

TEACHING ENVIRONMENTAL SUSTAINABILITY IN HIGHER EDUCATION

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Abstract

The challenges of sustainable engineering and design are complex and so are the challenges of teaching sustainability to higher education students. This paper deals with teaching environmental sustainability, with a specific focus on the sustainability of buildings. The paper addresses specifically the higher professional and academic education. What do we know about the efficiency of courses on sustainability as they are currently offered and what do students need to experience in their curriculum to be able to appreciate the challenge of sustainable engineering? There always seem to be three major problems: (1) the definition of the concept of sustainable engineering, which is ill-defined and on which there is little general agreement, (2) the fact that sustainable engineering has to integrate many different disciplines, while curricula are mostly monodisciplinary, and (3) the fact that environmental sciences are still under development and suffer from progressive insights. This paper addresses these three stumbling blocks and bring them in relation with the basic principles of education and course design: How to deal with the ill-defined concept of sustainability in curricula? What are the implications of teaching a discipline that is still under rapid development? What are possible conflicts between multidisciplinary and monodisciplinary approaches of education in sustainability?

Keywords

Environmental sustainability, education, teaching, sustainable engineering, multidisciplinary approach

1. Introduction

The challenges of sustainable engineering and design are complex and so are the challenges of teaching sustainability to higher education students. There are three stumbling blocks for education in sustainability.

First, when it comes to defining the concept of sustainable engineering, it appears that there is no description that is easy to use. It is well known (Filho, 2000; Right, 2002) that sustainability may be interpreted in very different ways, e.g. social sustainability, economic sustainability or environmental sustainability, all of these being legitimate. Inside these different partitions, there is no general agreement on precise definitions. For instance environmental sustainability may be interpreted from the view points of preserving ecosystems, reducing CO₂ emissions or reducing the uses of non-renewable natural resources (Carrew & Mitchell, 2006).

Second, engineers, architects or industrial designers have the task to continuously develop new technologies and consumption goods in order to solve (technical) problems that arise in the pursuit of fulfilling basic needs like shelter and food, health, comfort or economic gains for a still growing world population. The engineers also have to solve new environmental problems created by these technologies. It is not always possible to predict what sort of problems may arise, especially because environmental sciences themselves are developing rapidly. This major progress also means that knowledge gets outdated rapidly. How can we cope with this constant discussion about this lack of information?

Third, it is often believed that sustainability is a practice rather than a theoretical science. It brings together many different disciplines and therefore collaborative strategies are needed (Robinson, 2004, Holden et al, 2007). Educators need to implement collaborative strategies and interdisciplinary approaches in engineering practices and curricula, because these are often largely mono-disciplinary.

In paragraph 2 the literature is discussed. Paragraph 3 deals with the ill-defined concept of sustainability and how that relates to curricula. Paragraph 4 treats the implications of teaching a science that is still under rapid development. Paragraph 5 is about possible conflicts between multidisciplinary and mono-disciplinary approaches of education in sustainability. Finally we reflect on the questions that need to be answered to fulfil the challenges of education in sustainable engineering and conclusions are drawn in paragraph 6.

2. Teaching sustainability: insights from literature

Sheppard et al (2009) state that students who are on their way to become engineers, have to move from highly structured problems involving formal concepts toward building the ability to recognize and solve less structured and more uncertain kinds of problems. However, learning how to do this is not a linear process, starting with simple tasks and moving to more complex tasks progresses in time.

The increasing complexity of cognitive learning objectives is recognized and described by Benjamin Bloom in his taxonomy of educational objectives (1984). This taxonomy is shown in figure 1. The basic educational objective in the cognitive domain for students is to learn factual knowledge. Once students have mastered some knowledge and comprehend it, they can learn how to apply it. Once students can apply knowledge, the fourth step in complexity is to analyse materials and the fifth step is to synthesize all the prior knowledge and skills and to combine it in the design of something new. As Sheppard et al (2009) point out, learning these ever more complex skills is not a one way movement from down to up, but learning goals should be formulated in such a way that they reflect the complexity of the desired learning outcomes.

Segalàs et al (2009-1) analysed the bachelor level courses on sustainability in three universities in Europe: Delft University of Technology in the Netherlands, Chalmers University of Technology in Sweden and Technical university of Catalonia in Spain. They looked at the complexity of the learning goals that were formulated for these courses using the Bloom's taxonomy. They found learning goals formulated on all levels of the taxonomy in all three universities. The question is to what extent the content of the courses can truly be compared. The authors also fail to report on the kinds of assessment that are in place in the courses they analysed. Neither do the authors mention the long term effects in the learning and attitude of students who have taken the courses.

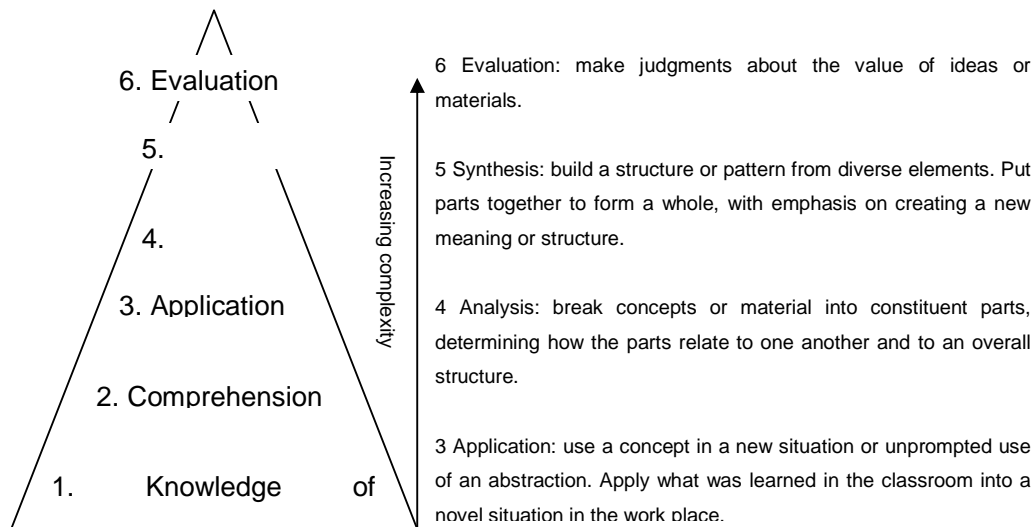


Figure 1: Bloom's taxonomy of the complexity of educational objectives (Adapted from Segalàs et al (2009-1)).

In a different research project Segalàs et al (2009-2) study the link between learning outcomes and the didactical model that was used. They did this at the end of bachelor level courses and they used concept maps to assess the learning outcomes. They found that that students achieved better cognitive learning results when more community oriented and constructive learning pedagogies were applied. This is consistent with other research in (engineering) education that shows that active teaching and learning formats yield better results (Heywood, 2005, Pascarella and Terenzini, 2005).

Implementing innovations in education

The three universities mentioned in the preceding paragraph have policies that require education for sustainable development (ESD) to be embedded in all mono disciplinary technical courses (Holmberg, 2008). This is harder to implement than adding a 'sustainable development' (SD) subject specific course to an existing programme. It is also harder to assess whether or not issues of sustainable development are incorporated in the courses and to what level. Holmberg et al (2008) studied how the universities had implemented their policies and they identified five success factors for embedding sustainable development. These factors are:

1. Legitimacy: is it seen as legitimate for lecturers to focus on environmental issues and sustainable development in research and education?
2. Commitment: Is the university management determined to integrate ESD in the educational programmes?
3. Responsibility: Is the responsibility spread between departments and individuals?
4. Skilled teachers: Are there many lecturers in the organisation that have a long experience of working with ESD?
5. Effective structure of organisation: Is the education organisation structured in such a way that it enables or facilitates ESD integration efforts?

The authors state that the stronger the basis in each of these areas, the higher the likelihood of success of an ESD effort. The authors do remark that for instance in technical University of Catalonia the “SD capacities of the students that are trained today do not differ much compared to those graduating in the 90s.” (Holmberg et al, 2008, page 278). Despite efforts to implement concepts of SD in education and its relative success, one could wonder how much of it percolates through to the students.

Holmberg et al (2008) refer to Peet and Mulder (2004) because all three universities used the individual interaction method to implement SD concepts in mono-disciplinary courses. Peet and Mulder (2004) found that top down attempts to influence the content of the courses triggered resistance among lecturers. Interaction with lecturers about integration of SD concepts in mono-disciplinary courses proved to be difficult, because of a lack of mutual understanding. Peet and Mulder experimented with a number of strategies to implement SD in engineering education and found that a semi-consultant approach directed at individual lecturers who were interested in practical ideas on integrating sustainability in their courses, yielded the most promising results. In this approach the lecturers were asked where they believed concepts of SD could be tied into their courses. The ‘consultant’ who was an expert in the field of SD would assist the lecturer in implementing the concepts in the course. Peet and Mulder observed that sometimes lecturers would be sceptical about SD, but a discussion on the different definitions of sustainability would often turn scepticism into enthusiasm. Many lecturers named the lack of time and material to adjust their mono-disciplinary courses as the main obstacle for implementing concepts of SD. Peet and Mulder observe that this method is very time consuming and a slow way of initiating change. They also make a point out of mentioning that even in an integrated curriculum, add on courses on sustainability are necessary, as not all the ins and outs of SD can be covered in an integrated curriculum.

3. The ill-defined concept of sustainability

Defining sustainability

As stated in the introduction, the diversity of definitions of sustainable engineering poses the problem which one(s) to use in specific educational situations. Generally the triple bottom line, also called 3-P approach is used (Elkington, 1987): People, Planet, Prosperity . It is impossible to treat the relevant economical, social and ecological view points. It may be possible to give technical students a basic understanding of social and economical sciences – although it is the question if this should be done in the framework of a course on sustainability, but it will necessarily remain limited. The art is then to make a consistent appraisal of what to take and what to leave. In a short introduction course for bachelor students from the faculty of architecture “Sustainability in building and managing dwellings” the themes of economical and social sustainability were skipped, not because these are not relevant, but because the scope was technical and ecological sustainability. Considering the relationship between physical dwelling qualities and social neighbourhood quality, neighbourhood development, life styles or social cohesion is relevant, but in the time imparted it is not possible to deal with these relationships at a sufficient level. Furthermore it is a completely different field of knowledge than ecological sustainability.

Measuring sustainability

The problem of measuring sustainability is closely related to the problem of defining it. There is a tendency to apply reasoning like “it is better to use recycled materials than raw materials” or “waste is food” (McDonough & Braungart, 2002).

In bachelor and master courses, we usually present four ways of measuring sustainability and explain their advantages and drawbacks.

- Using quantities of materials and energy used: the fewer kilograms of materials and the fewer megajoules of energy are used, the more sustainable the design. This is also known as Material Flow Analysis or Input/Output analysis (e.g. Daniels, 2002, Treolar et al., 2000, Yokoyama, 2005). The method is relatively simple and it leads to thinking about dematerialisation: how to achieve a same function with less materials. The Major drawback of this method is that the use a few grams of a harmful or energy intensive material (like steel) may be more detrimental to the environment than the use a few kilograms of a less harmful or energy intensive material (like brick).
- Using simple indicators, based on the three step strategy (Hendriks, 2001, Duijvestein 1997, Rovers, 2005, Brouwers & Entrop, 2005), like low environmental impact materials, high environmental impact materials, renewability, recoverability,

recyclability, downcyclability, and dismantle ability of materials and components used. This is a step further than the use of quantities but the question remains on the basis of what criteria a material is classified as low or high impact and in how far a material may be recovered, reused or recycled (Guerra Santin, 2008)

- Using the environmental footprint of material used and processes (Wackernagel & Rees, 1996). The environmental footprint gives the biologically productive land and water area needed to produce or extract the natural resources needed (plants, mineral resources, animals) to produce materials (including food) and energy. One of the greatest advantages of the environmental footprint is that it is a very strong communication instrument and a good proxy for the use of natural resources. A major drawback is that it doesn't catch environmental impacts, like depletion of resources, toxicity or CO₂ emissions. The collection of data necessary to calculate the environmental footprint necessitates however, like in a material flow analysis, an inventory of materials, energy and production processes used.
- Finally the use of environmental impacts from life cycle assessment (LCA) (ISO, 1996 & 2006). The impacts of the production, use and disposal of building components on the environment are calculated by first making an inventory of the flow of all substances to and from the environment over the component's complete life cycle. Each substance's potential contribution to environmental impacts is calculated. In order to do this, for each environmental impact, the effect of a particular substance flow is compared with that of a reference substance, a process that is referred to as the 'impact assessment'. The complete set of environmental effects is known as the 'environmental profile'. Three endpoint indicators are often used: damage to human health, damage to ecosystems and damage to resource availability. The quantification of these endpoints is subject to high uncertainties, because they result from the effects and interaction of multiple impacts. That is why the preferred method in a LCA is to work with so-called midpoint indicators that are a measure for reasonably understood environmental mechanisms (impact categories). There are different methods to quantify these impact categories, for instance CML, Eco-indicator, ReCiPe (Pre, 2008). In the CML 2000 method, 10 impact categories are used: abiotic depletion [kg SB eq.], global warming [kg CO₂ eq.], ozone layer depletion [kg CFC 11 eq.], photochemical oxidation [kg C₂H₄ eq.], human toxicity [kg 1,4-DB eq.], terrestrial eco-toxicity [kg 1,4-DB eq.], fresh water aquatic toxicity [kg 1,4-DB eq.], marine aquatic toxicity [kg 1,4-DB eq.], acidification [kg SO₂ eq.] and eutrophication [kg PO₄³⁻ 3q]. In the new ReCiPe 18 categories are used.

Life Cycle Assessment is the only method that quantifies the impact on the environment. Detractors of the method argue that it is too complex and too long to gather data, which results in large uncertainties, that the list of environmental effects is not complete and that there are differences between the impact assessment methods. For instance a major drawback of the CML method is that it does not include depletion of biotic resources. Next to this, some believe it is too difficult to deal with multiple indicators and to communicate complex results: Indicators should be weighted and summed up to one environmental indicator. LCA methods are still under development and one can expect a greater degree of completeness and harmonization in the future. Furthermore one should be aware that the determination of low or high environmental impact materials (like in method 2) or the determination of the ecological footprint (like in method 3) can only be achieved by using LCA-like methods.

Dealing with definitions in education

In most of the courses we teach, there is barely time to allow students to develop basic competences in making LCA. There are almost no LCA courses at the Delft University of Technology, which is quite an embarrassing situation: we ask students to think 'sustainable' without giving them the means of doing it in a proper way. Giving students simple software and method to design solutions is not enough.

To avoid the complexity of the aspects related to the measure of sustainability, the whole idea of 'measuring' is often replaced by a description of strategies to achieve sustainability, like the three step strategy (Hendriks, 2001, Duijvestein 1997, Rovers, 2005, Brouwers & Entrop, 2005), the ecocodevice model (Tjallingii 1996) or Cradle to Cradle (McDonough & Braungart, 2002). This can be powerful to understand basic principles and to give a design or research horizon, but the results of differing realization of a strategy need to be assessed and without a LCA this is not possible.

4. The burden of progressive insights

One of the often named drawbacks of LCA is that the methods and environmental profiles have changed over time and depend on the database used (Peuportier et al, 2005), which leads to large uncertainties in the results. This is a comment that cannot easily be outvoted. Changes in the evaluation method and new insights can change the environmental impact of proposed alternatives and their relative values, resulting in possible mistrust and negative attitudes by consumers/users that are not involved in the research itself.

Ecosystem and chaos theories show that small variations in a complex system may greatly affect the state of a system in a –up to now- quite unpredictable way (e.g. Folke et al, 2002, Holling, 2001). A simple model is: burning all fossil fuels will cause an enormous increase in CO₂ concentration. Simple models are necessary as basis to define new strategies or to make a rapid check on the validity of results. This is a quite common engineering practice: use complex models to make detailed analysis and comparison and use simple models based on intuition, experience and common sense to check the plausibility of the results – which does not replace strict validation procedures. Considering the interdependency of systems leads to differing insights than considering separate systems. However, being able to look at the interdependency of systems means being able to look beyond the own disciplines and therefore pertains to the subject of multi-disciplinarity.

5. Multi-disciplinary approaches against mono-disciplinary approaches

Should education in sustainability be organized cross-wise through all curricula, should it be one additional curriculum, or should each curriculum take care for its own courses on sustainability (see figure 2)? Model a) works only in the specific case of a curriculum on environmental sciences being offered. It does not guarantee that education in sustainability will be implemented in other curricula. In model b), a special group of teachers/researchers has the task to formulate and give education on sustainability in all curricula. An advantage is that basic knowledge on sustainability is made available to all curricula and that some kind of cross-fertilization may be expected (we then speak of inter- or trans-disciplinarity). A major drawback is that in-depth knowledge of sustainable engineering in the specific curricula will not be given, as it is not the field of expertise of the teachers. In model c) in-depth knowledge of sustainable engineering and design in a specific field will be proposed, but the relationship with advancing environmental sciences may be lost as it is beyond the scope of expertise of the teacher. Furthermore, as we saw in paragraph 2, this seems to be a promising but slow method (Peet & Mulder, 2004). Based on the reflections made in paragraphs 2, 3 and 4 it seems logical that a combination of models b) and c) is used, where the basics of environmental sciences will be taught in a common trunk separately from the curriculum specific items. A precondition for this system to be efficient is that teachers in the curricula are aware of the contents of the course in the common trunk and that the courses are sufficiently tuned: an inspiring course on sustainable chemical engineering can only be realized by a teacher having in-depth knowledge of chemical processes, chemical industry...and sustainability. However, this combination of models b) and c) is currently hardly implemented at the Delft University of technology.

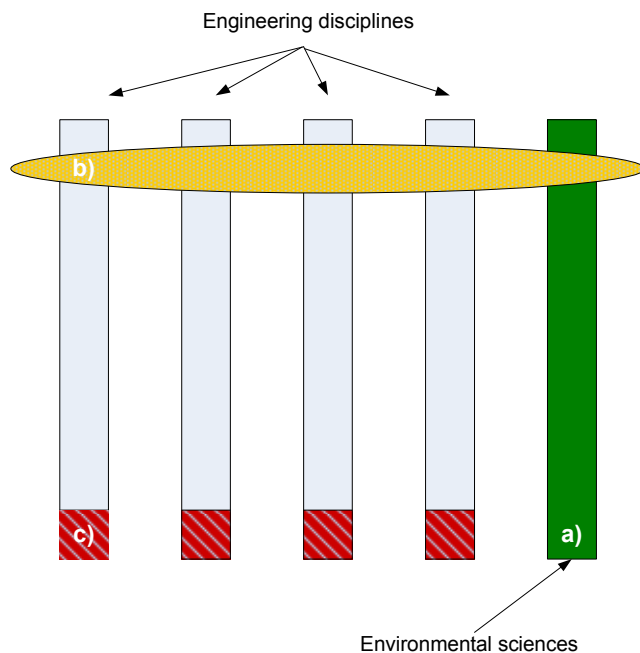


Figure 2: three approaches for the implementation of sustainability in higher education curricula.

At Delft University of Technology master courses on sustainable buildings are mostly based on “project education”, meaning that the students have to form interdisciplinary teams to work on a project. In many engineering courses, there is a gap between the theoretical curriculum and its applications in practice. This gap is often filled by including a project in a course, by internships during the curriculum and by experience in the practice after the study. If these projects are implemented as an add-on rather than a thoroughly set up educational activity, we may do the students more harm as it will be difficult to overtake theoretical basis during working life.

6. Conclusions

Difficulties relating to the design of courses on sustainable buildings arise from the lack of a clear definition and a well-accepted measuring method for sustainability, which may lead to a poor definition of the goals of courses and consequently to a poor design of assessment and contents. Because of continuously progressing insights in environmental sciences, the current insights and methods are likely not to be the ones of tomorrow and we must give students enough elements to be able to fully understand and even lead future developments. When it comes to multidisciplinary aspects, we argued that a good balance must be found

between the learning objectives in the courses and the teaching formats that are chosen. Obviously, the field of sustainability is in development and there are no clear cut solutions. Learning how to deal with this lack of criteria for sustainability should therefore be a central learning goal in all courses on sustainability. Once that learning goal is accepted as a central one in courses, we should reconsider the teaching formats like mono-disciplinary courses and more hands-on approaches like project based learning in which different disciplines are brought together. We suggest a common education trunk between different disciplines to give students a good basis on environmental sciences and insights in what sustainability means in other disciplines, combined with a mono-disciplinary approach of sustainability in the own discipline. Although our literature study showed interesting developments in the field of education for sustainability, there seems to be still a large gap to be filled between the goals and aims set by higher education boards and their practical realization.

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