A SYSTEMS APPROACH TO ENVIRONMENTAL ENGINEERING - Collaboration Between University, Research Center and Industry

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INTRODUCTION

University and college education of engineers and technicians face a sever dilemma. On the one hand is there a strong need and demand from society to enforce interdisciplinarity and systems thinking to master the intricate interactions between technology and society, and between technology and physical and biological environment, both globally and locally. On the other hand, there is a similar need and demand for specialists that can penetrate complicated physical and societal problems and sub-systems which are inherent in the global integration of society and technology, society and environment. The greatest challenge to educational institutions world-wide, is to master this situation and meet the needs in a rational, structured and stable way. Sometimes, educational systems start to swing from one extreme to another in their outlook and approaches, but the education is usually conservative and slow in their changes. This does not always agree with the fast changes in society, and the education lags behind. The consequences of that in society may be catastrophic.

Three important interdisciplinary areas.

There are three highly interacting areas of modern education where interdisciplinarity is a major issue, areas of great and increasing importance in the society. Those areas are:

- Safety and reliability of systems, including a major portion of human factors and their interaction with systems. Large economic and societal consequences are related to this area, which is truly interdisciplinary.
- Sustainable and environmental engineering, which comprises life cycle assessment of products and processes including their designs, resource requirements and environmental impact. Resource utilization at all levels of a system or product life cycle is a crucial question in sustainability, where clean natural environment, air, water and soil are among the most precious resources.
- Systems engineering, which implies the basic methodology and procedures for general system design, operation and support. Since the systems may be taken from any of the specialties in engineering, this topic is truly interdisciplinary, based on general problem solving, needs and requirement definition and trade-offs. The Life cycle analysis is the one of the fundamentals in systems engineering.

Three different ways of implementing interdisciplinary education

In terms of interdisciplinary education in general, and in environmental engineering in particular, there are three different concepts that try to meet the demands for this kind of education. In a brief outline, they may be:

1. The design of a completely new and interdisciplinary education, with emphasis on the interaction between technology and environment and between technology and society, where the topics and courses are taken from many traditionally different disciplines, but composed with an emphasis on interdisciplinarity. This is the Systems Engineering approach based on the general philosophy of problem solving, which is tried at many American universities, for example MIT, University of Arizona, University of Maryland and Virginia Polytechnic Institute

2. The integration of Systems and Environmental Engineering, Life Cycle Assessment, etc., into all courses, where such integration is natural and relevant. This is the natural science approach similar to the way mathematics, physics and chemistry are integrated into other courses as the core and reinforcement of all technical subjects. This approach is truly interdisciplinary, because the teaching needs to be coordinated (team teaching).

3. Interdisciplinary courses are given by one department for all others, without real inter-disciplinary integration, for example courses in environmental topics. The students are exposed to general environmental problems and issues, but without proper connection to their field of expertise, for example mechanical, chemical, electrical or civil engineering. The interdisciplinarity in the education becomes more of a cosmetic addition to the traditional education without real integration.

It may seem obvious that the second approach would provide the best point of departure for a successful interdisciplinarity for environmental engineering, but it may be the most difficult to achieve. Therefore, all three approaches above are found in the universities' attempts to implement the interdisciplinary areas in their education and research. The size, academic climate and financial situation of the university are important factors for the approach taken.

ENVIRONMENTAL ENGINEERING EDUCATION IN NORWAY

The Norwegian system of higher education is primarily based on four universities, five specialized colleges having university status and 26 regional colleges offering higher education.

Implementation at The Norwegian University of Science and Technology

The Norwegian University of Science and Technology, NTNU, now prepares for future stronger scientific cooperation across the fields of technology/science and the fields of humanities and social sciences, due to a decision in the Norwegian Parliament. One of the reasons for this is the need for new approaches in order to meet the more complex demands and challenges in future society, not least in the fields of sustainable development and environmental technology.

The university has a strong tradition in fields of ecology and environmental technology. The Faculty of Economics and Industrial Management give courses in the interaction between society, technology and the environment. Those courses are taken by practically all engineering students, but the integration in the traditional courses is marginal. Several other faculties have their own lines of studies or courses which are specially oriented towards the environmental issues. There is established a Center for Environment and Development, which is supposed to coordinate interfaculty cooperation in sustainable engineering. Since the faculties are pretty much autonomous, this coordination is not an easy task. So far, the university seems to follow the implementation sketched in the third paragraph above.

A promising natural development is found in the Faculty of Chemical Engineering and in the Faculty of Mechanical Engineering. Here, environmental engineering has become an integrated part of their professional education, focusing life cycle assessment, integration in chemical process design, recycling, regeneration, pollution prevention and clean-up. Other areas are environmental monitoring, chemical sampling and analysis of the environment air, water and soil. Finally, environmental engineering as integrated parts of thermal power plant design, general combustion theory and design of burners, and general systems engineering as related to life cycle analysis and assessment, and sustainable process engineering are all important parts of curricula in mechanical engineering.

There is a separate curriculum in product design as a cooperation among the Faculty of Mechanical Engineering and the Faculty of Architecture. These courses are very much inclined to general systems engineering also. However, the cooperation is marginal, partly because of slight conceptual differences, differences in terminology and differences in student background. It is fairly typical, that when the need for interdisciplinarity and systems thinking is felt in one area, that area develops and cultivates its own terminology and conceptual world, only slightly different from another, but different enough to generate a problem of appreciation and understanding.

The Center for Environment and Development works on several areas (biodiversity, management of environmental resources, and sustainable technology development) in a North-South and North-North perspective, all areas motivated by the interdiciplinary needs as part of sustainable development. The Center and selected departments across faculties are now aiming at the production of joint courses which focus the life-cycle oriented aspects of environmental engineering (industrial ecology, design for the environment and design for recycling), as optional parts of traditional engineering curricula. This way life-cycle thinking is naturally integrated as key parts of the course orientation. This project is strongly based on the strategies of the second paragraph above, as it take the systems approach to engineering activities and actively involve faculty staff among several disciplines.

Environmental Education in regional colleges

The regional colleges in Norway became effective in 1994 as a result of a merger of approximately hundred smaller regional colleges. They offer engineering education within the disciplines Mechanical Engineering, Civil Engineering, Marine engineering, Production Technology, Naval Architecture, Information Technology and Chemistry.

The overall plan for three year engineering education at college level emphasizes an education with the aim of enabling engineers to combine theoretical and technical knowledge and practical skills, in a way that they become conscious of the interactions between technology, environmental issues and social issues. All engineering students must take a course in environmental topics covering interaction between technology and the society/environment.

This course has truly some interdisciplinary aspects. In addition to traditional lectures, groups of 5 to 7 students work on projects related to environmental issues, so called «student projects». The majority of these projects have their basis in local industry which are normally very cooperative in giving the students access to sites and information. Each group has an advisor appointed among the teachers in engineering disciplines.

The «student project» activity was started in 1992 and frankly spoken, there was a considerable skepticism among the teachers whether it was worth the effort. However, when they experienced the student's motivation for and keenness on this activity, their skepticism seems to vanish. They soon found that their «own» discipline and the teaching would benefit from this project work. Hence environmental issues have in a way penetrated the traditional discipline boundaries.

Collaboration between university, college, research center and industry.

Aalesund College offers more than 20 types of education. The work is in close cooperation with local industry and with local research centers. One of those regional research centers, Møre Research, was established in 1980 and to a large extent based on the personnel resources of the colleges in the region. The objectives of this institution are to advance, initiate, make arrangements for, finance and carry out research and transfer of competence in various fields. The local industry includes fishing and fish processing, ship building and maintenance, furniture design and manufacturing. Based on this industry, strong clusters have developed among which shipbuilding is regarded as one of the strongest clusters within ship industry in Europe.

Sometimes for universities, it is easier to find partnership and cooperation in an outreach program with other colleges and universities, than it is within the same university. In 1990 NTNU and the Norwegian Council for the Education of Engineers agreed to develop a national network for the development and maintenance of competence in trade and industry. As a minimum the network should comprise the technical university, the regional colleges, the employers federation and the workers union. The work has been arranged as a project and the main areas of activity in the past years have been to support arrangement of conferences on R&D issues, upgrading and further education, making policy documents on visions and strategies for competence transfer and give financial support for development projects. Those projects may aim to identify competence gaps/needs, develop upgrading courses, arrange «open R&D days» and develop R&D projects in cooperation with the regional industry. The network also aims at arranging student placement in the industry, and develop cooperation agreements with different trades regarding competence requirements and concrete measures to fill the gaps.

RESEARCH AND DEVELOPMENT PROGRAM SPONSORED BY GOVERNMENT AND INDUSTRY.

In 1994 Møre Research joined a Research and Development program jointly sponsored by government and industry. According to an agreement with Møre Research, Aalesund College participates in the research activities hereunder. Some 25 researchers of which 12 are college teachers, have been involved till now. Three doctoral students will make their thesis based on work within this program. The program has proved a success so far and local industry, Møre Research plus Aalesund College, are now heavily involved in what we may call a tripartite effort to strengthen the links between industry, research and education. In this connection the contribution by NTNU in the field of Systems Engineering has been very important. The Systems Engineering discipline in many ways forms the basis for interdisciplinary thinking.

Several projects have been carried out, the one building on the experiences from previous projects, all together forming a development program. Participators in those projects have been industrial partners mainly from ship industry (shipyards, shipowner, subsuppliers and legal authorities), researchers and people engaged in education (NTNU and Aalesund College, through international contacts at Nordic universities, and Technical University in Delft, the Netherlands). The progress in this program has been:

1. Cleaner Production projects,
2. System Analysis - Life Cycle approach,
3. Application of New Technologies and Product Development,
4. Environmental Impacts and Activity Based Costing during operation of a Ship.
5. Implementation of Environmental Management System,
6. Environmental Indicators for Environmental Performance Evaluation,
7. Development of Manuals and Industrial Guidelines for Pollution Prevention at Shipyards.

The methodologies, the implementation, results and benefits will be commented in the following context.

The program has demonstrated a truly integrated, interdisciplinary approach, as pointed out in the second paragraph above. Programs like this is often more easily implemented in a smaller university and colleges. Interdisciplinary cooperation is easier in a unit where the faculty are closer, and their meetings more manageable. On the other hand, the financial resources are larger and sometimes more available in larger universities. Industrial participation and financial support are therefore a must to develop the type of program discussed in this paper.

1. Cleaner Production project.

In this cleaner production project five Shipyards participated. The initial driving forces for them were the potentials for reduced costs resulting from better control of waste generation, waste handling and sorting systems etc. During this project all kinds of emissions and releases from surface protection, -cleaning and repair or rebuilding of ships were measured for approximately two years. The participating shipyards ended up with priority lists of actions which could reduce environmental impacts. The reduction was calculated, and so were the economic profits related to each of those measures. Measures that required little or no investment were effectuated with a minimum of delay and gave almost immediate positive results. Some of the measures required substantial investments and in some cases development of new technology and further research were required. This gave rise to new projects such as the following projects 2-7.

2. System Analysis - Life Cycle approach.

The Cleaner Production project revealed a need for taking the total System Life Cycle of a ship into account when calculating environmental impacts and determining priorities. The system had to be properly defined in order to understand its structure as well as the interactions of systems and their impact on the natural environment.

This project was a part of a course in Systems Engineering delivered through the collaboration between Aalesund College and NTNU. In this project the ship industry was described from a systematic approach. Systems and subsystems with their system boundaries were defined, and a detailed activity scheme for each of the phases in a ships life cycle were described. In this project the participants learned the principles and the process of practicing systems engineering. The result from this project was a general rise in competence of Systems Engineering. This project also made a framework for other projects involving product development and environmental issues in the ship industry.

The methodology in the System Engineering Process is illustrated in figure 1.

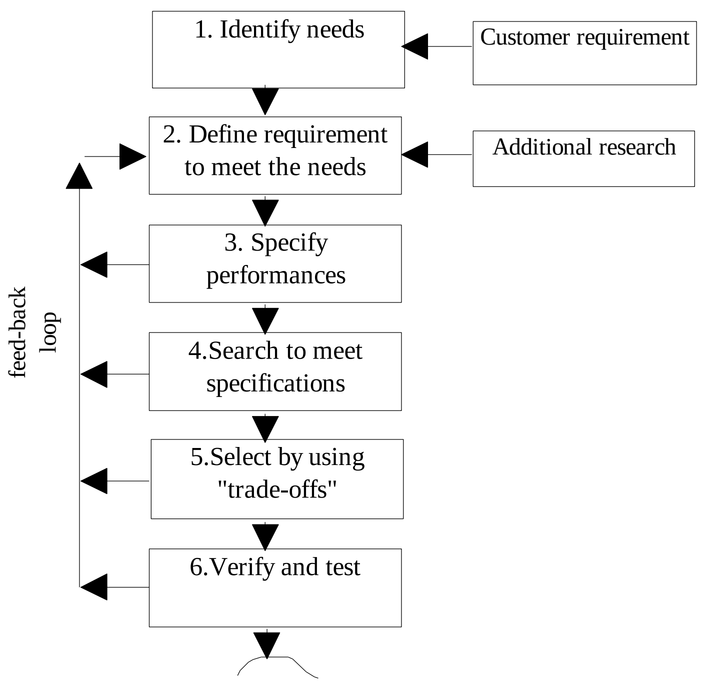

Figure 1: The Systems Engineering methodology described by six steps /1/, /2/.

3. Applications of New Technologies and Product Development.

The findings and priorities in project 1 gave rise to new projects aiming to solve urgent environmental problems within shipyards. Actual issues taken care of in those projects were cleaning and recovery of solvent, waste water treatment systems for dry-docks, high pressure water cleaning system for painted areas, systems for protection when outdoor sandblasting and painting, and waste handling systems.

The driving force for industry participating in these projects is mostly economical benefits through possible reduction of material costs, reduction of costs for waste handling etc.

4. Environmental Impacts and Activity Based Costing during operation of a ship.

In this project an activity based life cycle cost-analysis and a life cycle assessment study for a Norwegian Shipowner was carried out. The hull and the main machinery system, related subsystems, and activities as normal operation, maintenance and repair and related material flows for a ten year period, were studied. Applied methodologies were the Life Cycle Assessment (LCA)-methodology and the Life Cycle Costing (LCC)-methodology based on activity calculations. Those are illustrated in figure 2 and figure 3.

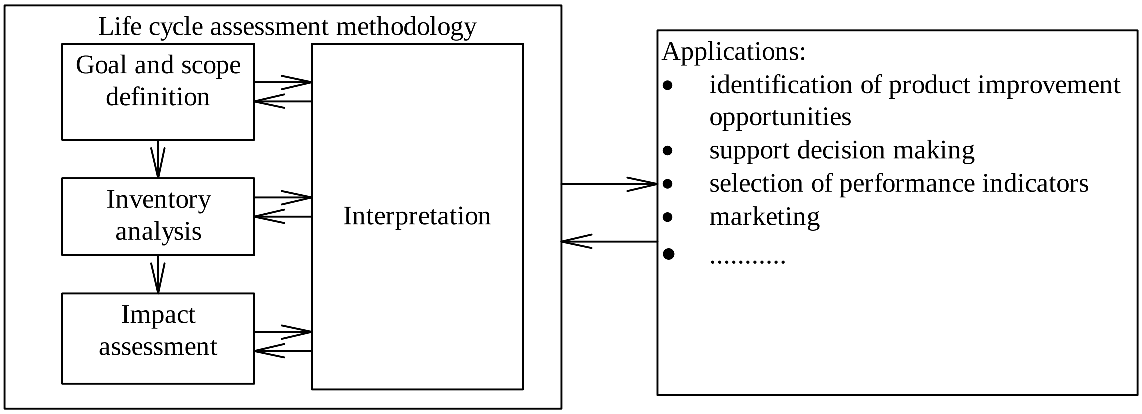

Figure 2: Phases of an LCA /2/.

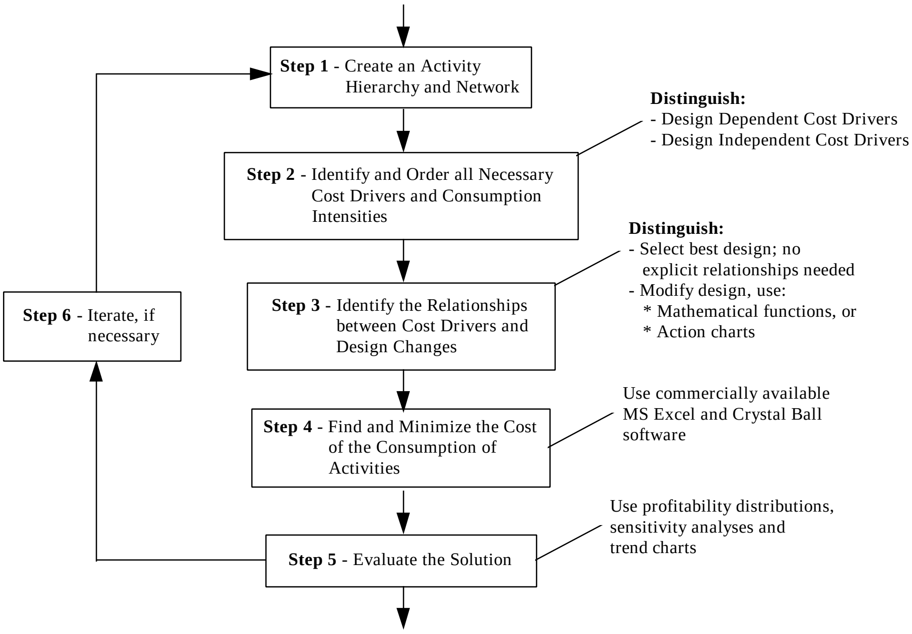

Figure 3: The method for activity based Life Cycle Costing. /5/.

Before detailed calculations, a Life Cycle Screening (LCS) was carried out to identify key issues for further investigations. An LCS is a simplification of an LCA.

The results from this project based on calculations related to selected paint- and fuel oil systems, will primarily be used as information for the shipowner. The experiences achieved from this project are however of great value for several parties involved in ship industry, both suppliers and stakeholders, for whom of the information of environmental impacts and repeated costs caused by material flows.

5. Implementation of Environmental Management System,

In Norway only a few organizations have an Environmental Management System (EMS) in place. This project focus the implementation of EMS at shipyards. Among relevant management systems as British Standard 7750, ISO 14001 and the European Eco and Audit Scheme - EMAS, this project focuses on implementation of EMAS. The methodology is illustrated in figure 4. EMS constitutes that part of the overall management system which includes the organizational structure, responsibilities practice, procedures, processes and resources for determining and implementing the environmental policy. In the performance cycle also checking and corrective actions and management review are included.

Experiences from this project are directly transferable to education in interdisciplinary areas, and therefore of great value for both participating industry and engineering students. The achieved competence for researchers participating in this project should easily be coupled to other activities taking total quality management (TQM) into consideration. This project was in also coupled to a national program in Norway aiming to spread knowledge and experience between companies.

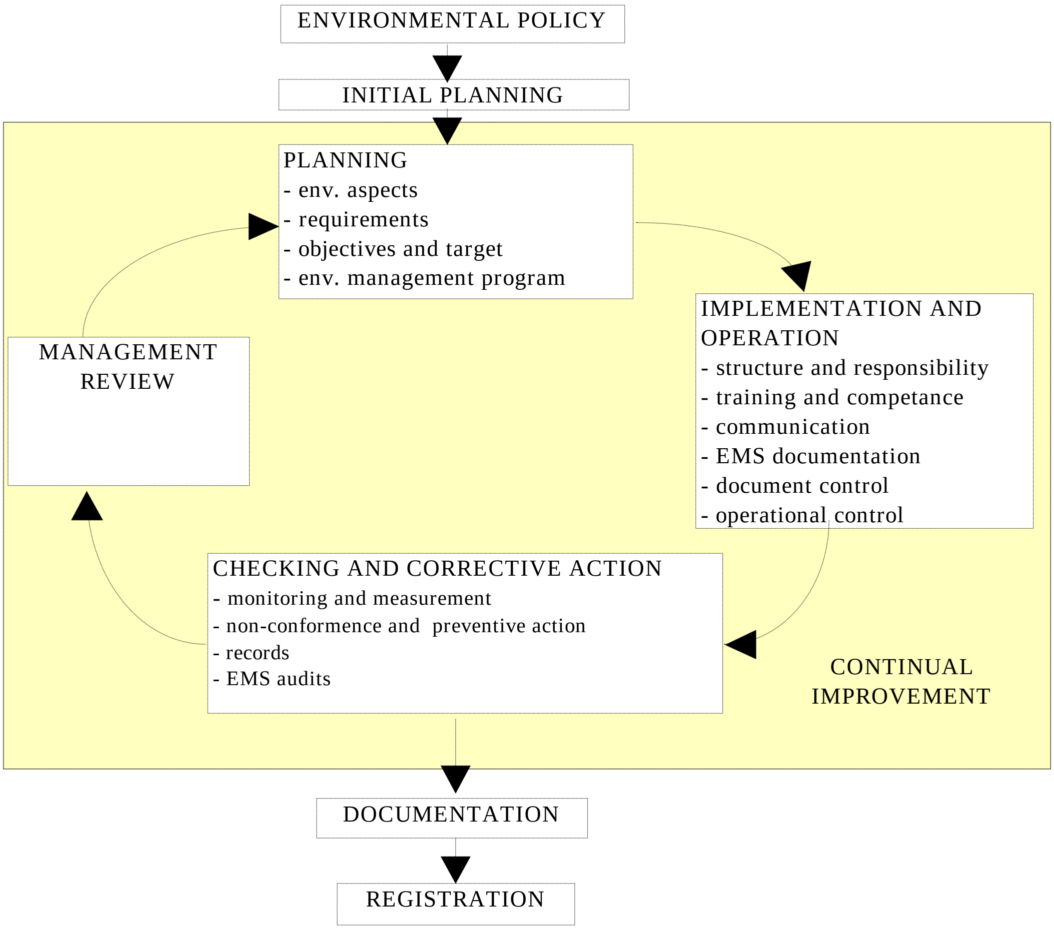

Figure 4: The methodology for implementation of Environmental Management System.

6. Environmental Indicators for Environmental Performance Evaluation.

This project aims on developing Environmental Indicators for the evaluation of environmental performance in the shipbuilding industry in Norway. Three shipyards are participating and this project is also a part of a collaboration between Nordic companies representing a broad diversity of industries. This project will be finished and reported autumn 1996. Environmental indicators will be of great value to industry in the future for internal and external communication to parties involved; employers, stakeholders in, authorities and financial parties; banks and insurance companies. Based on experiences from this project, training courses relevant to all kind of industries will be developed.

The methodology for the EPE-process are as indicated in figure 5.

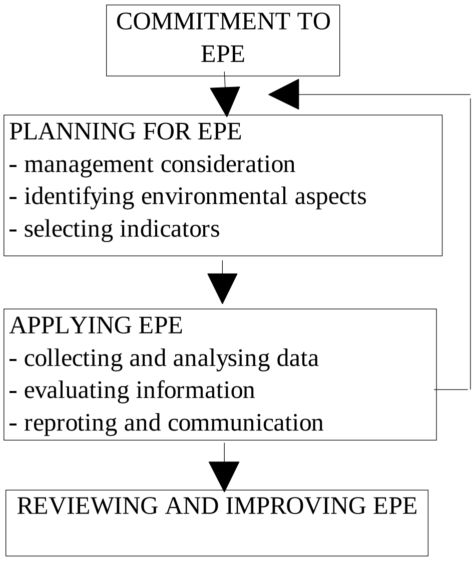

Figure 5: The Environmental Performance Evaluation process. /11/.

7. Development of Manuals and Industrial Guidelines for Pollution Prevention at Shipyards.

Based on experiences from these projects, a manual for pollution prevention, «Handbook in Cleaner Production in Shipyards» /7/ has been written. This manual are used as teaching material in environmental courses both for students in naval engineering and construction at Aalesund college and as a manual at shipyards. It has also been used in lectures for students at NTNU. The manual is written in Norwegian, but are partly translated to English and constitute a part of the Guideline «Shipyard Environmental Pollution Control». This guideline is now in use at shipyards at the Philippines as a part of a UNDP-program in Manila, hence an international transfer of knowledge has taken place.

Summary

Although the program has not yet been finally evaluated, we can already see some positive effects apart from promising R&D results, e.g. the establishment of a network between industry, research and education, promotion of interdisciplinary thinking through working in teams dealing with complex environmental problems related to industry. Feedback from projects has had a concrete influence on the curricula of Aalesund College, and competence in research procedures transferable to other industries.

We feel, however, that experience and know how derived from this program could be utilized more effectively in education with regard to, curriculum content and pedagogical issues. A key issue will also be how to obtain continuity in the network cooperation when the program terminates.

INTEGRATED ENVIRONMENTAL EDUCATION.

Systems engineering and inter disciplinary are key words in how to integrate educational disciplines. This is particularly important when it comes to a thorough understanding of the environmental issues related to human activity. Without the ability to see the coherence and consequences across discipline boundaries, we will not be able to give a fully adequate education in any discipline. Governments seem to be increasingly aware of this fact and try to introduce programs and policies that may improve the situation. However we still have a long way to go; old traditions and ways of thinking still prevail in the educational institutions, but attitudes are slowly changing at all levels as the concepts of interdisciplinarity and systems engineering gain ground.

The project examples discussed in this paper are true examples of close collaboration between industry, research center, regional college and university. Although purposely intended one might say that as a spin-off from these projects, one have obtained a higher degree of integrated environmental education. The model of integrated education related to industrial projects dealing with environmental problems - in this case focused on the ship industry, is illustrated in figure 6. As indicated in the model the experiences achieved through the interactions between the elements industrial projects, knowledge and research, will all give inputs to an integrated environmental education.

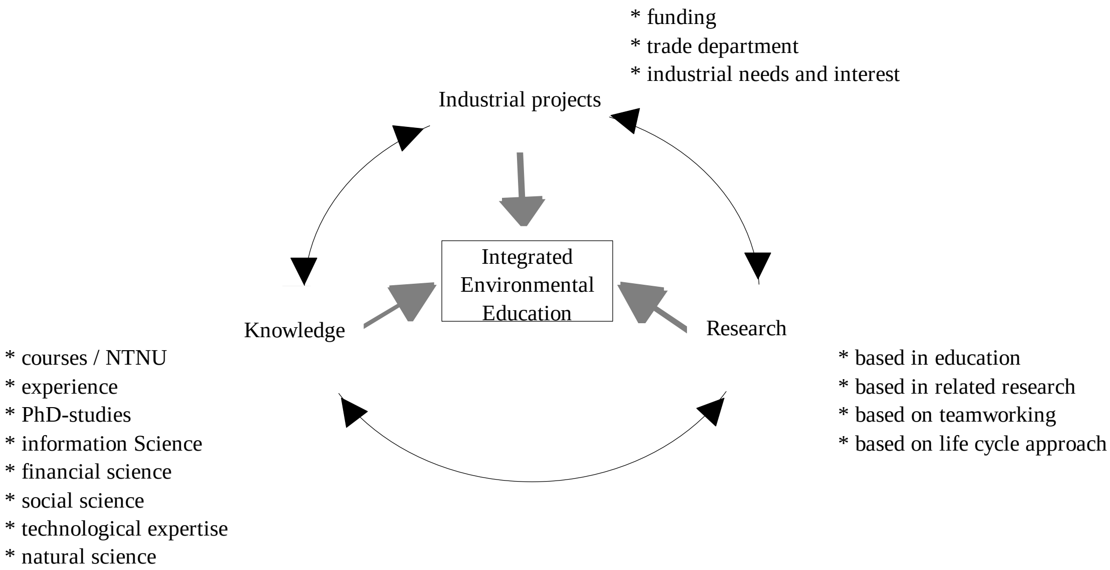

Figure 6: Model of an integrated environmental education program.

I would like to point out that an integrated environmental education based on this model must be based on principles in Systems Engineering / Systems Approach. An interdisciplinary teamwork is necessary to cover all aspects as indicated in figure 6. This model include the four basic disciplines in Systems engineering; Information Science, Financial Science, Social Science and technology, all interacting with the natural system including Natural Science.
Through project work, different methodologies have been applied. Experiences from the projects should be combined into one overall methodology, e.g. the systems engineering methodology. Although specifically developed for the ship industry the methodology has an universal value and can be applied for other industries as well. The most important aspect till

now has been to develop an adequate methodology and it has taken the concept from 3 to 4 years to mature within industry.

Discussion and conclusions

The present departmental structure of university organization and the academic meritation by specialization, partly work against the above model. The criteria for academic promotion in Norway, as in the rest of the World, are research, patents and publications. In depth knowledge in a fairly narrow field is required to succeed in those areas. This again is in contradiction with the interdisciplinary requirement, which is a broad, usually more shallow knowledge in many fields. The way environmental engineering evolves depends very much on such factors. Therefore, a combination of paragraph 1 and 3 in the introduction chapter is usually found.
Practical co-operation between research institutes, industry and universities in the implementation of research projects, education and training development are excellent opportunities for new knowledge transfer between participating organizations.

In order to function as competence centers serving trade and business, the educational institutions for higher technological education in Norway have an obligation to cover four main areas of responsibility; R&D functions, basic education, further education, upgrading, post graduate, and further development and dissemination of technology. It is important to emphasize that these four areas of responsibility should be seen in a total context and that pertinent measures are organized in such a way that they mutually support each other. At the same time it is of vital importance that the interconnections between the institutions are established with the Norwegian University of Science and Technology as a center of gravity. One of the main challenges in the time ahead is to build up competence in cooperation with business and trade. A strategic issue will be how to create a total concept within competence development where all the elements of technological education contribute in a concerted manner.

Elements to be incorporated in such a concept are

- Basic education, including student placement and provision of candidates that meet the industry demand;
- Research, including dissemination of research, exchange of researchers, R&D tasks related to industry, and technology transfer;
- Upgrading and further education trough traditional upgrading and further education, specialist education, internal company courses, and conferences and seminars both national and international;
- Competence as a discipline, achieved through supporting companies with respect to competence mapping, evaluation of needs, and development of strategic competence programs, competence on new technology for dissemination of knowledge, and the establishment of local and national fora for competence development and exchange of experience;
- Personnel, including associate professorates, trainee arrangements and exchange of personnel;
- Cooperation with Employers Federations and Workers Unions;
- Education of Researchers including research cooperation via doctorate programs.

Challenges for Environmental Engineering

According to recent and present thinking in business, industry and governmental agencies, modern environmental engineering strategies must focus four key aspects:

i) pollution prevention rather than end-of-pipe technologies;
ii) the need for life-cycle approaches and interactions technology/society/nature in a wider perspective than before;
iii) the need for market-based regulation mechanisms, and
iv) the need for strong improvements in environmental efficiency in a long-term perspective.

These aspects call for radical changes of environmental engineering education, however, such changes within the university curriculum is a difficult process.

The point is that life-cycle aspects of relevance to environmental engineering should be regarded natural, integrated parts of such key elements in engineering curricula. Environmental technology is one of the fastest growing markets world-wide, and the variety and number of technical solutions to environmental problems has evolved at great speed during recent 20 years. Now it is time to search for new solutions which may fulfill our demands decades ahead, and there is no argue that such solutions will have to be based on an environmental efficiency which is far much higher than that of present technologies. It is simply not possible to achieve such efficiencies by maintaining the add-on, or end-of-pipe, technology strategies. So, one of the most needed and demanding challenges of engineering education is the re-orientation of environmental engineering focus.

In the traditional education you will normally find the four phases; planning, design, construction, operation. Very often the total life cycle of a system, including decommissioning and disposal of waste, is not taken into account. This results in a very fragmented way of thinking. The challenge for future engineers should therefore be the systems thinking in a holistic perspective.