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Integrating Environmental Aspects in Engineering Education*

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The key role of engineers for the transformation of society towards sustainability is a strong motivation for increasing the environmental knowledge within engineering education. Doing this by the concept of integration is presently considered more appropriate than to develop more new education programmes for environmental specialists. This paper describes the integration of environmental aspects into a mechanical engineering education programme. The Natural Step Framework has been used as a basis for this integration. It has been possible to include environmental knowledge without compromising the engineering quality of the programme.

INTRODUCTION

THE TRENDS of the global society imply non-sustainable development. Natural resources are declining and so is nature's ability to assimilate waste and there is a strong polarisation between industrialised and developing countries.

Presently approximately 20% of the world's population are living in poverty [1]. The material wealth in the industrialised parts of the world is a natural target of many developing countries. For several reasons the quality of life can however not be improved globally by the same means as in the industrialised countries during the nineteenth and twentieth centuries, where it was reached and is mainly upheld by high consumption of natural resources and extensive generation of waste. It is unavoidable that environmental impacts will increase further, should this linear resource handling continue and extend to the whole global population, which is projected to rise to near 10 billion within 50 years [2].

For the future society to be sustainable the paradigm needs to be changed, and the main responsibility to set new trends and promote sustainable development rests on the industrialised countries, which have the necessary economic and technological resources. To stimulate and guide such actions, a framework including principles for sustainability and a backcasting planning methodology for sustainable development has been developed by The Natural Step (TNS) Foundation (in collaboration with universities, municipalities and industry (The Natural Step Foundation is a non-governmental organisation founded in Sweden by professor Karl-Henrik Robèrt in 1989. He was awarded The Blue Planet Prize 2000 ('Environmental Nobel').)

This framework is used today by, for example, many companies to provide strategic direction for their sustainability initiatives. It is known to create overview and engagement and improve communication between employees by creating a shared mental model of basic principles for the management of problems and visions and possible solutions [3–6].

An essential aspect of sustainable development is to include knowledge about it in the education of professionals. A multidisciplinary approach and a systems perspective are necessary to solve the present complex problems and to prevent new problems. This paper describes how the TNS-framework has been used as a basis for integration of environmental aspects into the programme of Bachelor of Science in Mechanical Engineering with emphasis on Product Development at Blekinge Institute of Technology (BIT), Karlskrona, Sweden.

BACKGROUND

Engineering science must be considered as one of the key disciplines for the transformation of society towards sustainability, having the potential of solving many present-day problems as well as avoiding new problems, depending on how actions are taken in relation to our collected knowledge.

The main sources of pollution in industrialised countries have for many substances changed from point sources to diffuse emissions from products [7, 8]. Large amounts of certain substances included in products also represent large unknown future environmental problems if these substances are not prevented from entering nature after end-of-use of the products. This has increased the efforts for identifying potential environmental impact from products already during product development. Because of increased environmental awareness among

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customers, environmental adaptation of products has become more and more important for companies also from a more direct business point of view. Much research is going on to find methods for how to integrate environmental aspects into product development. For examples, see reviews by de Caluwe [9] and van Weenen [10, 11]. Development of a method for sustainable product development based on the TNS-framework is described in references [12–15].

From the above it is obvious that engineers involved in product development indeed do have a key role. It should therefore be especially important to give this group of professionals a firm understanding of environmental aspects during their basic education. This should however be done in a way that does not compromise the engineering quality of their education. It is by proficiency in engineering that product development engineers can contribute the best to sustainable development, provided that they have incorporated a relevant overall framework for sustainability to guide the engineering measures. To reach this aim an integration of environmental aspects into the ordinary engineering curricula seemed to be a promising concept. Environmental experts in a more classical sense are of course also necessary, but to get a major breakthrough for the societal transformation, a much broader spectrum of engineers, as well as other professionals, should integrate environmental aspects into their profession.

The programme of BSc in Mechanical Engineering with emphasis on Product Development comprises three years of studies, corresponding to 180 ECTS (European Credit Transfer System). The two first years include mathematics and typical mechanical engineering courses. In the third year students specialise in product development and design methodology and do their thesis project.

A course called Environmental Basics comprising 7.5 ECTS was developed and included in this programme in 1994. The main purpose was to give a systems perspective on the current environmental and societal situation and to provide tools for the generation of attractive and relevant visions of a future sustainable society. Focusing on basic causes to environmental problems—upstream in cause effect chains where basic mechanisms are understood and where complexity is lower—makes it easier to correct root causes of problems and avoid new problems when the present problems are solved. Trying to cure symptoms at detailed levels, as have been the case for many efforts until today, often causes many new problems further ahead since the underlying principle mechanisms behind the present problems are not dealt with.

The TNS-framework is closely studied and its scientific background is explained in the beginning of the course. Major environmental problems as well as, for example, macro economic theory, legislation, eco-labelling, economic incentives, tax regulations, life cycle assessment, and environmental policies, are then studied and discussed in relation to this framework. Besides an ordinary written examination, students perform a project that is accounted for by a written report and an oral presentation at the end of the course. Questions based on the projects are included in the written examination. A few examples of project titles are: *Implementation of Environmental Policies, Ecological Food—Obstacles and Stimuli*, and *Environmental Handbook for Storeklimpens Day-care Centre.*

The reaction among students to the introduction of this course was an urge to discuss and consider environmental aspects also in the ordinary engineering courses, using the systems perspective provided by the TNS-framework. Some of the students also initiated an environmental section of the student's association of the university. These reactions became in turn added stimulation to initiate integration of environmental aspects into this programme.

TNS-FRAMEWORK

The Natural Step (TNS) Foundation grew from the concerns of Karl-Henrik Robèrt, an associate professor of internal medicine who wanted to comprehend in a structured way the mechanisms behind the destruction of our habitat. He talked with scientists outside the medical field to get help in describing the overall mechanisms by which humans induce complex negative effects in nature. In 1989 he initiated TNS in Sweden. Its main objective is to describe and communicate strategies for sustainable development based on principles for sustainability and to promote positive examples. This is done in a learning dialogue with scientists, policy makers in business and politics, and the public. This way of working is spreading with affiliates formed in the United Kingdom, Canada, Australia, New Zealand, Japan, South Africa, Israel and USA.

The TNS-framework is based on the following principles for sustainability. For a background and discussion see, for example, references [6, 16–19].

In the sustainable society, the ecosphere (defined here as the part of the Earth where life is active plus the stratosphere, including the ozone layer) is not subject to systematically increasing . . .

1. concentrations of substances extracted from the lithosphere (defined here as the Earth's crust);
2. concentrations of substances produced by society;
3. degradation by physical means;

And, in that society . . .

4. . . . human needs are world-wide.

These principles are elaborated through an understanding of the basic mechanisms (first approximation) by which non-sustainable activities occur, completed with a 'not'. The first three principles give a frame for ecological sustainability. The fourth principle provides the basic objective of social sustainability. These principles can be used as a frame for assessing today's activities from a sustainability perspective, as well as assessing visions and finding strategies for sustainable development. They describe the goals for sustainable development and define a certain favourable outcome in the ecosphere/society system [19]. Non-sustainable societal activities, such as large-scale use of persistent compounds foreign to nature, can be avoided without a specific knowledge of the details of the respective impacts of such activities (second and higher approximations).

The principles are implemented in a backcasting methodology. In backcasting, future goals and objectives are defined and used to develop a future scenario [20]. In the TNS-framework this takes the form of a so-called ABCD-analysis, in which a sustainable society, defined by the above principles, is used as a reference-state and goal for the development of the society. The steps, when used for strategic planning in a company are:

A. Understanding and discussing the principles for sustainability and backcasting methodology as a relevant framework for sustainability and sustainable development.
B. Analysing the current situation to assess flows and activities that are critical with reference to the principles for sustainability.
C. Creating solutions to the problems listed in B, and visions, through a lens of the principles for sustainability.
D. Forming strategies towards sustainability, i.e., prioritising such measures from C that will optimise the chances to integrate sustainability aspects with the economy and bottom line business.

The societal principles can be translated to objectives for the individual player, firm or municipality.

An organisation's ultimate sustainability objectives are to:

1. eliminate its contribution to systematic increases in concentrations of substances from the lithosphere.
2. eliminate its contribution to systematic increases in concentrations of substances produced by society.
3. eliminate its contribution to the physical degradation of nature through over-harvesting, introductions and other forms of modification.
4. contribute as much as it can to the meeting of human needs in our society and world-wide, over and above all by the substitution and dematerialization measures taken in meeting the first three objectives.

Based on these objectives, the following overall guidelines can be formed:

1. Substituting certain minerals that are scarce in nature with others that are more abundant, using all mined materials efficiently, and systematically reducing dependence on fossil fuels.
2. Substituting certain persistent and unnatural compounds with ones that are normally abundant or which break down more easily in nature, and using all substances produced by society efficiently.
3. Drawing resources only from well-managed ecosystems, systematically pursuing the most productive and efficient use both of those resources and land, and exercising caution in all kinds of modification of nature.
4. Using all resources efficiently, fairly and responsibly so that the needs of all people on whom we have an impact, and the future needs of people who are not yet born, stand the best chance of being met.

On a product system level, the principles imply, for example, that materials that are used should either be possible to integrate into natural material cycles within the ecosphere or be possible to integrate into societal closed materials cycles. (This includes all materials used in production processes, in products, and during the use of a product.)

Substances that have the potential to be integrated into natural material cycles are, for example, renewable materials, chemicals easily degradable (into common substances), and metals that are relatively abundant in the ecosphere. Societal closed materials cycles demand at least that:

- there is no dissipated use of materials, and
- there is a societal (organisational) system for recycling of the materials, and
- recycling, or destruction, is technically and economically possible, for example, with respect to the design of the product.

Some examples of application of the TNS-framework are given by, for example, Broman *et al.* [6].

INTEGRATION PROJECT

There is a classical dilemma of education, which is perhaps especially pronounced within engineering education. The amount of knowledge and engineering support tools is continuously increasing. Most teachers therefore continuously like to update courses and programmes. This is all sound. The problem is to decide which parts of the current curricula that should be removed to make room for the new knowledge. Much of the 'good old stuff' still needs to be there. Not the least for students to be able to understand and make the best use of the new things. The concept of integration can to some extent be a solution to this dilemma. An example may be the integration of modern software to support the learning of dynamics rather than replacing a dynamics course by a software course [21].

Regarding environmental aspects and mechanical engineering education the concept of integration has been found successful. The overall purpose of the integration project, performed in 1995 and 1996, was to give becoming product developers the necessary knowledge to support sustainable development through their profession. The course Environmental Basics was the only new course introduced. The room for this was created by decreasing the block of optional courses. All other environmentally related knowledge has been integrated into relevant engineering courses.

A project group was formed, including a director (first author) and an assistant (second author), two representatives from the student's association and one from the university library. Financing was granted by the Swedish Council for the Renewal of Undergraduate Education. Basic education of the teachers and supporting personnel such as librarians was given high priority to create the necessary engagement and basis of knowledge for further supervised individual studies and integration work. The outline of the project thus followed the same idea as it was supposed to implement, i.e., a firm base shared by all, completed with integration of more specialised aspects in relevant subjects. A series of thirteen seminars was given. The project director started out with three half-day seminars on the TNS-framework, which was followed up by several invited scientists within the environmental field and representatives from industry and municipalities. Some teachers also attended external conferences and visited companies. Librarians participated in the series of seminars both as one of the lecturers and for their own learning. They also took external courses and further improved their skills in finding information within the-environmental field to be able to better support teachers later on during the integration work. The library also complemented the environmentally related literature and started to subscribe for some environmental magazines and periodicals. Through the project the teachers at the Department of Mechanical Engineering (DME) were provided with the same framework and basic knowledge as the students get through the course Environmental Basics.

The series of seminars was open also for teachers from other departments. Their participation was however not financed by the project so they would have to be there on unpaid and unplanned time. The first few seminars were attended also by some teachers from outside the project but their participation then dropped off rapidly. The attendance of the teachers included in the project was however high throughout the series of seminars and their succeeding integration work was successful. This shows that to reach persons that are not already environmentally engaged it is necessary to provide financing and to allocate time.

A reason for having the basic education of the teachers in a series of seminars, separated from the student's course Environmental Basics, was to be able to better co-ordinate the seminars with the ordinary work of the teachers. Another reason was that many teachers were at that time less initiated in environmental issues than the young students, and this could risk impeding discussions among the teachers.

The course Environmental Basics is used as the basis for the maintenance of the integration after the project. New students continuously pass through this course. In engineering courses they then meet teachers who share the same systems perspective and relate the respective engineering content of their courses to this. As part of the ordinary course updating the teachers should continuously update also environmental aspects in their courses. To keep the engagement alive the teachers are each year invited to listen to guest lecturers within the course Environmental Basics. When new teachers are employed they will follow the course Environmental Basics and will then be mentored by the 'integrated' teachers and by the director. Due to a generally stressed personnel situation it has however not been possible to allocate sufficient time for a few new teachers to follow this intention entirely. Should this situation continue there is a risk that part of the good result of the project will fade out along with new teachers taking over integrated courses. Again it is seen how important it is to not consider environmental activity as something employees will do for idealistic reasons in spare time.

Examples of integrated courses

The results of the integration project are visible in, for example, syllabi, lecture notes, student projects within courses and in examinations. Approximately half of the courses of the programme have been influenced by the integration project. The more applied courses have been prioritised. More theoretically oriented courses such as basic statics and dynamics have not been worked with so far. Some examples of integrated courses are given below.

Engineering Thermodynamics, 7.5 ECTS. The purpose of this course is to give basic understanding of thermodynamics and its engineering applications, to practise and improve the student's ability to perform thermodynamic and fluid flow calculations, and to make clear the central role of the subject for the understanding and possible solutions of environmental problems.

Environmentally related consequences of the first and second law of thermodynamics and the concept of exergy, and their significance in the science behind the TNS-framework, are discussed. Other general aspects, such as relationships between energy and material flows, renewable energy capacities, and efficiency of different energy carriers are also commented on. When dealing with heat radiation the energy balance of the Earth and the greenhouse effect are discussed. When dealing with combustion engines environmental aspects of different engine cycles and fuels are discussed, including the fundamental difference between bio-fuels and fossil fuels related to the greenhouse effect. When dealing with phase transitions of substances this is discussed as a possible way of storing solar heat. When dealing with cooling cycles alternatives to CFCs are discussed and used in calculations. When dealing with fluid flow in piping systems the significance of the design of the system for possible exergy savings in industry are discussed. The significance of different methods for flow control of pumps is exemplified.

Besides an ordinary written examination students perform a project, which is accounted for by a written report and an oral presentation at the end of the course. A few examples of project titles are: *Heat Losses from an Ice Arena—a Resource? Alternative Energy Sources—Something for Blekinge?* and *Efficiency Potential in the Swedish Hydropower System.*

Choice of Materials, 7.5 ECTS. The purpose of this course is to give basic understanding of mechanical properties of materials and of the process of choosing materials in engineering design.

Environmental aspects such as the suitability of different materials for recycling, the risk of down cycling, i.e., loss of material quality if different materials are mixed during recycling, and environmental advantages and disadvantages of using alloys such as stainless steel, are discussed. Categorisation of metals as scarce or abundant and the implications of this are discussed. For example, it is explained that the use of relatively scarce metals such as zinc is linked to a higher risk of giving increases of concentration in the ecosphere, with negative impacts in the future, than the use of relatively abundant metals such as aluminium.

Product Development and Design Methodology, 15 ECTS. The purpose of this course is to give basic understanding of the product development process. A model for integrated product development or so-called concurrent engineering based on the work of Olsson [22] is studied and compared to some other models [23–26].

To consider environmental aspects during development and design of products is essential for preventing problems. For example, to comply with the principles for sustainability substances that pose substantial risks of creating relatively large increases of concentrations in the nature, should only be used in societal closed cycles. The design of the product does of course strongly influence the possibility to obtain such cycles.

Several proposals of how to integrate environmental aspects into product development exist [9–11]. Ideas of Pollution Prevention, Eco-design, Design for Environment, Design for Re-use and Recycling, and Life Cycle Design are discussed in the course. Inventory/impact tools such as the MET-matrix [27] and the Dow Chemical Company matrix [28] are studied as well as improvement tools such as the Eco-design Strategy Wheel [27] and Design for Environment Guidelines [29]. Examples of quantitative Life Cycle Assessment methods are also discussed. At the DME a method for sustainable product development based on the TNS-framework is being developed [12–15]. Prototype versions of this method are continuously integrated into this course as the research proceeds.

Development Project (Thesis), 15 ECTS. The purpose of this 'course' is to apply and further develop the basic mechanical engineering knowledge and the product development and design methodology from earlier courses. The course constitutes the Bachelor's Thesis and runs over three-quarters of the third year. Students deal with a product development assignment in collaboration with a company.

Students are instructed that environmental aspects should be included in the design criteria. Through this thesis work the students also have the possibility to transfer environmental consciousness and knowledge to the companies they are working with and to receive valuable practical feedback.

Production, 15 ECTS. The purpose of this course is to give basic understanding of common mechanical engineering fabrication methods, such as turning, milling, cutting, welding, and sheet metal forming. Fabrication of composite materials and structures are also briefly studied.

Environmental aspects of the different methods are discussed, for example, their efficiency and generation of rest material and the possibility to recycle this material. The influence of the organisation, control and maintenance of the production processes and machines, logistics, and plant design for the total efficiency of the production system are also discussed. Concepts such as Lean Production, Pollution Prevention, and Clean Technologies are discussed.

Quality Control, 7.5 ECTS. The purpose of this course is to give basic understanding of Total Quality Management.

Environmental performance is emphasised as a part of the total quality of a product. Producer's responsibility and environmental management systems are discussed. The similarity between quality management systems such as the ISO 9000 standard and environmental management systems such as the ISO 14000 standard and EMAS is exemplified.

CONCLUSIONS

This paper describes the integration of environmental aspects into the programme of Bachelor of Science in Mechanical Engineering with emphasis on Product Development at Blekinge Institute of Technology, Karlskrona, Sweden. The TNS-framework, which has previously been used successfully to provide strategic direction for sustainability initiatives in many companies and municipalities, has been found useful also as a basis for this integration. It creates engagement and improves communication among and between teachers and students. It creates overview and provides a context for the more specialised knowledge in engineering courses.

From the integration project and from the first years of running the integrated programme it is clear that environmental knowledge can be included in mechanical engineering education without compromising the engineering quality of the education. This is feasible:

- by using knowledge already included in the programme, such as laws of natural science, to obtain a systems perspective and overall framework by which the reasons for environmental and resource problems become clear at a principal level, and
- by using this as a means by which specialised knowledge can be structured and given an overall meaning, and through which the connection between different subjects/courses becomes clearer, and
- by giving examples in partly new ways, for example, by showing alternative applications and how engineering knowledge can be used to solve many of the existing environmental problems and prevent the generation of new ones.

This should be possible also in other fields of engineering. The common base of natural science in engineering education should be an advantage.

Students experience the integration of environmental aspects in their education as positive and important. They also express a belief that it increases their attractiveness on the labour market. There seems to be support for such belief. Kvernes and Simon [30] interviewed 110 representatives of industry, authorities and education in Sweden to find out about their views on the future development of environmentally related jobs. Some of the conclusions they draw are:

- The number of environmentally related jobs will increase, and this will be primarily through the integration of environmental knowledge in existing professions rather than the creation of new 'environmental jobs'. The demanded competence for these jobs thus primarily concerns the ability to relate environmental aspects to ordinary professions. Well-educated engineers, economists, lawyers and others will be more attractive on the labour market if they have this added ability.
- Too many environmental specialists are educated in relation to the expected demand. On the other hand there is a need for more environmental knowledge within other professions. Integration of environmental aspects in the education of all professionals should therefore be prioritised.

Furthermore, the major Swedish labour union for university-educated engineers (CF) has recently decided on an environmental policy and programme [31]. The great possibility and responsibility of engineers contributing to sustainable development is emphasised. It is concluded that environmental knowledge among engineers is today in general poor. Universities are recommended to integrate environmental aspects in all engineering education and to offer experienced engineers the opportunity to complement their prior education in this aspect.

The leading idea behind the integration project described in this paper—that it is primarily by being skilful engineers that engineers can contribute the best to sustainable development, provided that they have incorporated a relevant overall framework for sustainability to guide the engineering measures—thus seems to have a general support.

Another important conclusion is that to be successful a project like this, and the maintenance of the integration, must be allowed to cost money and time. This is necessary to reach and create engagement among people that are not already dedicated to environmental issues. It also signals that the state, university management, or whoever supplies the financing, consider it to be important. Some dedicated persons are probably still necessary, but it should not be taken for granted that environmental activity is something most employees will do for idealistic reasons on a spare time basis.

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