Saving the World (Techno)scientifically. Sustainable Development and Engineering Education

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Abstract. Engineering is an important force in the building of society. Engineers are identified as problem solvers, but also criticized for causing new problems due to a narrow focus on technology. Feminist theorists as well as researchers within sustainable development have called for a more democratic and accountable practice among engineers, in order to cater for widespread societal and environmental risks as well as moral questions of technological innovations. The introduction of sustainable development has been introduced by the Swedish government into the school system at all levels and specifically in higher education of engineers. Engineering education has a potential to prepare future engineers for engagement in societal aspects to a higher degree, but this requires a more integrated education program where values and discussions are integrated in courses.

Introduction

Among non-engineers, a common caricature of an engineer is a person who is doing his (!) detailed work excellently with little concern for externalities, and little interest in non-technical solutions to the same problems. Users of the technology may even be regarded as an obstacle to the perfection of the technological solution. An illustrating example of the caricature was given in a session within Dubrovnik 5th Conference on Sustainable Development of Energy, Water and Environmental Systems (29 Sep-3 Oct 2009). In one of the invited sessions, a handful of (male) researchers presented arguments and technologies for extra-terrestrial resource and energy extraction. Utilizing the galaxies was argued as a necessary next step to meet the ever growing demands of a growing global population.

Engineers are often blamed for destroying our world and discriminating between people. It can be seen as a paradox, since engineers are supposed to be problem *solvers,* not problem producers. The explanation is supposedly that new problems that arise from engineers' work are not planned, and emanate outside the context where the original problem to be solved is located. The blame, then, is distilled to the ignorance of factors and consequences lying outside the core of the engineer's specific work space or work task.

Engineering and technology have been constructively criticized by feminist researchers who claim that these powerful resources and persons must be accountable for consequences of their deeds, be it gender discrimination or destruction of ecosystems or groups from/in different countries (e.g. Harding, 1986 and 2006). Feminist researchers have also, although to a lesser extent, formulated alternative theory and practice, possible to adopt in order to find accountable ways of addressing problems technically. Mörtberg (2003) exemplifies with computer systems design, which integrates several academic disciplines and where prospective users, trade unions and other groups are involved. Nevertheless, the designers most often make decisions and define the limits of the system and its representations. Mörtberg uses the feminist figurations *nomadism* and *diffraction* in her attempts to make visible what is taken for granted or marginal, and to keep heterogeneous choices and criteria alive in the design process. The figurations guide the design process towards teamwork and towards construction within a specific situation where people without programming competence can participate in discussions about choices and their consequences, rather than merely evaluating a prototype after alternatives were dismissed.

Within engineering education in Sweden, the concept of sustainable development (SD) has been introduced as a mandatory aspect. The idea of the concept is supposed to be integrated into the approach to learning and knowledge rather than added on as a specific course. The epistemology of sustainable development shares many basic ideas with feminist epistemologies. The recognition of values and accountability for consequences in knowledge production is an example of a shared idea.

It is the aim of this paper to discuss how these partly shared ideas could contribute to a more accountable and sustainable engineering practice and how this is addressed in engineering education.

The paper begins with a short investigation into how engineers are defined by engineering education institutions and in a historical perspective. Engineering and (techno)science are then elaborated from a critical and feminist theory perspective. The introduction of sustainable development in engineering education is discussed in relation to what engineers are expected to know and be able to do. In this way, new and challenging ways of being an engineer in the present and future society are discussed.

While engineering is here used to define the practice of doing technological work in society and in academic institutions, science and (techno)science refer to the knowledge systems on which engineering practice is built. (Techno)science is a concept acknowledging the implosion between natural sciences and technological research in the present time, when advanced technologies are needed for scientific studies and in turn need advanced scientific knowledge to be further developed (Mörtberg, 2000, and Trojer, 2002). Putting (techno) in brackets indicate that the natural sciences are sometimes in focus, while technoscience is in focus at other times and/or by other people. It is my argument that engineering practice and (techno)science are and/or ought to be closely related, and both of the two concepts are therefore used in the text.

Definitions of engineering

A common definition of an engineer is "A person who uses scientific knowledge to solve practical problems." ("engineer", 2009) The definition seems to be so well established that several Swedish education institutions do not describe engineering as a concept in their general information. However, a few Swedish technical universities try to identify the work as an engineer in similar wordings. At Lund Technical University, the engineers are described as "creative, independent and responsible problem solvers" in a general marketing folder (LTH, 2009; my translation).

The problem solving capacity is also connected to engineers' central position in society. It is highlighted that "as an engineer, you have the possibility to influence the development of society" (www.lth.se accessed 20090813; my translation). At Chalmers Technical University, the relation between knowledge and doing is highlighted in information to potential future engineering students. On their website, they appeal to a person who does "not just want a job. You want to have influence and make a difference for real. You feel secure in knowing what you are doing, and respected by others knowing that you know" (Chalmers, 2009; my translation). Alas, it seems important that today's engineers are aware of and attracted by their possibility to make a change in society.

It can be noted in the general descriptions above, *technology* as a tool for problem solving was not mentioned. It has also been recognized that the working practice of engineers is much less about developing technology than understanding structures and negotiating about managerial strategies (Backlund, 2006). However, according to Torstendahl (1990), knowledge of how to run a project with negotiations with other professionals and stakeholders is often missing in education programs. Lecturers also emphasize technical know-how as the first priority in engineering education.

In a historical perspective, engineering has been not only a work description but a specific profession. When becoming an engineer, you do not only acquire technical skills and problem solving capacity. You are also initiated into a certain discursive practice, where you are supposed to possess certain assets, gain legitimacy and status in society (Torstendahl, 1990). In this way, a hierarchical structure regarding professionalism is created which will have consequences for the way engineers interact with other actors in society.

With these historical and current work definitions, it seems as though engineers have, and are expected to have, central roles to play in a society where so many, if not all, activities depend on technological systems. Individuals and organizations are critical towards the power of technology and engineers in shaping the societal development outside democratic decision-making structures (e.g. Leach et al., 2007). As Mörtberg (2000) argues, new technologies that are being developed at present, like genetically engineered living organisms, can only be tested in “real life” and have turned the whole society into a full-scale laboratory where the outcome is unknown but will have consequences for all of humanity. A Swedish example is the construction of a railway tunnel through the ridge Hallandsåsen, which in 1996-97 led to water wells drying up and to contamination of water sources used for animal and human consumption due to use of acrylamide in liner material. The engineers had grossly underestimated the problem with the large water flows in the porous ridge material (Banverket, 2008).

What could be regarded as a paradox, namely that engineers’ influence increase as advanced technologies are used in more applications and aspects of life, while at the same time their status in society is reduced through public critique is explained by an increasing public awareness of these complex and life staking uncertainties. Technical possibilities, not only unforeseen consequences, require moral and political standpoints and decisions before and during development and application.

Science, technology and feminist epistemology

Feminist scientists and researchers have provided powerful critique of mainstream natural science and technoscience. Part of the critique has concerned oppressive or untrue knowledge in “bad” science, as was the case in the early 20th century with both racist science and theories about the female psyche, but part of the critique also concerns attempts among scientists to be neutral and context-free as is the praxis in “normal” science (e.g. Haraway, 1988, and Harding, 1986). In her historical review of the development of science, Merchant (1989) argued that scientific investigations required a shift from viewing nature as a living organism to viewing nature as dead material, as it had to be torn into bits and pieces to be studied in the laboratory setting. Keller (1983) and Spanier (1995) both criticize modern molecular biology for ascribing human and value laden characteristics to genes, which becomes evident in language like “the master molecule”.

These are just examples of how science does not emanate from “a view from nowhere” (Haraway, 1988) but is deeply inscribed in its social context. As both Harding and Haraway argue, feminist critique is not aimed at reducing the bias or context-dependence. Instead, they urgently request scientists to make visible and be open about the prerequisites, partial perspectives and situated knowledges (Haraway, 1988) that shapes scientific studies and (presentation of) results. Keller’s (1983) biography of Nobel Prize winner Barbara McClintock is a manifest of the possibility to do science in other ways with “a feeling for the organism”.

Recognition of partial perspectives and directionality of (techno)science can change focus radically, as in the research of Martha Crouch. She was renowned microbiologist, investigating the genetic codes taking part in next generation development in plants and seeds. As biotechnology in agriculture was advancing parallel to her studies, she realized that her findings might be used in biotechnological applications terminating natural regeneration of seeds in order to control seed markets. Her reaction was to return research funding and turn into biological research of a different kind (Crouch, 1990).

Crouch’s action is an example of acknowledgement and accountability for the directionality of scientific and technological development. Whether (techno)scientific research works is not sufficient to establish. Using the terminology of physics, Keller (1992) describes the power of (techno)science as a vector, having both magnitude and direction, and hence, we need not only evaluate the success of the technology in terms of *if* it works, but also what it works *at*, for whom it is successful and towards what development paths it will lead us (Gulbrandsen, 1995, Bush, 1983, Mörtberg, 2003).

Recognizing science and technology as powerful, situated and with a specific direction, researchers in feminist together with other critical studies urge for accountability within and among scientists.

Science, engineering and democracy

In her research on hydropower built by Swedish engineers in Tanzanian rivers, Öhman (2007) demonstrates clearly that technology and science are both “carriers of values and political ideologies and also as products of values and societal power structures”. Political values are built into specific designs and technologies, and all technological systems are intended to favor someone’s particular interests (Winner, 1986).

In the work of Beck (1994), (techno)science is assumed to have increased its influence and at the same time lost authority. In part, this is explained by the increasing level of knowledge shared by more people, and the speed at which information can be spread on a global scale. Citizens are therefore in a more favorable position when it comes to taking part in decision making and direction of (techno)scientific directions of development. The negative (rather than positive) effects of technologies have also become central in debates and decision making, according to Beck (ibid.).

However, according to Wynne, it is not only (scientifically) calculated distribution of negative effects that drive citizens' engagement in disputes over technical innovation. Life, survival and fundamental moral values are at stake in several of the technological innovations and applications being promoted, and "lay public responses to expert knowledge is always potentially an epistemological conflict with science about the underlying assumed purposes of knowledge" (Wynne, 1996, p. 61). Citizens do not only react on arguments, but base their trust in the trustworthiness of the institutions behind specific arguments or technologies.

With the far-reaching and omnipresent nature of current technologies and technological development, it is argued that we as citizens can not rely on experts to make the right decisions and develop beneficial technologies. (Techno)science needs to be democratized and opened up to a broader stakeholder involvement in all stages of development. Nowotny et al (2001) define this as a mode 2 way of knowledge production, arguing that more robust knowledge will be the effect. The argument for mode 2 knowledge production is also an acknowledgement of scientists not being located outside society and neutral towards practical consequences of their research, but highly embedded in society. This becomes evident in the current debate over climate change, where the political and social expectations will guide individual researchers toward certain fields of research.

Learning for sustainable development

Sustainable development (SD) as a concept began to spread in the late 1980's, as it was defined by the Brundtland commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, 1987). Today, we discuss SD in terms of social, economic and environmental sustainability, acknowledging that these different aspects need to be addressed, and that they are interrelated. The implication is that when new systems, technologies and artifacts are developed, a long-term perspective should be applied and negative impacts on present and future livelihoods of all people should be considered. However, the practical implications of an SD perspective are still limited and ambiguous, given the wide and vague definition.

SD as a research field has been identified as a transdisciplinary theme, trying to address problems from a holistic perspective (Vikström, 2008). It can be seen as an academic field potentially opening up the recognition of values and directionality of research, since it is based on a willingness to contribute to sustainability in society. Even if SD is a concept open for a variety of interpretations, the idea of SD places a claim on each individual and on institutions to take a position in favor of some kind or direction of development in comparison with other directions and to argue for the choices made in research propositions.

In Sweden, learning for sustainable development has been given high priority in all levels of the school system (SOU, 2004). The Swedish National Agency for Education emphasizes not only *what* pupils (of all ages) learn about SD, but also *how*, promoting democratic forms for teaching, critical perspectives, interdisciplinarity and varied pedagogic methods (Skolverket, 2009).

The integration of SD in learning institutions has been identified as having some specific characteristics by Sandell et al (2005), who distinguish between three different ways of teaching environmental issues. Fact based environmental education is based on the view of environmental problems as scientific problems that can be solved by increasing knowledge and information. In this view, democratic processes are supposed to take place after education, when knowledgeable individuals can contribute objective facts for better decisions. A second perspective is the normative tradition, in which environmental problems are related to lifestyles, behavior and attitude. The democratic procedure takes place before education, providing education institutions with the norms that are to be taught. People are supposed to be persuaded to change their attitudes when they are informed. In the third tradition, education on sustainable development, environmental problems are seen as democratic issues and the education is supposed to engage students in critical discussions about alternatives and their implications during and after education. The third alternative places the students, regardless of subject orientation or future profession paths, in society as active citizens, preparing them through e.g. discussions and drama.

When distinguishing between these three different approaches to learning, Sandell et.al. bring up epistemological questions in relation to SD. Learning is connected to experience and encounters with the surrounding world. Subject studies need to be put into a context and into relation with other subjects to reach more complex understanding of both ethical and practical aspects of SD.

Engineering education and sustainable development

Learning for sustainable development does not only have implications in the compulsory school for children. Besides being enforced by law in higher education for engineering (SFS 1992; SFS 1993), it has been recognized by technical universities and individual lecturers as relevant and important in different engineering programs. At Chalmers University of Technology, for example, sustainable development is prioritized and marketed at university level (Chalmers, 2009).

Efforts to include “non-technical” subjects or “soft skills” in engineering education include sustainable development as well as ethics and other areas (e.g. Hyldgaard Christensen and Ernø-Kjøllhede, 2008). With reference to the inclusion of philosophy in engineering programs, Hyldgaard Christensen and Ernø-Kjøllhede (2008) conclude that although Danish engineering lecturers in general are positive towards the inclusion, there are few concrete examples of how to do it and who should do it at the Danish universities. It seems to be a long term process to implement this kind of subjects into the engineering curricula in practice.

To some extent, the engineering education has changed in response to changing environmental concern, with the introduction of a wider selection of courses and also of specific environmental engineering programs (Tansel, 2008). Engineering education is regarded as rather intensive and demanding, with advanced technical lectures, laboratories and exercises on Master level. Despite the length of the programs, it has however been difficult to introduce widening perspectives in the education. This is explained by overcrowded curricula and lack of SD competence and/or efforts to develop competences among lecturers (Segalàs et al, 2009). According to Holmberg et al (2008), some specific assets were needed to integrate SD successfully in engineering education. These include legitimacy, commitment in university management, responsibility spread throughout organization and skilled teachers who can act as ambassadors.

To address the requirement of including SD, education programs need not only to offer specific introduction courses in ecology or sustainable development. Rather, there is a need to integrate ideas of SD into the different technical courses to exemplify and concretize what it means in specific courses. SD is not an additive content but an integrative principle (Mitchell et al, 2004). The engagement in SD engineering education does not necessarily mean doing different technologies, but doing technologies differently. It means, for example, opening up engineering work to participatory decision making processes and openness about uncertainties (ibid.). In this sense, SD has many connotations to the epistemological arguments for openness about context dependence and situated knowledge discussed above.

It is argued that the education today is rather fragmented, which may result in engineers focusing on narrowly defined problem solutions instead of being proactive and innovative in a responsible way (Ashford, 2004). Sustainability requires the skills to differentiate between simple problems and complicated problems, of which the latter needs contextual and participatory problem solving processes. These arguments with close relation to concrete teaching experiences relate well to the argument by Schön (1995) for reflection-in-action, i.e. an openness to reflect and possibly redefine the problem in focus during work practice. This obviously does not only relate to engineers but to all professions. Neither does it indicate that engineers do not need technical skills and knowledge. On the contrary, it has been recognized that the engineers need to know a lot more than solving technical problems, *because* they are the ones who know how to develop technical systems (e.g. Tansel, 2008, Fokkema et al, 2005).

Discussion

Long-term effects of scientific findings and technological development will always include intended as well as side effects. It is my strong conviction that our future survival as humans depend on much more than technological development. Redistribution of resources, reduced material consumption and reorientation of symbols for a good life are likewise needed. To some extent, these processes have already started in parts of society. Nevertheless, based on a critical but constructive transformation ambition, I argue with feminist as well as SD researchers that there are more robust and accountable ways of proceeding in the production of technologies for a sustainable and just future. The development processes must be more open to public participation and debate with a real impact and not merely in the form of therapeutic information meetings. Openness about disagreements and uncertainties is essential when risks are substantial. This challenges engineers to acknowledge their role as reality producers and their main work tasks being located outside the pure technical realm. Values need to be expressed and accepted as part of decision making. Stakeholders need to be involved in processes of planning, design and evaluation.

I have argued elsewhere (Rydhagen 2002, see also Law, 1987) that engineering is a heterogeneous practice. In one way, I think this is also recognized by engineers, since as problem solvers, we need to address “real world” issues including physical space, economics, fitting in existing networks and so on. In another way, I think engineers are trained to search for technical solutions to problems, whether or not this is - in a long term or equitable or democratic or ethical - the best or even a possible way of addressing the problem. The emphasis on heterogeneity means going beyond technical capacity and addressing social and other issues within the work process and not as an external add-on. This does not only require communication skills for better cooperation with other stakeholders but also an inner reflection of a wide range of implications connected to the work (Schön, 1995).

The fallacies in mainstream (techno)scientific practice were and are brought to debate as they chafe the understanding or values of certain groups or individuals, as they have for example feminist or SD researchers. The norm, or discourse, or dominant paradigm, within which the main body of knowledge is produced, is by definition not discussed within, but by those who find its basic foundation questionable. It is therefore important to build alliances in order to strengthen arguments for change of the norm.

It can be argued that engineers who have the narrowest focus on specific technological development are attracted to remain within the academic institutions, since the academia encourages and rewards in depth knowledge. In these positions, they also become part of education of next generation engineers, thereby regenerating the view of engineering as purely technical. The reform of the engineers' self picture as well as knowledge package may therefore not necessarily take place by initiatives by individual lecturers. Requests from major employers may be important, as well as requirements from governmental regulating bodies to integrate a more problem (or challenge) based knowledge base in engineering education and, later, in working life. Obviously, commitment in the university management is crucial in order to create room for learning moments among lecturers (Holmberg et al, 2008).

In engineering education, the introduction of SD, as has been stipulated by the Swedish Government, will definitely have an impact on the way specific subjects are taught as well as the course content. At the centre stands the importance of recognizing and reflecting over values and politics embedded in technologies and technical systems. This shift from neutral, fact-based definitions of technologies and technical problem-solving is similar to the urge from feminists like Haraway (1988) for situated knowledges and accountability in knowledge production. Although the requirements may seem modest, mainly arguing for more transparent decision-making structures and debates within technical-oriented organizations, they have a potential to revolutionize the way engineers and other regard the power and the risks inherent in development.

While SD has been recognized on several levels from government to university management and individual lecturers, feminist epistemologies have not reached the same impact in the education system in Sweden. SD as a knowledge perspective has been elaborated in concrete terms, suggesting teaching methods and subject content. Feminist (techno)science on the other hand has put much effort into understanding and exploring the fundamentals of how we learn and how knowledge is produced in society. The development of SD course content and perspectives in engineering education could therefore be informed by feminist (techno)science as well as other critical studies (e.g. postcolonial studies). This could at the same time provide an opportunity to concretize feminist aspirations for a more accountable (techno)science and engineering practice.

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