Effective Teaching methods for Sustainable Design

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Abstract

Sustainable development (SD) requires novel technical solutions. These novel solutions have to fit in societal, environmental and economic contexts. Moreover they have to be robust to future uncertainties. Engineers are the main deliverers of these novel design solutions. We have developed a teaching method with this purpose in mind.

The competences of the course are the practical translation of the competences mentioned by Delors for the UNESCO learning for the twenty-first century(Delors, Unesco 1998): SD knowledge, SD design methods, internalisation of SD values and communication with all relevant stakeholders.

From our experience we evaluated and improved the method above in Master and PhD courses. Subparts of the course, such as on learning on LCA and scenario set method, became independent modules, which are also applied in other courses.

Finally, we have investigated the effectiveness of two forms of workshops: a central design case with integrated workshop where stakeholders are all present and separate workshops with specific cases and specific stakeholders. Student feedback scores show no significant preference for either of the forms. With these and other evaluation results, we report from a broad experience in effective, challenging SD courses for engineers, in which 360˚ and regular feedback is central.

1 Introduction

In their design, most engineers nowadays have to oversee and apply sustainability additional to the technical specifications (Davidson *et al.* 2007, Russ 2010, Segalàs, Ferrer-Balas & Mulder 2010, Segalàs *et al.* 2009, Jonker & Harmsen, 2012)**.** Directed by stakeholder requirements, a sustainable design introduces assessments on social acceptance and longer term scenarios on material and energy resources and on emission restrictions. From the perspective of education: sustainable design requires new competences of engineers, additional to the traditional focus on material and energy balances, and on cost. Sustainability requires engineers to develop insight into the broad implications of their design for the long term, and from the perspective of the society, environment and business. This paper addresses an effective education method to educate these sustainability related competences.

Our starting point is to make a sustainable design, which addresses all environmental impacts, all social impacts and all economic impacts and obviously without compromising usual design criteria such as costs, appearance and quality (Morris, Childs & Hamilton 2007). Both in a professional and educational setting, a key aspect of sustainability is to apply an holistic approach, constituted as the combined contribution of social, environmental and economic requirements of the design (Segalàs, Ferrer-Balas & Mulder 2010, Carew, Mitchell 2008). This holistic approach generally is viewed upon as a challenge in educating a sustainable design to engineers, because it only works if all three contributing aspects are properly addressed (Russ 2010, Mochizuki, Fadeeva 2010, Lozano García, Kevany & Huisingh 2006).

Of the economy, ecology, and social aspects on sustainability, the social aspect is an equally important factor (Missimer et al. 2010), but it is reported to be underestimated in education on sustainability (Segalàs, Ferrer-Balas & Mulder 2010). The reason is that the environmental and economic aspects of sustainability are relatively easy to teach (El-Zein et al. 2008) and usually within the scope of an engineering disciplines, as is e.g. shown for chemical engineering (García-Serna, Pérez-Barrigón & Cocero 2007), but educators in engineering disciplines have difficulty to address the factor concerning the social aspects of a design and its embedding in societal trends (Segalàs, Ferrer-Balas & Mulder 2010, El-Zein et al. 2008). Engineering assignments usually are rather determined processes, while society or individuals are not. In most engineering educations, this type of uncertainties, closely connected to the field of humanities, does not take part in the core curriculum, and subsequently, the engineering faculty is not used to teach it (El-Zein et al. 2008, Mulder, Segalas-Coral & Ferrer-Balas 2010).

This paper provides two practices on education in which engineering students within a relatively short period (2-5 ECTS points; European Credit Transfer System) apply an holistic approach in making a sustainable design, with special emphasis on embedding the design artefact in the social context. Required competences situated within a theoretical framework on sustainability are developed and discussed. Based on recent literature trends, we found out that involving representatives of stakeholders is a very useful and effective way to teach sustainability (Segalàs, Ferrer-Balas & Mulder 2010, Thabrew, Wiek & Ries 2009, Ehrenfeld 2008). As interactive education is strongly recommended (Mulder, Segalas-Coral & Ferrer-Balas 2010, Steiner, Posch 2006), we show that workshops with these stakeholders are an efficient form of education for this type of courses. Finally the students' evaluations of our courses are reviewed, based on various editions of the courses, leading to general recommendations for educators who aim to effectively teach sustainable designing to engineers.

2 Four competences

Developing courses start with defining learning outcomes, usually in terms of competences, for which we roughly follow the four learning pillars of Unesco (Delors, Unesco 1998, Jonker & Harmsen, 2012) proposed for education in the 21th century. These 'pillars' shortly are: 1) learning to know, 2) learning to do, 3) learning to be and 4) learning to live together, or also stated as knowledge, methodological, personal and social learning respectively (Delors, Unesco 1998). The four pillars of Unesco are the best base to define our key competences as they are generally accepted and, as we show below, provide a good starting point to define key competences fully covering the field of sustainability (the terms between brackets refer to the four pillars of Unesco (Delors, Unesco 1998)):

1. Internalization of sustainability competence ('Learning to know', or 'Knowledge') in jobs and future career. With sustainability we mean the development of a long term view on sustainability, including equity, resource depletion, climate change, biodiversity, and security of supply of energy. With 'Internalization' we refer to an active usage of the knowledge domain as defined by (Delors, Unesco 1998, Segalàs *et al.* 2009). The student is made aware that having the lead in design processes, engineers usually are the only one who thoroughly can evaluate the technological implications of choices on sustainability regarding the design (Russ 2010).

2. Ability to handle tools competence ('Learning how to' or 'Methodological'). This means the capability to optimize designs in terms of sustainability using appropriate tools for the environmental aspects (LCA), the long term aspects (Scenarios) and the social aspects (stakeholder panel discussions). This second key competence closely resembles the skills and abilities of (Segalàs *et al.* 2009) and the methodological ('learning to do') area of (Delors, Unesco 1998). We concentrate on tools which can be directly linked to the three main areas of sustainability (environmental, social, and economic). Especially linked to the social and economic area, an important skill is to be able to develop a long term view, as sustainability is strongly connected with future (generations) development (Davidson *et al.* 2007, Ehrenfeld 2008, Barth *et al.* 2007).

In the work field of engineers, environment is strongly connected to the usage of raw materials and energy, their possibilities of reuse and so to reduce emissions to the environment and depletion of scarce resources. In terms of sustainability this is not only important from an anthropocentric point of view but also from the perspective of the ecosystem (Carew, Mitchell 2008). A well-known tool is Life Cycle Assessment which not only systematically structures the material and energy flows in the system under investigation, but also is a way to evaluate consequences of decisions in development planning and implementation (Thabrew, Wiek & Ries 2009). Summarized, three key tools in making a sustainable design are:

a. Life Cycle Assessment is the monitoring and designing of the material and energy flow, related to resources;
b. Building sets of scenarios focuses on the social and economic long term view;
c. Stakeholder panel evaluation.

There are more tools which can be applied for a sustainability design, such as pinch technology, process intensification, industrial ecology, and eco-efficiency, but these do not have the generic and comprehensive space and time view of LCA and Scenarios. LCA directly focuses on resources and emissions and the possibility of recycling, which is of great value of engineers, as their designs usually involve large material and energy flows from and to the environment. Furthermore, a key aspect of sustainability is a long term view for which building sets of scenarios are very useful. LCA and scenario building are general applicable, irrespective the engineering discipline, giving a good understanding of a sustainable engineering design.

3. Performing well-balanced personal professional assessment competence ('Learning to be' or 'Personal'). This competence connects sustainability to the choices of the engineers, as a person, or as teams. It can be regarded as a specification of attitude (Segalàs *et al.* 2009). The social sustainability part is related to this third key competence. The *Gestaltungskompetenz* (Barth *et al.* 2007) elaborates on this area with competences as reflection, participation, empathy and motivation. In our courses this competence is acquired through making a personal statement (sustainable engineering declaration) and through making assessments related to a specific design assignments. The field of assessment involves and represents the uncertainties mentioned before, because one of the main features of a sustainable design is that requirements and specifications cannot be stated as fixed but is viewed upon as a dynamic process (Davidson *et al.* 2007, Carew, Mitchell 2008, Mochizuki, Fadeeva 2010). As engineers are mainly taught to work on fixed specifications, dealing with these uncertainties can therefore be looked upon as an additional competence for engineers (Sheppard, Pellegrino & Olds 2008). This third competence refers to that the engineer should develop the ability to make a well balanced assessment, in a professional setting.

4. Innovative design competence ('Learning to live' or 'Social'). The engineer has to make designs that meet all sustainability goals and constraints. This means in general that the designs are

novel and often have a break-through character. The designs have however also to be technically and economically feasible. This means that the student has to acquire knowledge about the innovation process, i.e. the steps needed from idea to commercial implementation, see e.g. (Nidumolu, Prahalad & Rangaswami 2009). Also from an education point of view, from the innovation processes the student learn to think in a radical way, as this is often needed to find sustainable solutions for the long term (Bacon *et al.* 2011).

In acquiring the four competences, the three factors of sustainability, social, economic, and environment, all should be simultaneously addressed. This means that the case design assignment by which these competences are learned needs to be rich (Carew, Mitchell 2008). More specific, as elaborated by (Segalàs, Ferrer-Balas & Mulder 2010), the environmental part preservation of the planet should be incorporated. The social part should include social impacts of the design, values, future and unbalances (inequity), and finally the technology and economy parts should be included.

Table 1. Features of our PhD course Sustainability for Engineers (SfE) and our MSc course Sustainable, Product, Process and System Design (SPPSD).

Competence	Role of stakeholder	Role of workshop in the learning process	*How*: active involvement of stakeholder (SfE)	*How*: stakeholder as problem owner (SPPSD)
1. Internalization of sustainability	show practical applications of implementing sustainability	provide feedback: to help students to make up their mind	stakeholders provide experiences on SD and reflect on students' findings	stakeholder provide a challenging case from daily practice
2. Ability to adequate handle tools (LCA and scenario building)	help with choices in LCA and scenarios: to focus on key parameters	LCA and scenarios are typical a product of group work, build during discussions	groups prepare a LCA and scenario (related to a case) on which stakeholders reflect	stakeholder provide basic practical information on LCA and long term view
3. Performing a well-balanced personal professional assessment	stakeholders represent professionals and the work field	workshops create conditions for debating, which is essential for a well-balanced assessment	in reacting on students' findings, stakeholders adds pro and cons from daily experience	in evaluating the final sustainable design, an industrial forum shows considerations from practice
4. Technical and economic feasibility	stakeholders have access to real life data	in discussing their results, students learn that technically sound is not always equal to usefulness	stakeholders reflect on intermediate design results and on the final design	the industrial forum evaluates the final design

3 Evaluation of course forms

Our insights in teaching Sustainability for engineers are based on many years experiences with Master and PhD courses. In the one-week PhD course *Sustainable Process, Product, and System Design* (*SPPSD*) chemical engineering students redesign an existing chemical plant, applying radical steps of improvement. The purpose of the course is to learn to design processes, products and systems with sustainable development goals and constraints. The case is composed and introduced by an industrial representative as problem owner of a company that has sustainable development goals in its strategy.

At the end of the course the student results of the case are presented to this problem owner and to others forming an industrial forum. In this way, the results of the case are immediately tested and compared with practical application in an industrial setting. The involvement of an industrial representative highly motivates the students to deliver an excellent design result in view of all three sustainable development aspects.

The master course *Sustainability for Engineers* (*SfE*) at the University of Groningen is based on teaching and coaching by stakeholder representatives. Students learn and practice in how to personally assess what and how they can contribute to sustainable development, depending on their position in a company or government institute. The size of the course is 5 ECTS and spread over 8 weeks. In eight meetings (half a day), each dedicated to a specific topic, (guest-) lecturers teach and coach the participants in specific aspects of sustainability. The technically oriented case is group project work, to develop and practice design and well balanced assessment methods. A broad view on the complexity of sustainability issues is given by representatives of a variety of stakeholders, such as the government, a research institute, the Business to Consumer (BtC), and the Business to Business industry (BtB).

As we have pointed out in the introduction, we have summarized our experiences with teaching these courses in terms of the role of the stakeholder and the role of a workshop in the learning process, because these two aspects reflect our main experiences in teaching sustainable development in an engineering setting. Table 1 summarizes the main features of both courses, concerning these topics, which will be the starting point for the discussion in chapter 4.

4 Experiences in developing effective teaching methods

Teaching sustainable development to students in engineering disciplines should concentrate in our view on effectively providing feedback and incorporating the external world. Starting with the latter point, for the participants, stakeholders introduce an usually new or unexpected view on sustainability. E.g., from the contributions of a food processing industry in the course *SfE*, it appeared that the Business-to-Consumer industry mainly focuses on sustainability aspects of the product, for example in Life Cycle Analysis projects. Representatives from the Business-to-Business industry are more involved in the industrial process itself, as they have less influence of consumer values and demands. Participants of the course *SforE* learn from the different views in the stakeholders' contributions the complexity of sustainability issues incorporating long term views on resources combined with market behaviors in combination with governmental regulations.

One of the items in our courses is the amount of feedback by the coaches, generally stated to all groups, or more specified per group. The way of providing feedback and the time spend are rather correlated. Feedback per group usually costs much time. What we found is an optimum: groups are really helped by specified feedback on their results. Usually we ask the groups to shortly present their results on which we (and guest lecturers) provide feedback. However, the time of giving feedback should be restricted, to keep all groups attached to the topics covered. From the many workshops we have giving, we discovered that the time spent to a lecture and to group work should be approximately equally divided. In the course SPPSD we originally reserve a lot of time for group work, which implied that information density of the workshops was not optimal. However, a lot of time directed to a lecture will provide a lot of information, which only is effective when applied in group work to a case. A rule of thumb to spend 50% to lectures and 50% to group work (and feedback) works well.

We also have found that the workshop is most effective when students prepare the workshop with an assignment. For example, for each case in our course, a LCA is necessary, which is discussed in a separate workshop. As a preparation of this workshop on LCA, we shortly introduce the main concepts of LCA in an earlier meeting. The groups prepare a LCA of the case which they present at the start of the workshop. The workshop leader gives feedback on their work and adds specific information on the topic covered and on the application of sustainability in general. In this respect, students are right from the start being involved in the workshop, which enhances the learning process.

Table 2. Evaluating two forms of workshops (independent and interconnected) and two different forms of applying theoretical knowledge on practical cases (assignments per workshop or a central case). Scores on questions in questionnaire is between 1 (very negative) to 5 (very positive).

	Independent workshops & central case	Interconnected workshops & central case	Assignments per workshop
Characteristics	Introduction of topic, group work and finalization during workshop	Introduction and finalization of topics distributed along series of workshops	During course separate cases, each applied on topic
Work load	Class 1 day	Class ½ day, ½ day on group work	2-4 hours of work per assignment
Elements	Lectures, group work, group reporting	Lecture, group reporting	Cases are designed for a specific topic
Benefits	Clear structure: topic started and finalized within one workshop	Intensive and efficient form of education	Cases can be optimally designed for topic
Pay attention to:	Many topics need more than one day time to internalize	Less time to coach group work	Sustainability is learned in separate topics
Challenges	Keep attendees motivated during whole day	Provide clear instructions on group deliverables	Connect all cases to real practices, without providing elaborate introductions
Evaluation	Averaged score 3,6	Averaged score: 3,4	Averaged score: 3,4

Originally the set-up of courses was along topics but we gradually changed this to competences and stakeholders. In SfE workshops were named as Energy, Food, Water, Industry. Competences as acquiring skills in tools LCA and Building Scenarios were coupled to the workshops, depending on the contributing stakeholders. E.g., LCA was done in the workshop on Food, and Building Scenarios in the workshop on Energy. Though not strictly applied, we tend to call our workshops to the competences, as LCA, Building Scenarios, Your Role, or stakeholders 'Government', 'Research'. The reason is that the main objective of workshops is on education on competences, as they are related to the learning goals of the courses, rather than handling specific topics.

Finally, as Table 2 shows, each different form has its benefits, points to pay attention to, and challenges. Throughout the years, we have applied all variations of Table 2 in our courses, depending on results of students' evaluations, new insights, but also on local circumstances as the number of representatives of stakeholders involved in courses and their time available. In some cases, the form of workshops was partly depending on the time schedule of students, regarding other courses running parallel. We also have varied with the position of cases in the courses, either cases as exercises of each topic, or a large case which functions as a continuing project during the course.

5 Conclusions

In developing effective teaching methods for making a sustainable design, key competences based on the four pillars of Unesco (Learning to know, to how to, to be, and to live) form a solid foundation to build a course on:

- Internalization of sustainability competence
- Ability to adequate handle tools competence
- Performing well-balanced personal professional assessment competence
- Innovative design competence

Courses on Master and PhD level provided data on the role of stakeholders and on the application of a workshop setting. Experiences from the courses show the importance of an adequate feedback, the effectiveness of workshop preparation by group work and the positive influence of representatives of stakeholders in reflecting on the students work.

Finally, students did not show a preference of a specific type of workshop, e.g., a workshop in which a central case is applied was not preferred above a set of workshops each having an own (small) case. However, we have summarized experiences which may help educators to effectively set-up dedicated teaching courses on sustainable development for engineers.

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