Sustainable engineering education: justified and justifiable

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Abstract: - Sustainable development is a complex concept which concerns a wide range of social, techno-economic and environmental issues. Institutions that shape the values and attitudes of future engineers are increasingly called upon to play a leading role in developing a multidisciplinary and ethically-oriented form of education in order to devise solutions for the problems linked to sustainable development and influencing the directions in which society might move and the choices it is able to make. A framework of this kind of education is proposed in the current paper.

Key-Words: - sustainability, multidisciplinary, systems approach, ethics

1 The sustainable development concept

Earth’s exploitation is threatening its very existence and delicate balance and structural problems like depletion of resources, clean water, poverty and malnutrition are threatening the safety and stability of modern society. The pressure on the global environment has become self-evident, leading to a common outcry for sustainable development. In the words of the Brundtland report [1], “we must learn to care for the needs of the present without compromising the ability of future generations everywhere to meet their own needs”. As highlighted by the Rio Conference (UNCED) in 1992 [2] and confirmed in the Johannesburg Conference in 2002, a comprehensive strategy is required for building a sustainable future, which is equitable for all human beings. This requires a new frame of mind, new sets of values and new technologies that are ecologically, economically and socially sound.

As Ashford [3] outlines, environmental problems driven by the demand of consumers, commercial entities, and government, affected “the amount, security, and skill of employment, the nature and conditions of work, and purchasing power associated with wages”. The unequal environmental burdens within nations, between nations, and between generations, give rise to equity concerns, often expressed as “environmental injustice”. Personal comfort and convenience have led to consumption patterns that are unsustainable, degrading the global resource base and the quality of the physical and social environments. They have generated much discussion and debate about social justice, and have provided a strong incentive for scientific innovation to deal with emerging problems. Simplistically, it can be argued that sustainability will be achieved when all consumers can make choices to conserve, to minimise damage and to maximise benefit [4]. In a more general definition sustainable development is a complex concept which concerns a wide range of social, techno-economic and environmental issues.

Current strategy agendas, even those that go beyond environmental goals, are defined as those that are focused on those policies that: improve profit and market share by improving performance in current technologies or cutting costs; controlling pollution/making simple substitutions and changes, and conserving energy and resources; and ensuring an adequate supply of appropriately skilled labour, and safe and healthy workplaces. We would describe these strategies as “reactive” technological change, rather than proactive.

Unsustainability problems cannot be resolved if we cannot correct a number of fundamental faults [3]:

- fragmentation of the knowledge base leading to myopic understanding of fundamental problems and the resulting fashioning of single-purpose or narrowly fashioned solutions by technical and political decision makers;
the inequality of access to economic and political power;
the tendency towards “gerontocracy” – governance of industrial systems by old ideas;
the failure of markets both to correctly price the adverse consequences of industrial activity; and
to deal sensibly with effects which span long time horizons which pricing and markets are inherently incapable of solving.

2 Higher Education challenge

Education is one of the key mechanisms through which we become human beings that act and interact on the basis of a common culture and one of the key ‘producers’ of culture and the way we see reality. It is, at the same time, and because of that a vital condition for realizing sustainable development [7].

Agenda 21 [2], a global action plan for delivering sustainable development accepted at the Earth Summit in Rio de Janeiro in 1992, stated that “education is critical for promoting sustainable development and improving the capacity of the people to address sustainable development issues”.

Many argue that the higher education sector bears a significant responsibility for sustainability by virtue of its influence on society and academic freedom to explore ideas [5] [6]. If we consider higher education as the completion of a long process of education which builds upon the education that was provided in earlier stages, education for sustainable development will have to reorient some of the things learned in previous phases. These issues have to be addressed again and some of the knowledge and understanding that students gained in previous phases of their lives have to change. We have to realize that this is a tremendously important and also a tremendously difficult job. What we learned in our very childhood has really become part of us and is hard to change. Changing that is like learning a new language. It takes time, can only be accomplished through much practice and becomes more difficult as one gets older. As such, the challenges higher education faces in order to actualise its potential for contributing to sustainability are worthwhile.

Most of us were brought up with an image of society in which there are winners and losers. We have learned to look at society as a playing field where we have to look after our own private interest. The way to survive and to become a ‘winner’ in society is by pursuing personal interest, often at the expense of others. Those images were rooted in a view of the world as an endless reservoir of resources without physical limits. Sustainable development shows us that this image of reality is incorrect and that in a world of limited resources we all stand to lose when we pursue individual interest without taking responsibility for the world as a whole. In this world collaboration is a better ‘surviving and winning’ strategy than competition. Yet most of us do not learn that in any stage of our education. That is why we think that education for sustainable development should be based on a new set of principles for looking at the world and at ourselves as parts of that world. Only such a concept can contribute effectively to achieving the common aim, i.e. “to enable people to develop knowledge, values, and skills to participate in decisions about the way we do things individually and collectively, both locally and globally, that will improve the quality of life now without damaging the planet for the future” [8].

3 Engineering Education

The focus is on engineering, more than on the natural and physical sciences or on social science, because the activities that implement scientific advance are generally rooted in engineering. Engineers were once able to initiate engineering projects, able to transform real need into design and finally material form. However, as Kenny [in 9] has argued: “the full scope of the social responsibility of engineers has been seriously curtailed, and hence impaired, by the socially, intellectually and culturally subordinate role of engineers in modern society. The narrowness of the world of the engineer is matched by the narrowness of real choices open to the individual in a society increasingly governed by materialism. Ideas and technologies are socially embedded, and that modes of thought and action are established as “mainstream” by interactions of human and non-human “actors” that generate a momentum of decisions and processes.

Conventional engineering education is limited to techno-economic issues; for example, micro-economic assessment (such as net present value) is usually presented as the basis for engineering decisions. Traditional academic courses have focused on the solution of problems and have equipped students with the skills to resolve complex problems within a relatively narrow solution space. This reflects “the Newtonian or deterministic approach rooted in commanding a thorough knowledge of engineering science” [10].

Institutions that shape the values and attitudes of future engineers are increasingly called upon to play
a leading role in developing a multidisciplinary and ethically-oriented form of education in order to devise solutions for the problems linked to sustainable development and influencing the directions in which society might move and the choices it is able to make. Universities of technology often looked on as establishments of stagnation, can take the opportunity to become forerunners of a sustainable future.

A cultural change is needed in engineering education to embrace broad skills, environmentally-aware attitudes, knowledge and values, behaviour patterns, as well as a sense of ethical responsibility, rather than the narrowly focussed technical excellence that had traditionally been accepted as defining a good engineering education. There is a need to use a twenty-first century “complexity” science model of the world, rather than the Newtonian model that engineers use every day, essentially, for design. “Linear causal-effect thinking should be replaced by systems thinking” [7] as many sustainability problems need solutions/concepts that take a systems view of the world. A sustainable development agenda is, almost by definition, one of systems change. But a systems representation of these problems is not capable of solution using only the language of mathematics. Judgements, morals, and seemingly irreconcilable differences need to be understood too.

Sustainable development engineering education is about giving engineers an understanding of the issues involved as well as about raising their awareness of how to work and act sustainably. The resulting concept is that “the engineer should be a first-rate technical expert who acts as a social agent, rather than just a technician” [11] with a “broad understanding of the social and philosophical context in which he will work” [12]. Thus, it is imperative to consider the economic and social factors that apply in the prevailing circumstances retaining a robust, rigorous and analytical approach and hence to reflect critically on traditional engineering paradigms recognising the context in which the solution is required. A new engineering paradigm has to be developed, targeting a holistic model that engineers use every day, conceived solutions SD to be encompassed. Encouraging breadth of study alongside depth of study will then make possible the formulation of more holistically conceived solutions [10].

Different learning activities and learning materials will be needed to deliver the sustainability learning agenda to students from different branches of engineering [8]. Trans-disciplinary teaching and research – literally “across disciplines” – transcends the narrow focus of one or more disciplines and is not constrained to adopt pre-existing models for problem definition or solution. Boundaries might necessarily have to be drawn as a practical matter, but they are not dictated by limitations of the analyst or designer. Where broad system changes are desirable, trans-disciplinary approaches are essential. SD is not just another specialisation. It has to be integrated into specialist courses through learning activities which are firmly set in the context of the specialism.

Throughout such a programme,

- Although strongly grounded in an engineering discipline, emphasis is given on sustainable development, on the problems that are created by human activities and on the contribution of the engineer to solving them, is on the multidisciplinary approach to tangible decisionmaking (more complex by a number of technical, economic, environmental, social and ethical constraints), developing bridges between the technical and physical sciences and the humanities, to allow effective function in multidisciplinary and multicultural environments
- students are equipped with effective communication and negotiation skills required for their new role, to respond to challenges posed by the evolving demands upon future engineers. These skills are “crucial to the task of appraising the wider environmental, social and ethical implications of engineering projects and developing answers to them in a multi-stakeholder environment” [13]. This means that it is important to educate students to recognise their personal values, recognise conflicting values, and then revise them so that sustainability becomes a priority when formulating solutions to human problems.
- value judgments play an important role in engineering education which is not just facts and empiricism, but embraces ethics, creativity and social responsibility. Modules on ethics explore the different value approaches and ethical principles underpinning sustainability, and cover subjects such as environmental values, intergenerational and intragenerational equity, the needs and rights of future generations, and relevant ethical issues raised by climate change,
the loss of biodiversity, genetic engineering and so on [12].

• vital is the understanding of the interdependence of natural, social and economic systems which help to recognize the problems of our global society, the way in which goods and services are provided, to develop and design new ways to meet human needs which impact less on the environment appreciating the need for precaution. A systems approach is necessary in order to deal with complexity through a recognition of wider system boundaries and of tools and techniques for identifying more sustainable solutions, as many times cope with inadequate information and uncertainty requiring construction of scenarios, making assumptions, performing sensitivity analysis and exercising judgement.

• Students appreciate what technology might offer in solving problems and that there are limits to what can be achieved through technology alone, and that singular prescribed technical solutions may not be capable of addressing real needs. Development and application of technologies to significantly reduce energy consumption. Such technologies are designed to reduce resource consumption and pollution, while they maintain living standards. Use of these new technologies may be encouraged by economic incentives, such as cost savings due to greater fuel efficiency, or by government regulation with penalties for non-compliance with standards, such as in building design [4]. There are many requirements for sustainability, such as stable social structures [17], for which there are unlikely to be technological solutions

4 Barriers - Solutions

Universities are conservative institutions, and engineering faculties are staffed by highly autonomous individuals, rightly proud of their specialist expertise and often narrowly focused. It is therefore no surprise that, changing the paradigm for engineering education in such a context is far from easy. However, such changes can and must happen. Indeed, we see change in engineering education as not just inevitable, but also highly desirable. We see change as most likely to be successful, and to be achieved with the minimum of effort and of disruption and distress to staff and students, if those immediately affected can understand and take some degree of control of the process.

Academic staff are “... often ideologically resistant to curriculum changes that emanate from outside the bounds of their discipline” [14]. Academics may:

• not feel comfortable working across disciplines, which is needed when disciplinary knowledge is taught in the context of environmental understanding;
• be concerned that this environmental understanding would not be considered appropriate for their graduates, or their disciplines, or that what is appropriate for one programme or discipline is not transferable to another;
• see the possibilities for changing current programmes as being too difficult;
• feel threat for the integrity (and ownership) of subject material at the individual course content level, with a nervousness about the true value of foregoing science for less readily measurable subjects.
• be concerned with the rapid changes in a developing field where teaching material needs to be continually updated, which is different to teaching scientific principles.
• be sceptical that the additional topics will be covered, but only cursorily and superficially, and that the technical rigour of the existing courses will be dissipated by the widening of subject matter.

Issues of organisation and culture act also as barriers to the process of change, including:

• discipline orientated divisions in the department with little well developed intra-departmental interaction and an academic culture of specialisation.
• increasing emphasis on winning research funding, manifested itself in the emergence of clusters of staff preoccupied with traditional forms of discipline-based research and consulting. Opportunities taken up for transdisciplinary and community-based research are exceptions to the rule of specialist focuses, which reinforced notions of enclaves of expertise. Research is a major innovative force and leader of change and sustainable development needs to become a focus for research as well as teaching.

• traditional “technical” focus of many staff (and students drawn to engineering by their [mistaken] perception of its lack of communication demands). The perceptions of these groups were framed around a focus on engineering science, and a concern that teaching
resources devoted to generic professional and personal development attributes would inexorably and progressively dilute technical excellence [15].

- introduction of subjectivity and judgement into the debate is anathema to some, and the open ended approach to some sustainable development issues can lead to a distinctly uncomfortable feeling for others, when customary approaches to the formulation of engineering solutions are challenged taking into consideration the successful tradition of engineering excellence [10].

- introducing sustainable development elements generates a tension between the traditional quantitative and the more current qualitative understandings of the issues. Students usually view technical subjects as the only essential part of their curricula. The perceived “qualitative” nature of the course is bound to devalue it in the eyes of applied science students who often equate “usefulness” with numerically-based design and analysis skills, rather than conceptual re-thinking, communications across disciplinary boundaries and complex decision-making where technical knowledge is only one among several other considerations. While the relevance of the learning outcomes is not in doubt, many students see “technical design and execution” as the only skill worthy of their curricular time accepting the defensive perception that “well it’s a soft, general, non-mathematical topic and so it will be popular with the less bright students”.

The problem, in other words, is to change deep-seated mental habits, and thus the predominant culture in engineering education [13]. To succeed such a deep change we have to provide clear directions and to recognise that the scope of curriculum change we are looking at is in essence organisational change.

Traditional models of change tended to assume initiation from the top, and a “machine” model of the organisation, in which processes dominate, and each layer does their part, to change overall. Kotter [18] suggests, particularly for such deep changes in culture and paradigms as sustainable development demands: “Major change is usually impossible unless most employees are willing to help. . . [and] unless they really believe that a transformation is possible”. In engineering institutions this is not the case. Academics have been encouraged to bring their individuality of expertise and research, to their jobs. This makes it difficult for top management to direct change, since guiding a group of academics who prize their individuality, analytical skills and creativity is not unlike “herding a mob of cats” [14]. Nonetheless, support, if not guidance from the top, is clearly an important factor in sustaining curriculum change.

At the same time there are many indications that for the sort of curriculum change we are discussing, a “bottom-up” approach may be important. This is the current situation, where the tertiary leaders have generally not given priority to developing a culture to support sustainability education. In this case, students could be involved in acting as advocates for environmental change. Dahle and Neumayer [16] suggest that this type of “bottom-up” approach might be effective, as students may feel freer to criticise campus actions. As “customers” at their institutions, students can have power to demand change. However, they caution that while the students’ advocacy role is necessary in raising awareness, a “top-down” approach is an essential component for change in order to engage, argue with and gain the interest of the teaching and research people in each division, to embed sustainable development materials in their own courses and projects.

Academics have unique power to inspire students to follow their example. Thus there is an imperative for every academic to consider how his area of expertise relates to other disciplines and how his teaching could contribute to developing graduate attributes necessary for work towards sustainability [4]. This requires support of the whole institution, and possibly considerable professional development of staff to help them appreciate how they can actualise the potential of higher education to lead the next generation to global sustainability.

Solutions exist and proposals have been made and applied. In Delft University of Technology (DUT) [19] the introduction of SD took place in three stages:

- Design an elementary course ‘Technology in sustainable development’ for all students of DUT.
- Intertwine the concept of sustainable development in all regular disciplinary courses, in such a way that it matches with the nature of each specific course.
- Develop a possibility to graduate in a sustainable development specialization, within the framework of each faculty.

Worthwhile is to mention the DUT experience based on the fact that students are more at ease with learning how to apply specific techniques, where the process is clear, rather than attempting to balance the conflicts and tradeoffs required in real world
problems involving engineering alongside a wide array of other issues. To motivate students with typical engineering culture, they preferred to express sustainability issues in quantifying formulas rather than vague definitions and abstract texts. An example of such a definition is that of the triple bottom line: People, Planet, Profit (The Three Ps).

According to the triple bottom line, a balance is needed between the pressure on the environment, social justice and economic growth. The three Ps represent an integral vision on sustainable development.

Another example is the IPAT formula:
\[ I = P \times A \times T \]
where \( I \) is the impact (total impact of mankind on the planet), \( P \) is the population (total population size on the planet), \( A \) is affluence (number of products or services consumed per person, i.e. GDP per person) and \( T \) is technology (impact per unit consumed; this factor is often called ‘technology efficiency’).

In University of Sydney [15] the introduction of sustainable development took place also in three stages:

- First, engagement of students in a discussion about their perception of their future professional paths, rather than tackling sustainability concepts head on,
- Second, gradually raised sustainability issues by building on environmental engineering technical material such as energy and climate change, land use and habitat loss. Starting with environmental engineering content allows students to begin engaging with the course on a relatively familiar note with technical material, including numerical skills. It also provides building-blocks which will then lead to policy and decision-making questions of sustainability and ethics. Third, it introduces ethics as a more systematic way of thinking about some decisions in engineering which include, but are not limited to, sustainability. Hence, all theoretical and policy questions and discussions are strongly rooted in engineering perspectives.
- Third, teaching of the social pole of the triple bottom line of sustainability. This dimension of the course encompasses the social impacts of engineering design, the politics of technological change and the role of engineers in decision-making processes.

In any solution proposed, we do not have to ignore the powerful connection between ethics and social equity in so far as it justifies the social power and financial privilege of engineers through its potential for serving the ‘least advantaged’. Such connections are doubly effective. First, they provide a strong thread running through the course and linking sustainability to ethics. Second, they promote “deep” learning by encouraging students in the workshops to engage with the course material as decision-makers, rather than observers or passive learners [13].

5 Conclusions

First of all we need to change existing education as it leads to the establishment and re-establishment of the existing, unsustainable cultures that must be changed. Secondly we need to re-invent education in such a way that it will contribute to a new culture that is in line with the principles of sustainable development such as, a respect for indigenous peoples and their culture, a knowledge of the state of the natural environment, an understanding of global dynamics, and the protection of routes of transmission of culture, knowledge and skills to future generations [20].

Such a re-invention means educate engineers:

- to ask a wider set of intelligent questions before formulating their solutions, rather than simply attempting to teach “technical solutions” to a narrowly defined set of current sustainability issues.
- to meet clearly defined needs, rather than simply delivering outputs.
- to rethink their fundamental approach towards a broader, multiple perspective approach in which problem formulation and context setting play a vital role in reaching consensual solutions with a disparate range of stakeholders.

The dominant culture in most institutions of higher education is still a culture of competition, of stimulating individual excellence and personal careers. Change in the academic culture is a prerequisite for changing the ways we teach students to work as a professional manager, engineer, scientist or salesperson. Only when institutions of higher education change their own culture, will students be able to learn how to integrate new ethics, new worldviews and new ways of collaboration, which belong to the paradigm of sustainability, into their own professional.

Also change is a central skill which needs to be encouraged in young engineers as a precursor to a new generation being able to implement their own sustainable solutions [10].

We’d like to underline that sustainability it’s a new word, but it is an old concept as it is an integral part of physical science which is the base of
engineering sciences. Engineers were never technicians, but “modern political mentors” subordinated them as pure instruments of development serving their unholy wishes to systematic management of mankind. Practically speaking for sustainable development, we speak for a “come-back” of what we traditionally knew, what we always respect and try to keep alive, “the true values of human life”. May it go much further, but we would like to point possible “dangers” of adopting a new mainstream (sustainability) as panacea for human prosperity, when it is just (again) part of our grandparents’ culture which we struggled to eliminate from our lives and now struggle to put it again in the agenda.

References: