – and thereby thinking “outside the box”. On a few occasions an external creativity facilitator has helped to initiate creative thinking, but in principle there are no fixed boundaries on how and where to find inspiration. The concept development team seldom includes environmental specialists – but they are consulted on an ad hoc basis.

However, it could be argued that a certain level of environmental awareness is needed among the concept development staff; as creativity research show that some level of knowledge is needed within a given domain as a base of creative thinking. As noted by [6: 409]:

*“Knowledge of a domain do not always lead to creativity, but such knowledge does appear to be a relatively necessary condition for it; people who do noteworthy creative work in any given domain are almost in variably very knowledgeable about the domain.” [6: 409]*

Therefore, we will argue that *knowledge of guidelines for environmental sound innovations* based on an eco-design approach (see for example Behrendt et al (1997) [7] or Tischner et al (2000) [8]) can enhance design for sustainability. From an ESD perspective, eco-design could therefore be engineering educations in any domain in general and industrial design in specific. Furthermore, *knowledge of current environmental challenges* might also motivate designers to include sustainability in their divergent thinking processes.

The next phase, the **product development** process, consists of seven phases, see Figure 2.



Figure 2. An illustration of the product development process at the Danish company Grundfos. [5, page 118]

The first two phases is strategic in nature. The first phase, the Idea phase, can be viewed as a strategic phase where wishes, expectations, and customers’ requirements are described and evaluated. The idea phase can be based on investigations from the concept development process or the technology development process or both. The second phase, the Pre-study phase, is also a strategic phase but with focus on the market potentials. Furthermore, the purpose of this phase is to outline a plan for the following phases, including who should participate in the process and when, including both internal and external stakeholders. As a part of this phase, the product developers already have to determine the environmental requirements.

Thereby *awareness of stakeholders on the environmental scene and their mutual relations* could enhance new collaboration to develop environmental sound products, for example with NGOs, users or suppliers. Furthermore, the role of existing and up-coming environmental regulations can be brought into the picture, e.g. by consulting environmental specialists from the environmental department. In determining the environmental requirements, the product developers have to *consider possible trade-offs* both in relation to the three pillars of sustainability; but also by assessing the different actors having an influence of the technology throughout the product chain. This calls for skills *to assess the overall environmental potentials of the technology taking company strategies into consideration*.

In the next two phases the technological development takes form. In the third phase, the Concept phase, the purpose is to outline possible technical solutions and requirements for the product based on the requirements presented in the two previous phases. During the concept phase the product design is specified and an overview of the product and component flow is created. In the fourth phase, the Development phase, the various requirements and investigations from the previous phases are combined and full-scale prototypes are created. Through this phase a detailed product design should be completed. Previously, it was a requirement in this phase to perform an LCA; however, it is no longer a requirement but should be created when relevant. Furthermore, the environmental department will then support creating the LCA as they possess the expert knowledge of the LCA tool. For these two phases, skills to *assess the environmental impacts from technology or at least be able to interpret the results and act on such assessments* are needed to insure that the environmental requirements are met.

In the last three phases the product is prepared for the marked. In the fifth phase, the Preparation phase, the focus is on preparing the product for manufacturing. This includes development of technical documentation of the product and testing production series. Based on this phase, it is also possible to create a plan for promotion and an educational plan for the product as well as service training. For the training of service staff, the focus could be on creating knowledge and awareness of sustainability considerations in order for them to support the customers in using the product in the most environmentally friendly way as possible. Through the sixth phase, the Production start-up phase, it is ensured that production, sales, marketing, and service are prepared for sale. This means that the market introduction is prepared in this phase. In the seventh and last phase, the Sales phase, the project and the product is evaluated in order to ensure compliance with the requirements. The requirements are outlined in the previous phases, and are for example based upon requirements from management and customer. Whereas the *environmental documentation* probably will be placed in the environmental, marketing and sales department, the product developers play an important role in *prescribing environmentally friendly use of the product*.

In summary, we will emphasise the following learning objectives for Engineering Education for Sustainable development (EESD):

* *Knowledge* of current environmental challenges,
* *Knowledge* of the environmental impacts of comparable technology,
* *Knowledge* of the diversity of environmental impacts and to seek a broad range of potentials for improvements,
* *Awareness* of guidelines for environmental innovation,
* *Awareness* of stakeholders on the environmental arena and their interests in the specific innovation,
* *Awareness* of the needs and potentials for using environmental documentation,
* *Skills* to use creativity techniques to propose environmental potentials,
* *Skills* to formulate and for environmental requirements for the solution and clarify trade-offs,
* *Skills* to assess or to interpret assessment of environmental impacts,
* *Skills* to use eco-design methodology to point to different solutions in all phases of the products lifecycle.

## TRAINING TO FOSTER ENVIRONMENTAL INNOVATION

The empirical foundation for this paper is two workshop experiments at the Danish company Grundfos Management A/S with the purpose of educating engineers to integrate sustainability in their product development thinking and practice. Tim McAloone from the Technical University of Denmark (DTU) and Niki Bey from the consultancy company IPU conducted one of the workshops. The purpose of this workshop was to investigate if a specific set of eco-design assignments could provide the engineers with knowledge and activities to improve the products environmentally. The workshop gave the engineers insight in both the environmental possibilities of the product as well as the internal and external network necessary for working with these environmental possibilities. However, the focus was primarily on learning about the environmental hotspots and the consequences of one existing product, rather than on creating knowledge and learning on how to environmental improve products from a broader perspective. [5]

The other workshop was conducted as a part of a the research project about eco-design within Grundfos Management A/S, and the purpose of the workshop was to investigate if workshops could be used as a learning object for integrating environmental considerations in the mind-set of engineers. In the workshop the focus was on investigating whether workshops could be used as a foundation for creating a common understanding for the environmental work in product development teams in companies. The workshop showed that this type of workshop can be used to create a common mind-set and was afterwards used by the engineers as a reference to the understanding of the environment. [5]

Overall, there are strengths and weaknesses in both workshops and they provide valuable knowledge on how to integrate sustainability considerations in product development through a workshop concept. Figure 3 illustrates the main input from the two workshops, in which the thick arrows indicate the main input and the dotted arrows indicate the areas in which the workshops provide indirect, but still valuable, input.



Figure 3. The main input from the two workshops. Based on [5, page 167]

Based on a synthesis of the two workshops conducted at Grundfos, three types of workshops can be distinguished by their purpose. The three types of workshops are [5]:

* *Consequence assessment workshops* to create overview of the environmental impacts of existing products as well as to evaluate the new products in relation to this update,
* *Creativity workshops* to generate action around eco-design and support developing more environmentally friendly alternatives,
* *Strategic workshops* to put up visions and targets for environmental performance – on company or at project level. [5]

Each of the workshops relates to environmental product improvements as well as learning through the daily practices of product development. The three types of workshops can be combined (as in the two described workshops carried out at Grundfos) or they can be held separately to increase the focus on the specific activity.

In the following we combine the knowledge and skills stressed in the analysis of technology concept and product development with the workshop approaches derived from the experiments with work based learning at Grundfos A/S and frame the findings in a PBL approach to engineering education.

## PRACTICE AND PROBLEM BASED DESIGN OF EESD

In engineering education at Aalborg University the students learn through problem and project based learning (PBL); the so-called Aalborg PBL Model. This means that a significant part of the study time takes place in smaller project teams and with point of departure in a real-life problem. To support the students with these projects, each team is given a supervisor with expertise in the specific field the students wish to investigate. [9]

Overall the student projects consist of two parts; a problem analysis and a problem solution [9]; however, there are different ways to initiate and structure the work process within the project. In some cases, the supervisor team prepare a catalogue of specific project proposals in the beginning of the semester, stating both the main problem to be addressed and suggested methods to cope with this problem. In other cases, the students are facilitated to develop the project proposals themselves in the beginning of the semester within the frame of an overall theme. As the self-directed project proposal phase offers the possibility for students to mirror a concept development process, as described in the Grundfos case, it is recommended not to neglect this phase in the design of EESD modules.

Inspired by the structure used at Grundfos Management A/S for development of new concepts, technology and products, we take our point of departure in three phases, which correspond to the different project phases:

* *Concept development* corresponding to the phase at Grundfos A/S by the same name; to go beyond incremental environmental innovations.
* *Appropriation of technology* corresponding to idea and pre-study phases in product-development at Grundfos A/S to appropriate and refine the ideas from concept development to the stakeholders.
* *Construction of technology* corresponding to technological development at Grundfos A/S and the last five phases in product development moving from concept to sale.

Whereas a gathered creativity workshop could support the project in the project proposal phase where there is a call for divergent thinking; the strategic workshop is aligned with the priorities, which have to be taken to appropriate the technology to the demand from stakeholders. In the construction of technology, the consequence workshops are suitable to support the project groups in finding possibilities for change based on interpretations of LCA of comparable products. However, this effort could be combined with a creativity workshop to point to possible ways to realise the potentials.

Whereas concept development envisage divergent thinking, construction of technology demand for convergent thinking focusing on fulfilment of requirements set up in the appropriation phase. The strengths of the appropriation phase are instead that the students get to analyse the problem from a contextual view; which calls for critical and holistic thinking. Thereby the phases foster different modes of thinking.

An overview of the framework for an EESD module in a PBL environment is presented in Table 1.

Table 1. A framework for an EESD module in a PBL environment. The category *“Type of thinking”* is based on inspiration from [10] among others.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Concept development** | **Appropriating technology** | **Constructing technology** |
| **Project phase** | Project proposal | Problem analysis | Problem solving |
| **Mode of thinking** | Divergent thinking | Critical thinking | Convergent thinking |
| **Supporting workshop** | Creativity workshops | Strategic workshops | Consequence workshops followed by Creativity workshops |
| **Learning objectives to enhance EESD** | Knowledge of current environmental challenges.  Awareness of guide­lines for environ­men­tal innovation.  Skills to use creati­vi­ty techniques to propose envi­ron­men­tal poten­tials. | Knowledge of the envi­ronmental impacts of comparable techno­lo­gy.  Awareness of stake­holders on the environ­men­tal arena and their interests in the specific innovation.  Skills to formulate and for environmental require­­ments for the solution and clarify trade-offs. | Knowledge of the diver­si­ty of environ­men­tal impacts and to seek a broad range of potentials for improve­ments.  Awareness of the needs and potentials for using environmental docu­men­tation.  Skills to assess or to interpret assessment of environmental impacts.  Skills to use eco-design methodology to point to different solutions in all phases of the pro­ducts lifecycle. |

For other engineering educational domains than environmental engineering, we suggest that the theme for the semester corresponds to the ambition of ESD as for example “Sustainable innovations” or “Constructions for climate change”. As one of the product developers in the case-study stated: *”Engineers are like dogs. If you throw a problem to them, they will run for it to find a solution. If you throw 100 problems, they will be confused.”* [5: 64, 11] (Translated from Danish). In other words, engineers like engineering students are typically born problem solvers – so to motivate the first learning cycle of ESD, it might be a good idea to challenge them by focusing explicit on the challenges of sustainable development. The next learning loops then have to support on the integration of sustainability in every product development project without regard to the thematic frame.

Furthermore, we suggest workshops to support the self-directed project work instead of more traditional lectures. An example of this type of approach has been performed with first semester students in Medialogy at Aalborg University, where a creativity workshop was introduced [12]. The workshop was a combination of theory and small assignments to solve a fictive problem during a period of approximately six hours, where the assignments were build upon the previous assignments in order to give the students an experience of a flow during the process [12]. Some students decided to use minor aspects of the creativity workshop in their project work. Bound to the limited time in the lecture, it would be difficult to adjust this type of workshop to the specific work in the project teams; exchanging the fictive problems with the problems addressed in the projects. Therefore it is crucial to obtain supervisor training and support in order to transfer the lessons learned from the workshop to the project at the right time and place.

The workshop concept as a whole is shaped to work-based learning; and the transfer of the concept into formal educational will require an educational model based on active learning principle. However, the practical implementation of the workshop concept in formal engineering education is yet to be explored.

Through EESD modules, we hope to support engineering students in creating a holistic view on the developed technical solutions and thereby will begin to consider environmental, social as well as economic perspectives as a part of engineering identity. Furthermore, if the engineering students have gained positive experiences in the process of integrating sustainable considerations in their development as an integrated part of being an Engineer.

## FINAL REMARKS

In this paper, we have explored the possibility of work and problem based learning by using a case-study analysing how environmental considerations have been integrated in concept, technology and product development in a specific company as a source of inspiration to design a work and problem based learning environment based on the Aalborg PBL Model.

The conclusion is that professional practice can serve as a valuable source of inspiration to design EESD activities. In comparing the developed framework for EESD to the daily practices at Aalborg University; more emphasis is put on workshops to support project work instead of traditional lectures. Furthermore, only few projects take their point of departure in students preparing project proposals by themselves in a creative learning environment.

However, how does the framework correspond to *“the postmodernist perspective on education for sustainability encouraging a deeper response to sustainability, which is more people/eco-centred than growth-centred and indicates a more critical and holistic approach to education for sustainability”,* as we so ambitiously outlined in the introduction with reference to Sterling (1996) [2]. Actually; even though the developed framework does not hinder the post-modernist perspective it is far from securing a broader contextual approach to foster ESD beyond company level. Therefore, educational activities to secure broader ethical reflections on science, technology and society are needed to provide a social formation of the sustainable engineer in an area of post-modernism.

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