Integrating sustainable development in engineering education
The novel CIRRUS approach

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1. Introduction

If sustainable development is to become an essential aspect of society and economical development, it has to become as well an essential part of education. In the Netherlands various initiatives have been taken to reach that aim. Different approaches exist on the various universities and UPE's [2]). Several pilot and demonstration projects have been started.
The CIRRUS project was set up as one of the earliest projects, to demonstrate the feasibility of a novel approach towards integration of sustainability and education and to develop the experience, knowledge, tools and methods other UPE's and universities can apply.[3])

Its novelty is the really complete integration of sustainable development in the studies, in all modules and part of the relevant subjects and activities through all phases. It is not being treated in a separate course or as an optional subject or additional specialisation, during or after the study. As far as we are aware such an approach is unlike what was, and mainly still is done elsewhere, in the Netherlands and abroad.
That makes it indispensable that much effort is put into 'training' the teachers and developing clear learning goals. Learning materials are intended for the various lecturers as information and inspiration when implementing sustainability in their own subjects, courses and learning materials. Only to a minor extent specific materials are made for specific sustainability courses and projects. Those are intended only for introduction of concepts and to act as integration moments for all different aspects.

Such far-reaching integration is an ambitious goal and poses many practical and educational complications. Nevertheless the fundamental idea behind this is that when we consider sustainable development to be essential for all activities within society and all sectors of economy, it cannot remain an isolated field of expertise but must form 'mind-set' for everyone.

The CIRRUS project started in 1999 within the faculty Technology and Natural Sciences (FTN) of the Brabant University of Professional Education (HSB). It focussed in particular on introduction of STD on the technical faculties of UPE's. FTN had already since 1991 a study that focuses on sustainable technological development in the department Environmental and Material Sciences. That formed the nucleus from which the project was initiated.
The project is sponsored by the Knowledge Transfer and Implementation Program of the Dutch Organisation for Sustainable Technological Development (DTO-KOV), the national UPE Council, the Province Brabant, municipalities and several large and small industries, which all recognised the importance of this novel approach.

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2 UPE Universities of Professional Education are the Dutch institutes of higher education for applied sciences (in Germany: 'Hochschule')
3 Several other papers in this conference report on the experience gained by the CIRRUS project.
- Multidisciplinary projects as learning tool for sustainable approaches, L. Dejong etal
- Integrating sustainable development, the case for chemistry and chemical engineering, J. Hageman etal
- Incorporating a life cycle perspective into chemical education: a first experience, J. Hageman etal
- The AISHI method for auditing Sustainability in Higher Education, N. Roorda

The CIRRUS project was awarded in 2001 with 'the egg of Columbus trophy' by the Ministry of Environment, Housing and Spatial Planning for its innovative approach to introduce sustainable (technological) development in higher education.
Officially it ends December 2002, although of course further care must given to develop it further and guarantee future progress.

2. The challenge of sustainable education

Requirements of sustainable development

The Dutch development program "Sustainable Technological Development" (DTO) [1] has defined the basic characteristics of the most likely and feasible routes towards real sustainable development. The essential feature of such routes is based on a paradigm shift in developing, designing and implementing technology. Asked for are 'system innovations' and 'transitions', aimed at satisfying needs and less at 'just optimisation' of the isolated performance of products and processes'. It is often not so much the character of technologies that influences 'sustainability' as the way they are used. A backcasting approach has been developed for generating some insight in what sustainable development could and should imply, technically, culturally as well as socio-economically.
Students must be trained to handle such a 'systems-approach' for finding sustainable solutions and implementation options for the short and for the long term. It requires multidisciplinary and 'lateral' thinking. The attitude and the competencies to do that are essential for a really sustainable development oriented engineer.

A sustainable future for education

Defining how a STD oriented study and curriculum should look like, requires fundamental insight in the way society, industry and the professional requirements will develop in the future. It is logical to use also for this the 'backcasting' method to find out what has to change in education now when taking into account where we want to be in the short and the long term. [2]
A visualisation of future developments should be translated requirements for a practical intermediate phase based on how will industry, business and other organisation, the students will work for, look like. From this the requirements, the present studies must train for should be deduced, with some leeway.

Within the framework of the CIRRUS project we tried to orient ourselves on a study program fitting the requirements of society, as it will be around 2010. Several back-casting sessions have taken place, involving staff form the various departments and in some cases representatives form industry and authorities. The results strengthened the vision developed and added new requirements and issues to focus on.

Specific new knowledge has to be taken up in the subjects learned. But education will have to concentrate too *on the methods* through which solutions are to be found, how resources, technology, materials and products are to be used and how acceptable and comfortable solutions, also in the long run, can be found and implemented to satisfy present and future human needs and still leaving room also for nature. And even more than already is the case, in view of the dynamic development of 'sustainability', students have to learn to learn.

Sustainable competences

'Sustainable thinking and doing' must be fitted in 'competence focussed learning', a new approach, with growing importance in Dutch higher education. That can be done easily.
The task of a graduate working in a company or organisation that wants to act responsible with respect to sustainable development was during the backcasting formulated as follows:
"taking into account the quality of life for present and future generations in all activities, designs and business operations."

A formulation of the competence fitting that is:

- *Being able to define the influence (positive and negative) on the "critical sustainable conditions" regarding human quality of life, environment and ecology on the short and the longer term of existing and new products, processes and/or activities.*
- *Being able to develop and use approaches that substantially contribute in decreasing negative influences and increasing positive ones and which eventually lead to a better quality of life and sustainable economy*

It is a rather abstract definition but the most practical to fit with the various sets of competences developed for the different studies in the departments of the faculty.[4])

The CIRRUS project takes up the challenge

In summary, the conditions set for the CIRRUS project approach are:

- Including a paradigm shift in developing, designing and implementing technology, aiming at 'system changes' and not on 'only developing and applying innovative technologies;
- Attitude and insight are the essentials for a really sustainable development oriented engineer;
- Students must be trained to handle a 'system-approach', which requires interdisciplinary and 'lateral' thinking. Backcasting must be a part of developing a vision.
- Students still have to become experts in their respective fields, but with 'an extra', being the competences mentioned in the points before.

The practical steps taken were:

- Developing a 'model' for integrating STD in the studies, fitting with those conditions
- Definition of criteria and learning goals for such integration
- Development of an implementation program, involving all departments and lecturers

3. A model

The model we developed has three components:

1. Each course, project and other activity in the 'normal' curriculum takes care of the issues relevant for sustainability connected with its own subjects such as materials use, energy, design approaches, economics, business operation methods, etc.
2. An introductory course on an early moment elucidates the concept; sets out the 'line of approach' sustainability needs and creates the general framework for issues and details treated elsewhere.
3. Attitude, lateral thinking, interdisciplinary ability aimed at sustainability will get much attention throughout all activities in the study and increasingly so towards the end. Learning by doing the various tasks, practical work and projects offer the best opportunity for this.

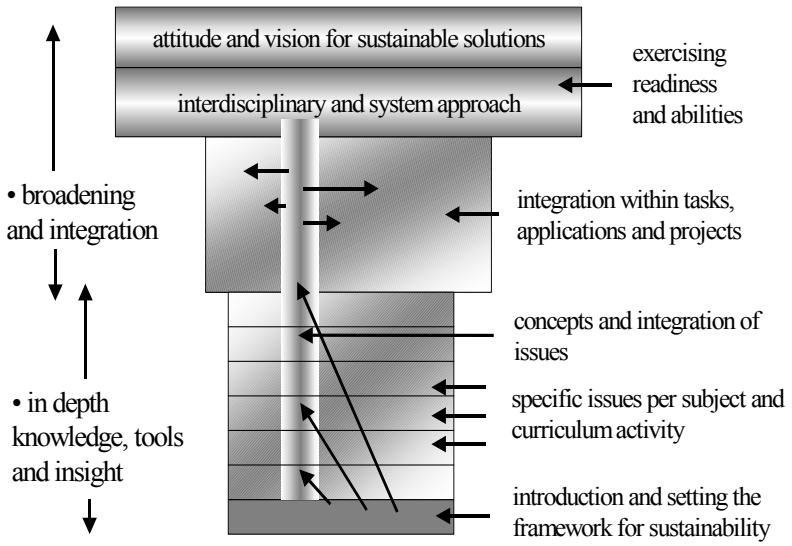
The goal must be: students will still become experts in their respective fields, but with 'an extra': those knowledge, competences and attitude needed for ' sustainable thinking and doing'.

Figure 1 visualises this approach, from a basis of in depth and mostly specific 'narrowly' profession related knowledge and skills, building up towards broad capabilities and attitude for 'real sustainable thinking and doing' based on having broad view and working with an interdisciplinary system approach. It is dubbed the 'T-model' for integrating sustainable development into curricula.

Figure 1. Integration model for sustainability in a study: the T-model

4 There is a tendency to include in the definition of the 'sustainable competence' broader and more general items such as: being an able professional, working in projects, innovation oriented, etc. In our opinion these are essential for a graduate in general and not exclusively connected to a sustainable competence. It is therefore undesirable to include those, because it would draw away attention for real relevant items.

The shading indicates that attention for sustainable aspects is really spread through all of the curriculum and not a well-defined and separate issue. The horizontal beam of the 'T' signifies the broader view including the 'systems approach' needed as well as the inter- and multidisciplinary understanding needed to work with other experts from other fields, technical and non-technical.



4. Criteria and learning goals

Knowledge and capabilities to be integrated

As result of a lot of brainstorming and inventory actions a whole multitude of issues is chosen to be essential for the 'sustainable competence' as defined. Those have to be covered and learned to a 'sufficient' level. They form the 'learning goals' for a curriculum intended to include sustainability and the criteria by which the extent sustainability is covered can be measured.

They fall into three main theme's which each has its own role and shows a specific angle to look at sustainability.

- ✓ environment, ecology and socio-economic oriented issues as degradation and depletion, poverty and social disruption, for understanding the basic causes, policy development, history etc. It gives the 'WHY' of sustainable development.
- ✓ system oriented issues, as product chains and technology development. It gives the specific knowledge for methods, technologies, the overall approaches to be able to come to sustainable solutions and development routes. It gives the 'HOW'.
- ✓ human and society oriented issues, as need and function, cultural aspects, ethical issues, human behaviour etc. It gives the context that has to be taken into account and determines the gap between desirable and feasible. It gives the actual 'SCOPE' that counts.

Level and extent

Defining the detailed criteria and learning goals of 'sustainable competence' for the separate studies also necessitates that to each of those a level must be assigned.
In education commonly four levels or categories of training and awareness are distinguished:

- o Knowledge
- o Understanding
- o Skills
- o Attitude

For the different studies / professions such 'thinking and acting in a sustainable way' the required level and extent of the various issues will of course be different.

The minimum level for key issues, spread over all three themes, is in our opinion as follows:

Knowledge is required regarding the basic facts and concepts. That includes environmental pollution issues, resources, and possible technological solutions but also the present policies and history of the field, laws and regulations, scenario's which have been developed.
Understanding is required for how 'things work' (technical but certainly also socio-economical and cultural), problems occur and how sustainable options might function.
In particular one must understand the different angles to look at options and constraints:

- Function oriented: consumer-needs and preferences, requirements of society
- Culture and structure oriented: socio-economic fitness, required adaptation of economic structures and behaviour, background of rebound effects, business management issues;
- Chain oriented: the cohesion of activities, potential for transfer of problems, local suboptimalisation;
- Multidisciplinarity: essential contributions of other disciplines, technical and non-technical issues involved, ethical and cultural aspects
- Time oriented: learning from the past, short term options against long term strategy

Skills are required for assessing effects, positive and negative, and designing in particular:

- Use of 'practical tools' such as LCA, design methodologies as DFA and DFD, exergy analysis, water and energy pinch and the like.
- Handling integrated system oriented approaches, which involve communication, finding information, working together in projects, understanding other professions.

Attitude goes beyond it all. It is deemed essential not just to understand but also to be committed to sustainability. Only then knowledge, insight and skills are used 'automatically' and effectively.

Example of a set of learning goals to be attained throughout the study

Level → / ↓ Theme	Knowledge	Understanding	Skills	Attitude
Environment, ecology and socio-economic oriented	- causes of pollution, - resource availability - policies and laws, national and international - history of technological evolution - future scenarios	- cause – effect relations for the various issues	- developing a vision on possible developments and their effects, backcasting - finding and assessing relevant information - operate from existing laws and policies	- keep a view on possible and wished for developments - own, critical, opinion on sustainable development
System oriented	- basic facts of various relevant technologies - overview of resource options and their drawbacks - set-up of care systems,	- function oriented character of sustainable approaches - the systems structure of fulfilling human needs - the role of other disciplines - broader 'profits and costs' assessments - relation of short term actions and long term strategies	- LCA - design for sustainability - use of DFA and DFD methods, - exergy analysis - water and energy pinch, - product chain management -multi- and interdisciplinarity - sustainable business operation	- 'automatically' use the knowledge, insight and skills effectively - willing to include inter- and multidisciplinary aspects
Human and society oriented	- relation of the various actors in society	- consumer behaviour and rebound effects - cultural aspects in using technology	- critical assessment of potential uses of technology	- understanding own responsibility as an individual in society - critical attitude

Important learning goals are 'systems thinking', multidisciplinarity and capability to work from a future oriented vision. What is needed is not just knowledge and practical application of technology and methods, but also, and maybe even more, an all-encompassing attitude towards 'sustainability'.

Working in a ‘systems oriented way’ is seen as essential for a student to be able to really develop sustainable options. It however is one of the hardest to learn and to teach. ‘Problem oriented education’ and projects in which students, preferably from different studies, work together is seen as the best method to train this.

A combination of learning goals and levels must form a complete set of criteria for each study that can be used to assess the ‘sustainability’ of a curriculum. It will differ for the different studies and can be made as extensive and detailed as needed. See the above example.

Time involved and phasing

A logical outcome of total integration in the form chosen is that sustainable development is a continuous area of attention in all phases of the study. The aspects treated and the specific learning goals to be attained differ in time, dependent on the specific subjects and courses in each phase.
What is defined is a minimum amount of time, i.e. attention that has to be dedicated to ‘recognisable’ aspects of sustainable development and covering the specified learning goals. That amount of time is presently set on 5%, which signifies 80 study hours. In some studies in which sustainable development is already a strong issue, eg Building Design and Construction, that is already substantially more.

As is indicated during all phases short courses, projects and presentations are given to introduce and to integrate concepts and to stimulate specifically the development of ‘a sustainable way of looking, thinking and doing’.
During the study there is a shift in attention for the three themes. In the first phase much attention is paid to the background: the environment, ecology and socio-economic oriented issues. That shifts in the later years towards the system and the human and society oriented issues. Understandably, during the last phase of a study, during practical work and the final project the system approach gets most attention.

Some discussion is going on regarding the moment a complex issue as sustainable development can be introduced to students, when they are ready to become interested able to understand it. Consistent with the vision that sustainable development is an intrinsic aspect of all subjects; in the CIRRUS approach sustainable development is introduced in the earliest possible moment. That proved indeed to be possible and was actually quite effective and rewarding. If brought in a ‘light and easy way, in a short project students are very interested and early insight is easily gained, on which can be built later on.
Such projects were commonly based on issues that concern ‘aspects of daily life’: own energy use, environmental effects of household products and activities and excursions to ‘sustainable building projects’. The latter were done actually already during the introduction weeks for the study.

5. The implementation

The choice made to aim for real and total integration, led to the following principles for the implementation:

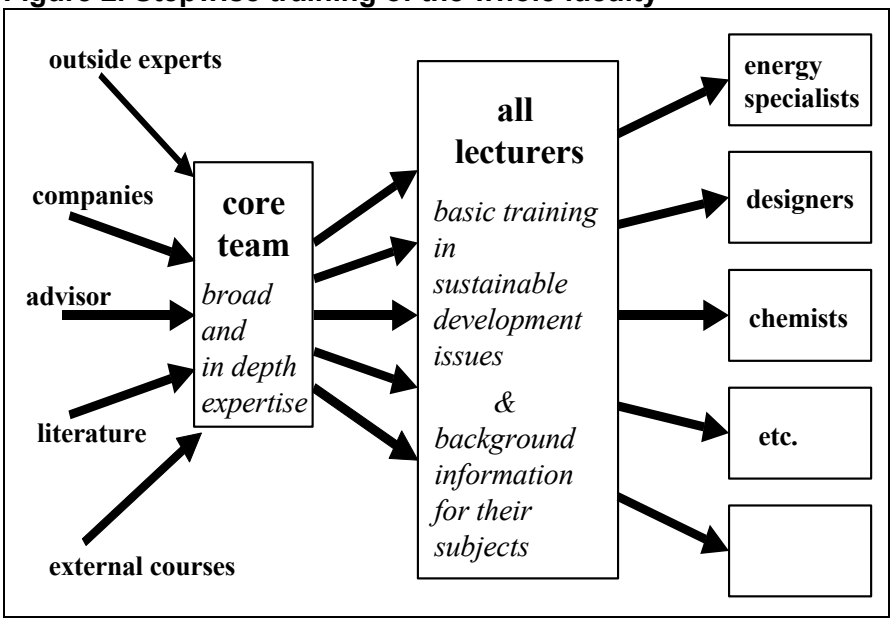
1. All lecturers have to get involved and must therefore be trained.
2. Dealing with sustainable development will be done within the framework of the existing educational structure, although that might change somewhat under influence of new insights and approaches created by this new scope.
3. Teaching materials for sustainable development are developed mainly with the aim to help the lecturers to introduce the relevant issues and subjects in their own subjects and to let them develop their own teaching materials.

Training the staff

This is seen as the most essential part of the whole project. If this is insufficient and the majority of the staff remains indifferent and not involved, real integration is impossible.
There are a large number of lecturers to be trained because of this approach. It had to start more or less from scratch because only few lecturers had prior knowledge above just some general idea about sustainable development. A two-step approach was chosen therefore.

- A core group was formed of about 10 lecturers from all departments involved and trained.
- This was made responsible for training the total of all staff involved (around 250 persons).

Figure 2. Stepwise training of the whole faculty



The ***core group*** responsible for the training of the other lecturers, also formed the project team that functioned during the whole of the project. They also developed the various learning materials. Furthermore they will continue to act as an expertise group to continue the further development and implementation, and maintain the quality of what is reached.
The training of this core group was in the hands of an outside expert on sustainable development who stayed on during the whole 4 years of the project and acted also as adviser on other project-connected issues.

Training started through presentations and discussions by outside experts and visits to companies and institutions involved in sustainable projects. Gradually the members of the core group trained itself and one another through doing literature research, writing essays, setting up workshops and doing project with small teams.
The basis of the approach is that lecturers start with their own specific expert knowledge, develop that further with respect to the related sustainability issues and teach one another with what they have learned themselves. The systems approach and the multi and interdisciplinary aspects are learned ‘ hands-on’ just by doing many projects.
The written results of that training form part of the learning materials. Moreover, developing learning materials was excellent training too.

The training of the whole staff was done through a series of introductory courses for all departments with groups of 20 persons. It was developed and given by the core group and concentrated on general aspects of sustainable development. It included a project/workshop with as case a more or less department related subject. The courses were concluded with a discussion on how to implement sustainable development in the specific study.

Also here further training has to be done through self-study and by doing external courses. For sustainable use of energy a separate course was developed in cooperation with the UPE Enschede and ECN[5]) and given for the about 20 lectures whose courses deal with items on energy which are deemed essential for sustainable development.

Redesigning the curricula

The different departments themselves have to take care of the implementation of sustainability in the various curricula, with assistance of their representative from the core group. Because new things start slowly, that representative did in fact at the beginning most of that, certainly for the first year. That forms however a good basis for the work of others for the successive years.

First step in the process was a review done by the lecturers of all present subjects in the courses with respect to their relevance for sustainable development. That was to find all aspects and issues that were already dealt with, but maybe not explicitly related to sustainability. That review together with the learning goals defined for the specific studies formed the basis for a total program that defines which aspects and issue should be treated and their place in a study. How that has to be done is left to the lecturers themselves. The responsibility for the sufficient implementation lies with the lecturers and for the 'sustainable quality' of the program as a whole with the management of the department.

An observation is that those studies in which the knowledge areas have clear links with specific issues of sustainable development (energy, designing) and where in actual practice someone working in that field is faced with much sustainable development already, implementation in the study is more easy and directly more 'integral'. Examples are Building Design and Construction, Chemistry and Chemical Engineering (see separate paper) and to a large extent also Production and Operation Management.

During the project it became clear that project and problem oriented education are very apt methods to develop the capabilities for systems approach and multidisciplinarity that are essential for real sustainable solutions. They form also the best tools to train a 'sustainable view and attitude'. For that reason within the framework of the CIRRUS project a specific project was started to develop multidisciplinary projects and to find the right way to use those for 'learning sustainable thinking and doing'. (see separate paper)

Most of the separate introductory courses for sustainable development are based on problem oriented education and projects. For some studies this was already the standard way of working, for others it is a new approach, in which this introduction of sustainable development now is instrumental for introducing it in the whole study.

Teaching materials

As discussed learning materials are needed for:

- The introductory and 'integration' courses, mostly in the form of short presentations and projects in which the students get acquainted with basic concepts and issues.
- The background information which the lecturers must use to integrate the relevant sustainable development issues and aspects in own subjects, courses and learning materials

Additionally much literature and background information have been collected, also reports from institutes and groups active in that field, which is made available to the lecturers and students.

Introductory reader

5 Dutch Centre for Energy Research

To make available basic information for the introductory courses a reader was developed that deals with all relevant issues and concepts concisely. It gives the background on the "why and how" of sustainable development and treats the important issues, such as sustainable energy, use of materials building and consumption.

Toolboxes

For a number of issues that are important and/or have a large relevance for lecturers, so-called toolboxes are being developed. Those contain a basic amount of information, sufficient to understand the ins and outs of the issue and give its position and role within sustainable development as a whole. It supplies also some examples for teaching. Examples are: sustainable use of energy, sustainability and ethics, industrial ecology, consumer behaviour.
For easy accessibility and use a standardised set up is followed: an introduction, the most relevant literature and websites and when available some examples of projects and other learning material. Of course students can also use it as initial information in projects and problem oriented learning, in which these issues are arise.

6. Dissemination

The CIRRUS project is set up as a demonstration project. So much effort is also given in making the results and the experience gained available to other UPE's.

The Introductory reader (although still a 'draft') has been distributed to all UPE's, and is at least being used or functions as example in five of them.
Much of the information is placed, or will be, on the project website www.projectcirrus.net (however mostly still in Dutch). On several occasions presentations are given and papers published, also in international forums.[2,3]
In close cooperation with the Project and Training Centre of the University courses and workshops are being prepared to train lecturers of other UPE's that are interested in implementing sustainable development and courses for specific subjects are set up.

Furthermore the faculty is an active participant in the committees and projects of the Dutch Platform Sustainable Higher Education. Those activities included also the development of the AISHI auditing method [4] (see separate paper) and a review of the curricula of the departments Production and Operation Management of all Dutch UPE's with respect to 'sustainable content'. Exchange of information internationally is done through the Network of the European Copernicus Program.

7. Present status, further implementation and securing progress

In this phase full implementation has only been achieved in the first year of all studies involved. Implementation in the second year is done now. Nevertheless, already in various subjects and courses in other years sustainable issues are integrated because they prove to offer excellent challenges and training opportunities for the students, which are much interested in it too.
A yearly award is established, starting this year, for the student whose final year project embodies the best contribution to sustainable development.

As one of many others the Faculty has applied for the Dutch certification Sustainable Higher Education and received one. That will require further development and involve regular audits. An audit is planned for half of the departments involved at the end of 2002 using the AISHI protocol.

Furthermore, a so-called knowledge centre linked to a lectorate 'Sustainable Business Operations', is being established at the Brabant University of Professional Education. Its role is to develop knowledge in that field, in particular practical approaches for small and medium sized

enterprises and bring education in that field on a higher level. It serves also a wider role in acting as focal point and centre for further implementation of sustainable development in the faculty. An important characteristic of that knowledge centre will be the extensive interaction with external groups, companies, institutes, authorities etc. The intention is to stimulate 'knowledge circulation' as was an important characteristic for the CIRRUS project too.

8. Conclusions

The approach chosen in the CIRRUS project was ambitious. The results, in our view, support however its feasibility. The first observations show that total integration is possible, rewarding and also can bring the whole of a study to a higher level. It is clear however that it asks much time and involvement, and requires patience and flexibility. Although obtaining acceptance was difficult, the validity of the approach is becoming apparent for most of the lecturers involved. An important factor for that was finding a good link with the existing subjects dealt with already in the studies, the actual sustainable development issues the profession is working on already and using as much as possible the existing set-up of the curriculum and education methodology

The two-step structure to train the lecturers, worked very well. Not only because of its efficiency but it created a very competent and motivated nucleus of lecturers that is essential to assure progress of the implementation and future quality. Besides it forms a useful reservoir of expertise for exchange of information with industry, municipalities and other UPE's.

Supplying 'just background information', in the form of an introductory course and toolboxes, to the lecturers leaves them the responsibility and the challenge to upgrade their own courses and materials. Although it did and still does lead to a sometimes, at least initially, poorer content and level with respect to the criteria set, it took away much discussion, prevented emergence of a 'not my idea' attitude and in fact stimulated involvement. At the end that will guarantee good quality!

Summarizing: sustainable development as a 'systems approach' and a way of 'looking at problems and solutions' is now getting ingrained in the studies of FTN, their content and their organisation. It is becoming part of the way students learn and the way lecturers teach. And others rapidly take up those ideas and approaches, at least parts of it, too.

Literature and references

[1] Jansen, J.L.; Vergragt, Ph.; STD Vision 2040 – 1998: Technology, Key to Sustainable Prosperity Multi-disciplinary Research Program Sustainable Technological Development, DTO; Den Haag, 1997

[2] Roorda, N.; Backcasting the future; Internat J. of Sustainability in Higher Education 1,2(2001),63-9

[3] Venselaar, J.; The CIRRUS approach towards integration of sustainable development in higher technical education, Proceedings European Congress on Chemical Engineering, Nuremberg, Junet 2001

[4] Roorda, N.; Auditing Sustainability in Engineering Education with AISHE. Proceedings ENTREE2000, pg13-30, Belfast, November 2000, ISBN 90.76760.02.0