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Teaching contextual knowledge in engineering education – Theory of Engineering Science and the Core Curriculum at the Technical University of Denmark

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Abstract: Despite contextual knowledge is considered very important for engineers in performing their profession, experiences from decades in Europe and the USA have shown that teaching such topics in engineering education is challenging and often unsuccessful. One of the dilemmas is that social science based reflections related to the use and uptake of technology in society often conflicts with engineering students' self-understanding and identity. Another dilemma is related to the specificity and modeling reductionism in engineering science compared to the complexity of problems in engineering practice. Consequently courses added into engineering curricula emphasizing contextual issues stay in stark contrast to the dominant instrumental disciplines of mathematics and techno-science content of core engineering courses.

Based on several years of teaching and experimenting with Theory of Science at the Technical University of Denmark, the paper argues that teaching contextual knowledge needs to overcome several barriers that tend to be neglected in engineering educations.

Introduction

Engineering and engineering education has throughout history been faced with challenges impacting not only the engineering practice but also the identity of engineers. In recent time, the dilemmas and challenges facing engineering practice and engineering education raise, according to Gibbons (1994), Christensen (2009), Downey (2006) and Williams (2002), a need for response strategies to:

- handle the societal problems related climate change, for example, how to handle environmental deterioration, increased populations and poverty.
- handle the increasing complexity of technologies which require responses not only to its impact on society but also to how to define and educate social responsible engineers
- handle ever increasing blurring boundaries between science and technology, also known as techno-science within new 'fields' such as biotechnology, nanotechnology etc. requires engineers to develop competences within cross-disciplines such as modeling, simulation and design.
- how to act as engineers in a hybrid world, where engineering is pulled *'in different directions – toward science, toward the market, toward design, toward systems, towards socialization'* (Williams, 2002, p.70)

Professional as well as higher education in general produce communities of people with skills, insights and influence as specialists providing these groups with a monopoly of knowledge. This raise questions to their role as experts in constructing material and organizational structures and making decisions crucial for other groups in society and framing important aspects of working conditions and everyday life. The specialized knowledge that has become the core of most engineering educations with their emphasis on mathematics, techno-sciences has also contributed to the image of a self contained professionalism difficult to understand and assess from other parties in society.

Demands put on engineers are a result of technology's impact on society resulting in demands for these professionals to oversee and eventually foresee social impacts. The demands also relate to placing responsibilities in often complex situations of accidents and unexpected outcomes. As the demands and the responses are ambiguous the complexity in the division of influence and

competences may render simple ideas of responsibility invalid. Consequently the interpretations of the challenges and the identification of the problems at stake do not result in simple and straightforward solution to how engineering education should respond to these challenges (Jamison, 2011).

Responses to context in engineering

The reactions and response strategies of the engineering institutions towards these challenges has been and are currently different in their scope. Since the 1960s humanities and social science, covering issues of creativity, cultural aspects of technologies, ethical considerations, political training and social engineering, have been part of the engineering institutions response strategies to educate engineers. But incorporating humanities and social science in engineering education has in many cases failed or created a disinterest among both engineering students and faculty members. Downey (2006, p.6) argue *'Because of the dominance of images of engineering as technical work, especially technical problem solving, prior to this movement most engineering curricula demonstrated a relative disinterest in liberal education. Either it was fundamentally irrelevant to engineering education, as was often judged to be the case in Europe, or it was a necessary but peripheral contributor to 'broadening' the engineer as a person, as was often judged to be the case in the United States. Also, in the case of peripheral participation, faculty from the humanities and social sciences regularly experienced a tension between providing introductory experiences in the liberal arts, for which the concept of competencies was an inappropriate label, and serving the professional needs of engineers, e.g. by facilitating skills in communication'.*

Other responses have been taking from the outset of engineering disciplines themselves adding discussions of social challenges and scientific problems to the already instrumental teaching and taking the outset in the problem solving strategies proposed in the technical disciplines. The need for including 'real life' experiences and problems have been an obvious response as these often transgress the boundaries of the technical disciplines themselves and render the challenges from the complexity of professional practices absolutely crucial.

The 'liberal arts' curriculum requirements in the US being part of the first years of engineering studies is a good example of an externalist response strategy based on the idea of educating learned citizens. The motivation taking the outset in creating a democratic, political culture bridging the vast differences in American society. This has some resemblance with the German idea of free universities providing a basis of 'Bildung' that comprise of a broad insight and an ability of critical thinking. While motivations might be different also France focused on including a broad education for their elite of state professionals including engineers. While the add-on disciplines from the humanities and social sciences have been institutionalized in the US, the European situation is much more diverse in how the demand for a broader knowledge base in engineering has been installed.

During the 1970s the critique of technology and its impacts on society resulted in more specific topics taken up at several technical universities including environmental issues, working environment, job degradation, business economy and use aspects of technology resulting in more specific courses taught based on sociology, psychology and economics but emphasizing these disciplines' take on technological development and its consequences. Though more specific and related to the engineering profession, the courses played more a role of 'social and green' add-on to the still dominant core of engineering courses. A specific approach has been taken by introducing ethics into engineering emphasizing the personal dimension of responsibility and how it is embedded in social structure. While the focus in sociology and economics tend to be on the societal institutions and their role in regulating technological development and implementation, the ethical framing tends to emphasize the individualized responsibility in engineering.

The EPICS (Engineering Projects in Community Service) programme founded at Purdue University in 1995 is an example if such an engagement taken from the theoretical realms into students practices within a 'community service learning' perspective by working with real life demands from community groups in a non-business perspective. This approach expose the students directly or indirectly to moral responsibility and ethical challenges at the same time as they learn to communicate with non-

professionals on goals for design tasks. The underlying assumption is that engineers 'do good' and seeks to meet the needs of civil society. In many ways the EPICS programme can be compared to the so-called Science Shops established in the Netherlands in 1970ties and spread mainly in European throughout the 1980ties and 1990ties (Brodersen, 2010). The idea of providing students with possibilities of real-life experiences as illustrated in the role of partnerships between student project teams and their partner organisation: '*During this phase, the project team learns about the mission, needs, and priorities of the project partner. A key aspect of this phase is identifying projects that satisfy three criteria: they are needed by the project partner, they require engineering design, and they are a reasonable match to the team's capabilities.*' (Coyle et al., 2005, p.6). The dilemma is that the technological knowledge is not at stake, but present a set of background capabilities where the limits lie in whether they perform as a relevant design object and are in reach of the project team.

The EPICS programme is a response to the more general requests to engineering education coming from a.o. the ABET 2000 criteria demanding: '*In setting the goal for any system they [the students] are asked to design, they will be expected to interact effectively with people of widely varying social and educational background. They will then be expected to work with people from many different disciplines to achieve these goals.*' (Coyle et al., 2005, p.1). Again in this phrasing, the problem of technology adaptation and relevance appear more or less unaddressed and the problem of making solutions useful for people is at large reduced to the 'effectiveness' interactions in identifying needs. Other similar examples can be found in student projects provided by for example Engineers Without Borders emphasising development projects with focus on technologies and engineers as core parts.

EPICS as well as Engineers Without Boarders illustrate a classic progressive perspective on engineering; where technology and engineering are perceived as a rather 'neutral' and professional entities that have to find their masters and ethical values offered from outside engineering knowledge. This produces a rather dominant, contemporary new heroic interpretation of engineering that can offer services to communities in parallel to serving international corporations and economic interests. It keeps engineering 'clean' and 'unspoiled' in its intrinsic values represented by the de-contextualised disciplines and the independence of engineering schools and educations. It also gives way to heroic strategies where 'innovation and entrepreneurship' can be interpreted broadly as innovations for society and mankind as well as several ways of performing as entrepreneurs.

These response strategies can be characterized as internalist strategies as the take the outset in the practices of engineering and how technology impacts societal actor groups. Engineering training is viewed as a specific, instrumental way to reduce the complexity of issues related to the use of technology as ways to order and improve social practices. This leads to several, different interpretations of the boundaries of the teaching and disciplines in engineering education. Engineering disciplines and their problem identification can be viewed as complete and the challenges are seen as a mere question of understanding the application context which brings the responses close to the add-on strategies of including new topics and disciplines outlined under the externalist approach. At the same time the disciplines and their framing and reduction of the problem space are crucial for understanding the challenges and the need for broader competencies encompassing communication skills and the ability to translate community needs into engineering problems.

Technology studies and the study of techno-science provide a useful social science inspired alternative knowledge base that addresses the specific questions of relevance for the practices of the engineering profession and thereby for broadening engineering education (Latour, 1988; Bijker, 1995; Downey, 2006). In this perspective engineering disciplines are not seen as complete, but rather limited in their scope. The integration of practical knowledge and problem identification in educational challenges the existing organization of course topics and disciplines in engineering programs, as many disciplines are very specialized within narrow fields of technology. This leads these disciplines to present solution spaces that in a broader perspective are superficial and very difficult to integrate in a meaningful way. Even though the integration seen in the perspective of practicing engineers may be possible in e.g. project assignments, the core engineering disciplines dominate the curriculum and provides the students with an instrumental approach to engineering knowledge that guides the formation of their identity. This leads to response strategies that demand a revision of the content of technical subjects

and courses to support design projects and to bridge between the needs of different actor groups and engineering education and the skills provided.

These different response strategies all open up for broader perspectives on engineering expected to improve the professional insights and competences of engineers, but what is considered important and taken up as the context that engineering is embedded in points in very different directions. These include differences in assessing the character and completeness technological solutions included in techno-science leading to different interpretations of the boundaries of core engineering and defining contextual knowledge and the context of engineering.

The scope of the paper

Throughout a period of several years of teaching contextual knowledge and more specifically a basic and mandatory course in 'Engineering theory of science' at the Technical University of Denmark (DTU), we have been faced with the challenge of having quite a large proportion of the students finding the course irrelevant compared to the core discipline courses they are taught during their bachelor education. Despite several improvements in the curriculum, the production of a specific textbook for the course and changes in the pedagogical approach, the criticism remains fundamentally unchanged. This has lead us to assume that other matters are at stake, than merely the students criticism of the pedagogy and content matters, but that their criticism instead reflects the course's position in the overall education and the role of contextual knowledge in relation to the engineering students' self-understanding and identity. Resulting in the scope of this paper being to analyze and discuss why contextual knowledge seems to challenge the engineering students and thus which barriers need to overcome for a successful integration of contextual knowledge in engineering education and curriculum.

The analysis is based on focus group interviews with students after finalizing the course, students' course evaluations from a period of 5 years, an evaluation carried out by Learning Lab DTU (Hussmann & May, 2009) and the analysis and suggestions for a future model of 'Engineering theory of science' based on the work of an interdisciplinary dialogue forum commissioned by the dean of bachelor educations at DTU in early 2011 that resulted in suggestions to integrate and anchor the course in clusters of disciplines at DTU and establish a cooperation between teachers from engineering disciplines and from technology studies (Jørgensen & Brodersen, 2011).

Theoretical framework

To understand the role of disciplines in education include an understanding of how these disciplines are framed within a scientific universe - whether this includes visions of objectivism and instrumentalism or perspectives of interpretation and history and site specific conditions for understanding processes (Latour 1988; Cartwright, 1999). These are basic questions raised in the theory of science and in the study of scientific practices where the technical sciences are caught in the space between having a mathematical and natural science inspiration for objectivity and at the same time is dependent of the institutional and human actors' engagement with the implementation and working of technology (Pickering, 1995; Bijker, 1995).

As important – seen from our experiences – is the role of identity formation among students influenced by the 'hidden curriculum' implied in the core courses of engineering education taught as mathematical and natural truth and given an instrumental flavour that support a rather reproductive and uncritical approach to knowledge. This implies questions of how this 'engineering ethos or identity' is created and sustained and which role it plays in students' approach to learning. One of the important things that identity formation provides is an ability to select what can be considered to be relevant data and an 'engineering problem'. Following this the dominant focus in engineering education on problem solving strategies with often only little emphasis on problem identification and the 'wicked' character of real life engineering problems also is expected to impact the building of an instrumental identity among engineering students asking for more of the same instead of asking critical questions to their own knowledge base (Downey, 2006; Newberry, 2007).

Findings

The course analyzed is the 'Engineering theory of science' course at DTU (in Danish: Ingeniørfagets Videnskabsteori). The purpose of the course is to enable the students to understand and evaluate:

- the relationship between scientific knowledge and practical experience in creating new technologies,
- the types of knowledge and skills needed in engineering work, and
- technology's properties, its historical dependency and meanings in a societal context.

The course is structured in three themes: 'Technology and Development', 'Engineering work and competence', and 'Theory of engineering science'. In the first, theoretical part the students learn to see engineering practice as a field of competences that combine theory, empirical data and models, as well as experience-based heuristics for solving problems in various technological domains including the social and environmental challenges that adds complexity to the specific problem space of the domain. In the second, project part of the course the students analyze selected problems in one or more technology domains relevant for their engineering discipline. The students are encouraged to identify problems for their projects taking the outset in the technology domains relevant to their engineering program. The course material is presented in a textbook (Jørgensen, 2009).

One of the most crucial conditions for the course so far has been set by DTU as it is mandatory for all engineering bachelors programs and has to be provided in a generic fashion which implies that approx. 250 students follow the course every semester and the teaching has to be organized as a combination of lectures held by senior faculty and class and group supervision carried out by student instructors trained in a special series of seminars to deepen their knowledge of the course topics.

In 2009 the teachers of the course asked the pedagogical unit at DTU to perform an independent evaluation of the course. This was triggered by a situation where several improvements in the textbook material, in the cases used in the class teaching and in the lectures improving the engagement of student turned out not to change the students assessment of course though it clearly improved the quality of the student project reports and showed that there was almost no correlation between the students assessment of course and the quality of the reports seen as a measure of their learning during the course. Prior to the evaluation, several focus group interviews with students following the course were carried out by the team of teachers, to explore why the students felt this resistant towards the course. One explanation launched by the students was, that it was not the course in itself, but rather the fact that the course was mandatory and in some ways challenged their core disciplines (Brodersen, 2008).

Some of Learning Lab's conclusions from the evaluation (Hussmann & May, 2009, p.1-3) were:

1. Experiences from other Danish university in teaching the course theory of science show the same problems as at DTU. Thus it seems to be a general challenges to make the course relevant to the students as well as to ensure a successful integration of the course.
2. It is the ambition that the students learn to analyze and discuss various theoretical concepts and theories. This may be impossible within a 5-point course with approaches from human and social sciences that seems so different from what engineering students are accustomed to.
3. One of the major contextual problems for the course and its placement at DTU is the lack of integration between the course and the bachelor programmes. The possible synergy effects are not utilized, and the course is consequently seen as an appendix to the core courses.
4. It is clear that students' attitude toward the course is affected by older students and advisors.

The dean followed up on the evaluation with the following statement: *'In 2008, due to critical CampusNet evaluations, the teachers responsible for the course requested LearningLab DTU to conduct an evaluation of the course 42610 Engineering Theory of science (IFVT). The evaluation resulted in a general recognition of the course content, format but it also pointed out some aspects of improvements. These improvements are implemented, however it is clear that many students still have difficulty in accepting the course's relevance, and the course does not match their picture of what is relevant knowledge for engineer.'* (Vigild, 2011)

Resulting in a dialogue forum: *'In order to create a greater coherence between the contents of the course 42610 'Engineering theory of science' and other engineering subjects at undergraduate education and to improve the students' perceptions of the course, a group is set up with the objective of - through dialogue - to develop proposals to replace the current generic training concept with a solution that to a higher extent integrates the course in the undergraduate programs.'* (Vigild, 2011)

The dialogue forum found that a major challenge for the teaching of contextual knowledge, very difficult to change, is that students perceive 'real' knowledge as something that can be expressed in mathematics and formulas contrasted by the open ended problems raised in the course. This despite the fact that the course is filled with guiding methods, that almost makes its approach appear instrumental and not particularly loose and discursive.

Concerning the possibility of handing the course over to the specialized departments, the conclusion was clear, as the group assessed that the different technical departments' specialization would make it very difficult to maintain a holistic perspective and the skills needed to maintain the course at a reasonable level. The obvious risk is that societal aspects and the theory of techno-science soon will be lost due to 'local' department interests in expanding their own teaching, as is has happened in most of the introductory courses established at DTU to introduce students to 'engineering work practices'.

One of the big challenges is the size of a generic course that gives little opportunity for the teachers to provide examples that are relevant to all students. A conclusion was that the size of the course itself gave the students the impression that this course had low priority and compared to the mathematics courses teaching contextual knowledge differs dramatically as the course is expected to address the students own problems and questions while mathematics introduces an abstract knowledge that provides an impression of not needing a context of use.

The dialogue forum therefore sustained the conclusions of the dean by stating that a reform cannot be achieved by making minor changes within the already existing framework. It is the curriculum premise of the course that is wrong, including the idea that this is a generic topic that can be taught with a minimum of resources.

Recommendations

The proposal from the dialogue forum concluded that the main challenges for the teaching of a course in 'Engineering theory of science' is grounded in the relations to other core engineering courses and the implicit and explicit identity formation of engineering students.

To overcome these barriers for teaching contextual knowledge a co-called 'hybrid' model was outlined as an experiment to foster motivation and commitment among the students (Jørgensen & Brodersen, 2011). Where the course presently is implemented as a common generic course for all undergraduate programs, the revised 'hybrid' model will be tailored to groups - clusters - of undergraduate programs with similarities in their practice domains and disciplines and by the involvement of a combination of teachers with an interdisciplinary knowledge of socio-technical analysis / science and teachers with specialized knowledge in specific undergraduate programs.

An important supportive element of the proposed hybrid model of the course is to establish an academic center for 'engineering domain science' inspired by a model that MIT has used about systems theory across different applications. The idea here is that teachers meet to seminars organized around different academic themes that can be mutually inspiring and lead to research publications across the academic divisions. The professional networks can also play a role in the training of scientific staff at DTU.

The hybrid model requires the involvement of the bachelor program teachers in planning and implementing the course. It is not possible exactly to specify how extensive the cooperation in practice should be, as it still is the idea that the primary completion of the course is run by teachers with an interdisciplinary knowledge of the main themes included in course.

The case discussed in this paper, demonstrates the need to overcome some of the disciplinary dis-integration that has developed in engineering education and to avoid – at least partially – the role of contextual teaching and learning to end up as marginal, add-on courses and disciplines that stay in contrast to 'hidden' curriculum supporting an instrumental view of competences among students and supporting a rather technocratic identity building. Further studies of the identity building and its impact on engineering problem framing and problem solving strategies will also support the improvement of the teaching of contextual knowledge in an integrated fashion.

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