EDUCATING ENGINEERS FOR/IN SUSTAINABLE DEVELOPMENT? WHAT WE KNEW, WHAT WE LEARNED, AND WHAT WE SHOULD LEARN

by

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In the past decade, several engineering universities, mainly in Europe, but also in Australia, North America, and Japan, have been addressing the issue of sustainable development. Engineering education in sustainable development has been discussed at many occasions. What questions have been addressed, what answers have been provided, and what are the main remaining topics for research into engineering education in sustainable development?

What should engineers learn regarding sustainable development? How to trigger institutional change within engineering schools: top-down or bottom-up? How to trigger cultural change, how to win the hearts and souls of the faculty? Curriculum change: starting new programs or changing existing ones? The contribution of active learning and project based learning? The role of external stakeholders, external cooperation? How to measure sustainable development learning effects? Practice what you preach: how to green the campus, diminish resource consumption and sustainabilise procurement? How to teach normative content in an academic context?

The paper, based mainly on the European literature on EESD of the last decade, discusses the answers that were provided and present an agenda for further research in EESD (This paper has mainly a European perspective. An overview of sustainable development engineering education in the USA can be found in [80].

Key words: *engineering education, sustainable development, curriculum change, environmental education, engineering ethics*

Introduction. The emergence of engineering education in sustainable development

Engineering education (EE) in Europe has a long tradition of dealing with environmental problems. Waste water cleaning, municipal solid waste disposal, and energy efficiency

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have long traditions in various engineering schools. For effectively solving some environmental problems, it was important to educate users and the general public. This was one of the reasons why engineers, working on these problems, were to be trained in communication with users and the public [1].

The environmental wave of the seventies, as well as the societal upheaval of those years, affected engineering schools in various ways:
- environmental and energy issues were included in some curricula, especially civil engineering, architecture, and chemical engineering, and
- engineering schools introduced more democratic structures, thereby facilitating the engagement of lower scientific staff members and students.

However, environmental issues only marginally affected most other engineering curricula. A second wave of environmental awareness was triggered by the Brundtland report [2] and the subsequent conference in Rio de Janeiro in 1992, which adopted Agenda 21 as a seminal piece. This renewed interest in environmental issues resulted in several new initiatives.

On the European level the EEE Network was established in 1990. The University-Enterprise Training Partnership in Environmental Engineering Education was approved in 1990 and funded by the European Commission. The UETP-EEE project has been co-ordinating an extensive number of training programs, as well as student exchange programs. When the project was terminated by the end of 1994, the number of partners decreased. An open network of partners emerged. The name was only slightly changed: "EEE network". This network organized annual Environmental Training in Engineering Education (Entrée) conferences until 2001.*

Although the ENTRÉE conferences had annual themes, the issues that were discussed within each conference varied considerably: in fact the conferences were more a kind of market place for environmentally engaged engineering educators. Main themes were:
- environmental design and LCA courses,
- chemical processes, and prevention of emissions,
- environmental philosophy, meaning of Sustainable Development, and
- recycling.

Especially the later conferences addressed more the issue of sustainable development (SD), instead of environmental engineering, and addressed wider ranging issues like stakeholder involvement. Most of the contributions to these conferences described courses or other experiences of authors within their own university.

In 2002, the first Engineering Education in Sustainable Development conference was organized. Besides some changes in organizers, it meant several other changes:
- SD was explicitly the challenge which meant a wider scope,
- the title was explicitly formulated in an ambiguous mode to express that:
  - EE could contribute to SD,
  - EE should adapt itself to the demands of SD,
- learning experiments, active learning and project based learning played a stronger role in the program,
- by its wider scope there was also more emphasis on the issue beyond the SD course: integration of SD in the whole curriculum, institutional change within the engineering school, *etc*.

* http://www.eeenetwork.net/main.html

The basic consensus was that SD requires a different type of engineer, and a fundamental change in engineering qualifications. What issues need to be resolved to work on that?
(1) What should engineers learn regarding SD?
(2) How to trigger institutional change within engineering schools: top-down or bottom-up?
(3) How to trigger cultural change, how to win the hearts and souls of the faculty?
(4) Curriculum change: starting new programs or changing existing ones?
(5) The contribution of active learning and project based learning?
(6) The role of external stakeholders, external cooperation?
(7) How to measure SD learning effects?
(8) Practice what you preach: how to green the campus, diminish resource consumption and sustainabilise procurement?
(9) How to teach normative content in an academic context?

Although the Engineering Education in Sustainable Development (EESD) conferences were focussed on SD and engineering, several other societies and organisations organised activities in this regard. For example SEFI (Federation of Engineering Educators) and the INEER (International Network for Engineering Education and Research) organised special conferences. National professional engineering associations made statements and stimulated universities to address SD in EE. Professional societies that dealt with specific technologies that were important for SD, like energy, environmental technology, materials, dealt with engineering education. To highlight the main issues of discussion, we will mainly review the content of the EESD conferences.

What should engineers learn on SD?

At first sight, the answers to this challenge look pretty straight forward: engineering students should learn:
(a) what the problems are, and
(b) how to solve them.

(a) Some SD problems are better known than others, and some methods to develop technologies that could contribute to solutions were not well-known in the engineering community [3]. In general SD problems often do not fit into one of the engineering specialties or scientific disciplines. It therefore implies that SD learning should be interdisciplinary. Moreover, the problems are often contested by various stakeholders, which implies that there is not one problem for all stakeholders, but each stakeholder has his own perception of what is problematic. Naturally, the issue arises to what degree engineers should know about the intricacies of SD problems. In their careers, providing solutions is considered to be more important than analysing problems. One could observe a growing consensus in the EESD community regarding some main SD problems (climate change, resource depletion, equity, participation, destruction of ecosystems). Recognising that these problems are not perceived in the same way by various stakeholders around our planet is considered another important aim for the educational process. Therefore, one important competence to be learnt is the capacity to analyse the problems at different scales, with a systems approach. Efficient engineering solutions only developed at a process level can reveal negative effects when analysed at a broader dimension.

(b) Generally, complete solutions for SD problems are not yet available on the shelf. The reason behind this is twofold:

- SD is a concept that often refers to the imbalance between our use of the planet and its regenerating capacity; to reach a situation of sustainable development, many options are available that contribute to restoring this balance; however, the imbalance is in general at a global or continental level; it is therefore impossible to call a specific technology the sustainable solution for a certain problem: the regenerative capacity of the planet allows for some pollution and resource consumption, but it is a societal choice for which need we will use it,
- it is rather clear that various new technologies should be developed for a sustainable development. Should we teach the principles of these technologies in our courses?; clearly some technologies, like for instance hydrogen production and fuel cells, would become more prominent [4]; however, given the limited time for SD courses, and the diversity of technological options, something else might be more important: providing students with insight into what it takes to successfully develop new technologies for a SD; classic prejudices among engineering students are for example that "the best technology will win at the market", and that "technology is a neutral force in society" [5]; students should learn to think in longer term processes, and define their work within such longer term processes that cannot be fully controlled; meanwhile an engineer should be able to deliver solutions for short term problems [6]; taken together this implies that an engineer should understand the complexities of the societal setting in which he/she is developing solutions ([7, 8]), and the complexities of making short term improvements that fit into a long term SD path.

What we learned and experienced in the last decade is that this takes interdisciplinary course material, and it takes active interdisciplinary learning [9-12]. Social relations, culture, religion, and organisation are not to be underestimated aspects of our societies, and the social aspects of SD should not be forgotten (*e. g.* [13-16]). It is not easy. Often students want to learn an easy trick by which they can make their designs not only effective and efficient, but also sustainable. It is often disappointing to recognize that there is no easy trick that leads to sustainable technology. There is a long way towards sustainability that takes sacrifices, but can also give intellectual rewards. Moreover, many teachers suffer from the same shortcomings, *i. e.* not being able to develop a more strategic vision regarding the mission of the engineer in regard to SD.

The discussion of what sustainability should imply was often nicely reflected in discussions on criteria for student awards for sustainability [17].

Institutional change within engineering schools: top-down or bottom-up?

How to start the process of change to integrate SD into an the activities of an engineering school? In general the enthusiasm of many people for SD coincided with the worries of engineering schools for declining numbers of students. This created an important starting point. Naturally, without flourishing engineering schools, Europe could forget about becoming leading in sustainable technology development [18]. Therefore, SD often served as a vehicle to attract more interest in the engineering profession.

In general, academic organisations are sluggish and resist change. Normal procedures of curriculum reform are rather time consuming [19]. SD as being an ill-defined concept certainly meets some resistance [20-22]. Should students and committed teachers at the grass-roots level start the process? If this bottom up process does not take place spontaneously, should we then refrain from introducing SD? Or should deans and university boards initiate the process of change and lead (or even enforce) the path to sustainability in research, education, and campus facilities? There were two radical views on this issue that appeared in various discussions at EESD conferences:

– the disciplinarization of knowledge and the no-nonsense culture of engineering create strong barriers to more interdisciplinary SD approaches; every real change therefore needs to be enforced, by university boards or even by government, and
– if the culture of engineering does not change, then a single SD course, top-down enforced, will only be window-dressing; it will disappear as soon as the political climate allows it; so bottom up change is essential.

In practice these two radical positions in the debate proved both wrong: there is a strong coupling between bottom-up and top-down initiatives, and they need to be seen in co-evolution:

University boards appreciate it if active communities of students and teachers support SD. It means more support for top down actions. So only active political support by grass-roots movements may allow top down action. On the other hand, if grass-roots movements fail to mobilise top down support, then frustration can easily occur, implying that the grass-roots movement soon vanishes. Most SD activists were opportunists as is expressed by this paper title: stone walls, labyrinths, draw-bridges and side doors in the ivory tower, challenges and opportunities for sustainable development in higher education [23].

Active communities of SD minded students and teachers were created as a result of top-down policies bringing new "open space" [24]. For example, top-down initiated symposia and courses built new communities of committed students, which in turn proved to be powerful allies to plea for more SD. Within the bottom-up movements, it is important to underline that very little change has occurred until now due to the pressure of students demanding more SD orientation of degrees. However, the authors think that the level of that pressure might grow rapidly, as new generations of students have experienced a strongly more SD oriented primary and secondary education. A procedure that was integrating bottom-up and top-down approaches was the Cirrus approach from Tilburg: Management led the SD process but provided means for departments to develop their own skills and develop SD education in their own manner [25].

The level of sustainable change in a University/department should be accounted for. A quality assurance system, AISHE, was developed [26]. Ferrer-Balas [27] presented UPC evaluation indicator system to benchmark progress. A main problem of these systems is that they are time consuming. This is a major problem as it creates resistance among faculty that needs to be convinced of the merits of SD in engineering education.

Pressure for SD should come from all sides. Professional associations, for example, could also play an important role [28, 29]. Another important issue at research universities is the connection between education and research: SD in education cannot survive at these institutions if it is not connected to research [30].

Cultural change, how to win the hearts and souls of the colleagues?

Adding SD courses or even changing the curriculum for SD is insufficient for a lasting change. Program directors might include new courses to be politically correct, and remove them again from the program at the first occasion when they need scope for other subjects. For a lasting change, it is important that there is considerable support for SD within the university community [31]. Initially, many universities estimated that their lecturers needed to be trained for that [1, 32]. However, it often turned out to be not so much a matter of education. "Teach the teacher" projects were started in several universities, but they were generally not very successful. "Teachers hate being taught", as it infringes the sense of expert autonomy that they developed within their own (sub-) discipline. Moreover, SD was often regarded as an ill-defined world view, not as a discipline rooted in scientific knowledge.

Other strategies were proposed for cultural change. Among them were stimulating student pressure, the founding of networks [33], and cultural events. However, it seemed that disciplinary pride was a main factor that prevented that lecturers were affected. A very successful approach was to reverse the "teach the teacher approach": instead, "ask the teacher". In the individual interactive method, lecturers were invited to suggest contributions of their own (sub-) discipline to SD. These suggestions were collected and discussed and led to adaptations in education as well as in research [34, 35]. This approach turned out to be very successful in various universities [36]. The crucial factor in the success of this approach was that it was in line with the sense of autonomy of the lecturer. However, it required much qualified human resources, which is a relevant drawback for its systematic use.

Another factor of importance was funding opportunities for research. As SD often became an element in research funding, lecturers had to address the issue. This often also influenced student graduation projects, and indirectly, education programs [30].

Curriculum change: starting new programs or changing existing ones?

Various progressive universities have adopted the position that all students should have a basic course on SD for engineers, as knowledge of SD is a basic qualification for engineers [37]. Some made such a course obligatory, others more or less offered this course as a voluntary option. The argument to make it a voluntary option was often that SD should not be forced upon students.

In practice, obligatory and optional courses were more or less competing: if there were first voluntary SD options that attracted only part of the students. Faculties used this as an argument not to introduce obligatory courses: students should have their freedom. This could lead to more extended optional SD programs for students.

Basically, in depth-SD education programs can co-exist with obligatory SD courses for all students. However, in practice there were often interrelations:
- optional courses were an argument against obligatory courses (motivated students have already an option),
- less interest in optional courses was seen as sign for students' disapproval of SD, and
- more interest in optional courses was seen as a threat to established courses.

In fact beyond these organisational struggles, it became more or less clear that both options do not need to exclude each other: apart from a basic knowledge on SD for every engineer, there is a need for SD engineering specialists. Specialisations that have been developed include:
- optional SD specialisations within existing masters programs,
- Master programs in Industrial Ecology [38], Sustainable Energy Technologies, Sustainable Technology [39, 40], Environmental Engineering (waste and waste-water treatment) have been created, and
- post graduate master programs have been created on several SD subjects. (An overview of sustainability related higher education can be found at the SDPROMO website: http://www.sdpromo.info/web/page.aspx?refid=48)

Generally, these specialisations co-exist with broader and more general SD courses. The graduates from these specialized master programs very often end up in management or consultancy positions.

The contribution of active learning and project based learning?

Another aspect that has been arising in EESD is the importance of renewing pedagogical methods. As SD is oriented towards learning (while the final goal might be uncontroversial, there will be plenty controversy in the transition path to reach it), in the SD learning process, the methods and approaches might become also more important than the contents.

The first SD courses were often a series of lectures that were add-on to existing programmes. However, for educational as well as for political reasons, it was important to attract many students and get high satisfaction rates. Learning effects had to be good. The average retention of learning varies from one pedagogical methodology to another, but active learning is the most effective one (*e.g.* [41, 42]). This is even more important for in-company training [43]. However, active learning takes a lot of effort, and is often done most effectively in co-operation with external parties. Over the years many examples of active (often project based) learning were discussed. Active learning also allowed interdisciplinarity. Often it was established that this was the preferred way of teaching SD (*e. g*. [44, 45]). Segalas [46] demonstrated that Active Learning education is more effective in terms of interdisciplinary and systems thinking learning. Often Project Based Learning is the preferred method of active learning. Doing a project in a real life setting, like a developing nation, can be a life changing experience for a student from an industrialized country [47- 49]. However, project based learning takes more resources, good contacts with external stakeholders and motivated staff that are trained in working in interdisciplinary groups. Moreover, project based learning also poses some challenges for example how to certify individual learning accomplishments that are sometimes required, or the important amount of resources needed. Simulation, gaming, role play, and case studies are often cheaper means though somewhat less effective than Project Based Learning [50-52]. Students should have a more active role in education and therefore they should also learn to manage their own learning [53].

The role of external stakeholders, external co-operation

SD requires multidisciplinary active learning. This should not be an unrelated sequence of single discipline active learning projects: integration is crucial. Problem based learning implies that a concrete problem serves as the integrating mechanism: various disciplinary aspects of the problem will be integrated in one solution [46]. However, problems should not be artificial, and so real life problems, that are actually put forward by a real stakeholder are most motivating for students. Especially problems of small scale enterprise could be interesting, as these problems are often multidisciplinary and students will not compete with professional consulting companies [54, 55].

Problem based multidisciplinary learning with real life problem owners poses new challenges: how to guarantee the learning process as the interest of the problem owner is primarily in solving his problem? How to prevent students from "going native" *i. e*. only seeing the concrete problem of the problem owner without recognising it as a cases of a more general nature, that can be seen as example of theories that have been learned at university? How can student work be made effective for external stakeholders [56].

When co-operating with corporations or government bodies how to deal with their commercial or political interests if they play a role in the project? How to stimulate public debate? [57- 60].

It has become clear that this form of education has been very rewarding. However, there are some conditions:

- relations between university and the external commissioner of an educational project should be of a more permanent character; these educational projects cannot guarantee results for the commissioner and they should understand that learning is the primary goal; interfacial structures between universities and other organisations have an important role. (*e. g.* Regional centres of Expertise, RCEs, [61]),
- not all multidisciplinary problems are fit for an educational project: subjects might be too political or commercially sensitive, or there are too strict deadlines, and
- the experiences have to be designed based on new methods for transdisciplinary work, which is in itself a new field of interest for many SD researchers [62].

Measuring SD learning effects

In the university system, individual learning achievements should be certified. In order to evaluate the SD understanding of engineering students there are many options: written assignments, tests, written exams, oral exams, interviews, questionnaires. However, many of these methods are giving evidence of the ability to reproduce small pieces of knowledge. For SD, however, it is of crucial importance that students are able to think in systems, *i. e.* in connections between various elements, and in dynamic processes (that often involve long time frames). Lundholm [63] presented a study how engineering students interpreted sustainability and ecology before and during SD courses.

Conceptual maps were introduced by Lourdel [31] as an appropriate method for evaluating SD understanding. Conceptual maps (Cmap) were initially developed as a data analysis tool in 1972. Cmaps are graphic representations for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line referred to as linking words or linking phrases, specify the relationship between the two concepts. Concept mapping has become a powerful tool which is frequently applied in different contexts in science education. Teachers ask their students to describe their knowledge by means of specific terms and explain connections between them. Researchers ask students to construct concept maps to gain information about students' conceptions of various topics in science [64, 65].

Conceptual maps were explicitly used by Segalas [46] to evaluate SD learning. He showed clearly the learning effects that were obtained by SD courses as students in various countries drew far more complex and varied conceptual maps after taking an SD course.

Practice what you preach: greening the campus

Some universities started their SD activities by initiating environmental projects at their campus. Very often, active students groups were the initiators of campus greening projects. These projects often also served educational aims: students learned about ecological systems at their campus, about waste and waste streams generated by the university and about resource consumption. Learning by doing was rewarding for many students. Campus greening was the focal activity of a new international network, Environmental Management Systems for Universities (EMSU) that was initiated by Lund University.

However, the importance of campus greening remains more in providing coherence between various activities of the university (indirect) than in its final impact (direct). As an example, it was calculated at the Technical University of Catalonia that the main impact of a school of architecture was in the education that they provided for the designing practice of their graduates. *By many years of research an academic might develop a 1% more efficient technology. Compare that result to motivating 10 students a year to develop and apply technologies that are 1% more efficient for the rest of their lives...**

However, a university that only promotes SD learning, without applying it in its own organization looses credibility. Greening the campus should be integrated with "sustainabilising" education but also with "sustainabilising" research. In fact, there is a high synergistic effect of using campuses as experimental laboratories for education & research, which is a growing trend (ISCN network, AASHE network, AAAS working group). UPC introduced this for various student groups [27, 66-68]. Sammalisto [69] showed that environmental management systems could be an effective tool within university organizations, even regarding education and research.

Teaching normative content?

Teaching SD cannot be done without touching political issues [70]. On several occasions pleas were made for a new engineering ethics [71, 72]. However, there is a general consensus that science should not be driven by ideology. In history, academic freedom allowed the professors a certain independence in regard to rulers. It did not imply giving up community engagement. Academic education should respect a certain impartiality towards value systems. However, SD implies at the same time to stimulate reflecting on value related issues. Can we teach values without prescribing them? [73]. For the situation of today, one might ask what engineers are contributing to "community" goals [74].

Lemkowitz *et al.*, published a paper in which they argued in favor of "subversiveness of education" *i. e.* to be distrustful of established theories and facts. However, the term subversive also has an "anti-establishment" connotation which makes it a too strong statement. Students should learn to be critical to all theories, ideologies and facts, not only to the ones of the establishment but also to the ones of the anti-establishment. ("Teaching to doubt", [75] and [76]).

In practice, it turned out that the normative content of SD is not a big issue as SD is formulated in such a way that almost nobody will oppose it. However, the acceptability of more specific normative statements in academic education turned out to be different among various countries and depending on national cultures.

It therefore seems that EESD learning has always to incorporate value controversial cases, situations and their solutions under different perspectives. Students might then construct their own schemes and understand that cultural factors will condition any engineering solution's viability. Moreover, awareness of values and value gaps is essential, especially in intercultural development cooperation [77].

* In 1999, the UPC School of Architecture of the Valles compared all of the schools direct CO_2 impact with the CO_2 impact of graduates that would build more sustainable buildings. The impact of the latter was almost a factor 1000 larger.

Key topics for further study

In the past decade, a lot of insight has been achieved regarding the task ahead. The mainly European EESD conferences have been the focus of this paper, but similar discussions have taken place elsewhere. With hindsight, one could say that the ideas to "sustainabilise" engineering education in the 1990s were somewhat naïve: developing an add-on course, teach the other teachers about SD and create a track for SD specialists are at best just the first step.

This is not to say that we know all we have to know for EESD. But there is at least far more clarity about what the challenges and barriers are. The next steps in EESD are not so much on what course we should add to make engineering more sustainable. Instead of adding something to an always "crowded" curriculum, we should address the question how a curriculum should look like to contribute to SD and to have motivated students and lecturers. Instead of adding SD to, or adapting an unsustainable curriculum, we should rebuild curricula by taking the contribution of a field of expertise to SD as the leading principle for curricula. This will not happen if there are no capacities among the faculty. A next problem is then the organisational and human resource policies: how can we stimulate universities to take this next step? How can we renew our organisations? How can the speed of change be increased? How can sustainability be integrated in the selection and promotion process? Is this a leverage point for changing the culture?

A more mature and complex systems approach to engineering education is needed. Important questions are in our view:

- What changes in institutional framework should be promoted to allow and reward interdisciplinary education and research?
- We need to rethink what it means to be an engineer. Only providing technologies or orchestrating the process of solving (sustainability) problems?
- How to move from the "optimisation" type of solutions to sound "systems renewal"?
- How to incorporate external actors and stakeholders in EESD in engineering education allowing for transdisciplinary learning spaces?
- How to measure the effects of EESD on the professional engineering graduate?

It is hard to believe that universities will help solving societies' problems if they are not capable of addressing their own sustainability process. Educating SD capable engineers can only be done in a co-evolutionary process with the rest of the society. Hence, if we consider SD as a learning process, universities should be at the forefront of sustainability given that universities are supposed to be learning-centered organisations. However, some authors [78] claim universities should learn to be learning organisations, and therefore allow innovation and change processes to happen more rapidly. Organisational learning is mainly reached by enhancing the vitality of the network of relationships within one community, and needs participatory methods, very much aligned with the type of interactions, learning and pedagogy that has been discussed before. If at the end every student will promote sustainability changes in the organisations and communities where he/she works or lives, then universities should offer the experience of organisational learning.

This brings us to further research questions:

- How can we use university paths to sustainability as an own learning path for our students and faculty?
- How can we create co-evolutionary relationships with our stakeholders in order to practice and learn transdisciplinarity?

How can we measure the cultural evolution within the student and faculty community?

How can we use active-participatory learning (interdisciplinary approaches using existing resources and at low-cost) to be able to extend it generally?

What has to change to make engineering education creative, effective, societal engaged, open to other disciplines and really fun? [54, 79] This question is not just crucial for the engineering community, but also for society at large as we are convinced that committed and engaged engineers are crucial for our common future.

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