# Chapter 15
# Constructions of the Core of Engineering: Technology and Design as Modes of Social Intervention

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**Abstract** For a long period of time math and science subjects have undisputedly been seen as the core of engineering education that unifies the field despite the still growing diversity of engineering domains. These disciplines are assigned the role of providing an instrumental, common basis for the development and operation of technologies serving society and human needs. Though the relative part that these disciplines cover has been reduced in the wake of new technical disciplines and the resulting curricula congestion they are still serving as an ideological backbone in discussions of engineering and have made the introduction of other perspectives very difficult as demonstrated in the history of engineering education. The question raised in this chapter is whether new areas of teaching and new disciplines should be considered as alternative candidates to the core curriculum or whether the mere idea of a core should be revised and given up as part of the 'expansive disintegration' observed within the field of engineering. Socio-material design of not only products and services, but also of technological systems takes seriously the important role that technology has in defining social ordering mechanisms in society. This makes socio-material design a potential candidate to become the new core of engineering, coming together with other approaches that emphasize the social part of technology. If accepted on equal footing with the use of models and science, design could serve to moderate the technocratic and instrumental focus that prevails in engineering education due to the dominance of math and science in the core curriculum of engineering education from the very first lectures.

**Keywords** Core curriculum • Engineering education • Response strategies • Translation of challenges • Technology • Social order • Entrepreneurship • Design as intervention

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## Introduction

The starting point for this exploration is the observation that the core curriculum of engineering education has for a long time been, in somewhat hegemonic fashion, focused on math and science methods, as well as on the instrumental view of engineering as a profession serving human needs through technical means. Attempts to reform and deviate from this established ‘classic’ view of engineering training, including decades of initiatives to expand or change the core engineering curriculum, have experienced only limited impacts and have been met with resistance.

Several new forms of multidisciplinary educational programs have surfaced combining technical knowledge from engineering disciplines and domains with business economics and organization, entrepreneurial models for innovation, planning of infrastructures, etc. But in general these have not changed in any radical way the nature of what is considered core engineering, as they mostly have operated with an add-on model where the teaching of new disciplines at best have been integrated in some few students projects. The recent strong campaign for adding an entrepreneurial perspective to engineering educational training does not differ from this add-on approach, though it (again) raises questions as to the core values implicitly taught in many engineering disciplines.

The last three decades have seen an explosion in the number of specialty domains represented in educational programs at engineering schools. Together with the large number of educational programs having technology as an important part, but taught outside engineering schools – e.g., in science departments or even from humanities and social sciences – this has been characterized as an ‘expansive disintegration’ in relation to the ‘classic’ vision of the core topics of engineering. Rather than changing the core of engineering to reflect new and cross-disciplinary approaches to technology, overly rigid engineering disciplines and domains have requested more and more space within limited curricula, often at the end resulting in handling the expansion by adding new programs. At the same time, this development is paralleled a loss of hegemony over technology by engineering professionals due to the pervasive nature of technology within a large number of societal activities and functions.

Engineering is indeed challenged by several fundamental new problems and ongoing changes, but the strategies have been rather different and lead to quite different developments when it comes to the institutional and educational responses. At the institutional level this is reflected in either a conservationist focus on the ‘classic’ core of math and science as the basis for engineering approaches and values, an add-on strategy responding to a demand for change in engineering competencies, or a more radical rethinking of technological knowledge and practice. The latter is most often found, e.g., in relation to educational programs focusing on design and introducing new ways of working with technology – sometimes outside engineering schools.

Still other factors influence how teaching and learning can be organized within engineering schools. Societal visions of technology and progress prevail and support the codes of knowledge dominating in engineering, as does the building of student identities already from their time in primary and high school. What is considered core in engineering does not only set the stage for disciplines and teaching, but is interwoven with the recruitment of students and their views of knowledge and use of methods. While most technical and mathematical disciplines are taken for granted as operational, instrumental, and objective, other fields of knowledge challenge these views and become objects of controversy. This has shown in the difficulties met when introducing add-on disciplines into engineering education, often rendered 'soft' not only by the engineering faculty, but also by students preferring the closed world of methods of problem solving within given technical designs.

This chapter will illustrate the challenges, the institutional response strategies, the identity formation process and the different impacts this may have for educational programs and disciplinary approaches to learning about science, technology, and professional practices within engineering. A comparison will be made between the different response strategies in relation to building professional practice, and how different disciplinary approaches and methods influence the problem identification and problem solving heuristics of professionals, giving room for rather different social ordering expectations and implications. Following this, questions will be asked about the potential role of 'socio-material design' in engineering in combination with actor based, ethnographic approaches to problem identification and as a new core of engineering education. The term 'socio-material design' refers to the integrated material and social impact of technology as the condition for engineering designs and problem solving heuristics. Consequently knowledge and experience of both should be a part of the design process.

The empirical material backing this chapter's examples and analysis combines experiences from teaching several disciplines of philosophy, technology studies, professional practice, and design with a number of field studies of engineering identity formation, engineering professional practice, and the construction of disciplinary approaches, models, and methods.

Finally, it may be appropriate to clarify that this chapter is about the role of engineering education and training, and how it affects engineering practices. The criticism presented does not target engineers or engineering for generally being narrow-minded or lacking vision. Though some engineering institutions could fall prone to such criticism, it is not the aim of this chapter. Also, while many engineers may in their practices reflect narrowly what they have been taught in educational programs, others have taken on other visions and perspectives going far beyond the instrumental and often also technocratic views implicit in the majority of engineering educational programs. Without lessening the need for reforming engineering teaching, we must also realize that educational programs are only one part among a multitude of societal influences that shape engineers and the engineering profession.

## Math and Natural Science: The Common Core of Engineering Education

Even though the idea of a common core of engineering education has been challenged several times throughout the history of engineering due to the growth in specialties and new technical disciplines, the idea has remained strong that math and science form the backbone not only in the introduction to engineering, but also in the formation of the engineering profession as a science-based endeavor driven by objectivity and rationality. This core has thus not only provided engineering students with a common neutral and rational set of methods to be used to calculate and optimize technical constructions and machines, it has also maintained the idea of a profession basing its work on expertise that tries to maintain independence from human interest and politics.

Following this, one of the intriguing aspects of engineering is the gap between engineering curricula and the categories of employment of engineers very visible in accounts of the labor market for engineers and in the advertisements of new positions. For example, while roles such as sales engineers, technical application specialists, or technical consultants very often are found in conjunction with specifications of the desired technical domains of engineering education, experience, and training, these functions are seen mainly as just as experiences to be learned in practice. They are typically not viewed as an integral component of engineering education on the same level as the technical domain as defined by the big four, civil, mechanical, electrical, and chemical engineering, or later diversifications and new areas of technical expertise such as environmental, computational or biotechnical engineering (Auyang 2004).

Historically, academic engineering institutions were seen as producing the builders of society's technological infrastructure, often in direct relation to nation building activities. More recently, academic engineering institutions have shifted to become more and more entrenched with, and involved in, industrial and business activities that apply technologies to the production of diverse products and services. The self-images of engineers have undergone corresponding changes, though the foundational role of engineering as a profession still has strong roots in the period where engineers were building the backbone of modern society's machinery. In contrast to the rather complex and multi-faceted picture of the drivers of change provided by the history of technology, the idea of math and science as main contributors to modern technology was developed in close connection with the development of the idea of 'polytechnique' – a basic knowledge able to support any technical specialization within the technical universities and engineering schools. The multiple origins of new technologies was kept alive through the two tier system of theoretical- and practice-based engineering educations until the late 1970s, but even the education for vocational practice has been taking over this idea of a common core (Lutz and Kammerer 1975; Reynolds and Seely 1993; Jørgensen 2007).

## Controversies within Engineering about the Core Curriculum

In more practical terms, the growing pressure on engineering curricula from new topics and new domains of technology has not left the proportion of math and basic science teaching untouched. These topics have lost terrain in many engineering programs and the common parts to be covered by all programs across technology domains have over time been reduced similarly. The interesting question is then what consequences this has had for the idea of a core curriculum defining the common basis for engineering education?

There has been controversy over the role of math teaching in engineering, with pedagogical questions being asked about the quality of learning abstract math detached from fields of application. Similarly, the role of natural science teaching as abstract and generalized physics and chemistry has spurred controversies within and between different parts of the faculty at the engineering schools and institutions. Typically the experience of teachers of advanced technical subjects was (are) that the students are not well equipped to apply and use math and basic science as ready-at-hand models when drawing upon this knowledge in a later stage of their education, resulting in a de facto repetition of topics. Some of this may directly relate to a misunderstanding of learning, where abstraction does not automatically also lead to a production of student abilities to use this abstract knowledge in specific new settings (Patel et al. 1991; Jakobsen 1994).

Seen from within, the conception of engineering as being the application of natural laws and mathematical principles has not necessarily harmonized well with the different approaches to teaching math and technical sciences. For instance, the reduction and compression of math and physics into courses restricted by less teaching time has led to a compression of these topics into a less open and questioning type of teaching, and a more factual and instrumental presentation of the remaining, reduced curriculum.

Achievements within the field of logistics and control systems in WWII, along with developments in the post-war period, led to a new belief among engineering scholars that an even more science driven development within engineering and the technical sciences would finally bring engineering out of the shadows of the natural sciences and put its new science-based disciplines on par. This thought is intriguing in light of the debts that the natural sciences owe to the technological revolution, and of the progress within engineering of gaining independence from the more speculative fields such as philosophy.

These developments gave systems theory a boost, and for a period in the 1960s and early 1970s the complexity of technologies and their social application resulted in quite challenging problems to engineering. Systems theory provided a new blend of methods that both could be used in analyzing and structuring problems, as well as could provide tools to identify relations even at the most advanced levels of contradiction between different representations and models (Hughes and Hughes 2000; Mindell 2002). But what the new theoretical language did not provide was a set of tools and methods that took into account the actor-based diversity in the ways properties and relations were understood and acted upon. This pushed systems theory back into being another – maybe more complex – tool used by engineers to machinate and order social processes from a technocratic position. Systems theory, despite its open-ended language and pervasive entrance into other disciplines, even within organizational theory and biology, did not fundamentally change the idea of math and science being the common core of engineering.

In the last decade the divide and boundaries between the natural and technical sciences has increasingly been challenged. This has resulted in the coining of the new notion 'techno-science' to cater for the interrelations and blurring boundaries (Latour 1987; Gibbons et al. 1994). This not only demonstrates the transformation and growth of the technical sciences, but also the change in aims and content of the natural sciences, with the latter increasingly being involved in the development of technologies based on constructive interventions in what hitherto might have been seen as the autonomous sphere of 'nature' – a repository of interactions and processes independent of human intervention.

## Questions from Practice to the Idea of a Unifying Core

In contrast to the idea of a common math and science core providing engineers with a 'lingua polytechnique', engineers trained in different technological domains often have very different perspectives on what constitutes a problem. They may differ in their repertoire of methods and solutions, and even assign different properties to the objects they work with. This problem has been caught and described in the studies by Louis Bucciarelli (1996) pointing to the existence of rather different 'object worlds', each of which belong to the different specialized branches of engineering, and are reproduced in the educational specializations. This is not just a question that relates to the specific views and objectifications that belong to different engineering professional groups, each looking at different aspects of a technology with their problem solving and optimization strategies resulting from the practical experiences of professionals (Schön 1983). It goes deeply into the ways basic disciplines are taught. For instance, thermodynamics is seen as a theory to optimize the working of energy machines in the mechanics version of the course, while its focus is on chemical processes in the chemistry version.

The consequences of these different and often divided object worlds goes far beyond the problem of communication and differences in the use of notions as it defines both the visible and the black boxed parts of engineering practices. As shown by Louis Bucciarelli (1996), Eugene Ferguson (1992), and Kathryn Henderson (1999), engineering communication extends beyond the formal communication that uses math as the common 'lingua' of technology, and also extends beyond the laws and known principles of physics and chemistry when it comes to the creation of new technological objects and new designs. As their properties are not given but result from the experiments, discussions, and tests that is part of the design process, new notions and ways of describing the new features and objects is in the making as well. The standard view may be that engineers know what properties are relevant and therefore rationally can work with design specification and a 'catalogue' of properties in their design process. But even when it comes to testing already developed prototypes there are open-ended problems that include processes of verification and testing of hypothesis. Design communication builds on a broader 'lingua' that includes analogies, drawings, sketches, and models.

The problem that design and the solving of wicked problems poses to engineering is very clearly demonstrated, but also reproduced, in the foundational book on understanding engineering work and problem solving strategies written by Walter Vincenti (1990). He almost completely black-boxes the generation of engineering design concepts and describes most engineering work to be about the optimization and testing of already-established technological constructions and machines.

The problem with the focus on manipulating already-established technologies and methods was nicely summarized by Gary Downey (2005) in his article on engineering problem solving. He notes the dominant roles played by problem solving based on existing design concepts, and by the application of methods developed and refined within different engineering disciplines. But he also highlights that the process of problem identification and reduction more or less has been left out as an explicit part of the curriculum – maybe with the final thesis project as an exception, at least at some engineering institutions (Downey 2005; Downey and Lucena 2007).

## Technology as the Material Means of Social Order

The dominant conception within engineering of technology as the result of an application of natural laws and mathematical principles for societal purposes correlates well with the philosophical idea of technology being a rather autonomous driver of social change. Historically this idea has been the main inspiration for a variety of technocratic movements emphasizing that technology should not be politicized but instead should guide politics.

Though questions could be raised concerning the relevance of historic cases, the birth of the polytechnic ideal in France, and its application in Denmark, for example, was closely related to the idea of an objective and technology driven development devised by government through the utility of an engineering and bureaucratic elite corps of civil servants and managers. In the vision of the Danish first rector of the Polytechnic Learned Institution (established 1826), engineering education should soon be complemented by an education focusing on civil servants with a basis in political science and law – a combination made with reference to the German notion of government chambers called 'Kammeralwissenschaften'.

Such technocratic neutrality and objectivity may not be gained without the construction of an operational base of action that creates the ground for a whole profession, and the conflicts over the role of science and math in engineering is therefore also related to the historic project of constructing engineering as a profession that can present itself as objective in its statements and interventions, and as a servant of society (Williams 2002). Several scholars have demonstrated the role of technology in ordering social practices from forces of production (Noble 1977), military organization (Roe-Smith 1989), professional engineering cultures (Hård 1994, 1999), gendered identities (Faulkner 2007), large technical systems (Hughes 1987), socio-technical ensembles (Bijker and Law 1992; Jørgensen and Karnøe 1995), and socio-technical regimes (Rip and Schot 2002; Geels 2004).

Technologies comprise of a rather varied set of socio-material practices that are made operational in society, ranging from the building and operation of machines to the construction and use of methods and processes governing infrastructure, communication network, security systems, energy provision, etc. Most technologies today are not simply single machines or devices but are operated as parts of larger technological systems that combine, regulate, and govern the individual technical devices within a larger systemic framework that include aspects of control, state shifts, operators, etc. Maintenance and operation as well as continued adjustments and repair works are needed to account for unforeseen problems in the running of these machines and infrastructures.

Theories of technology have evolved from a state where social scripts were seen as properties closely linked to the specific technology, into a more open and interpretative state where domestication (Lie and Sørensen 1996) and interpretative flexibility (Bijker 1995) opens for actors influencing and using technologies in different ways. Yet the institutional settings and governance structures associated with technologies implies that the social order perspective is still relevant for understanding technology in society.

## Engineering Objectivity in Constructing Social Order

Having demonstrated the role of technology in delivering the material structures and objects that are crucial for the socio-material ordering of societal activities, addressing the role of engineering in this construction process becomes important. It seem obvious that simplification and black boxing, as demonstrated in the above examples, is a necessity to make technology work, as a certain level of standardization and ordering is needed for the machination process to provide the anticipated outcomes of technological interventions.

The problem is not whether black boxing and standardization have to be avoided, as these processes are an intrinsic part of the design of socio-material constructions, and are necessary to make them become operational. This is also a core finding from the studies of technology. The problem lies with what parts and actor interests are black-boxed, and therefore blinded and left out in the standardization process.

Following the conception of engineering problem solving practices as grounded in specific object worlds stemming from the existing repertoires of technological concepts and solutions, the reproduction of implied social orders become visible, though also at the same time it becomes blurred and black-boxed and therefore requires a thorough analysis to be identified. The ability to overcome the limitations of the object world is crucially related to the ability within engineering to reflect upon both problem definitions (plural) and to transgress the boundaries created by the object worlds. As once stated by research manager of the Danish Learning Lab, the fundamental problem within the field of engineering is the lack of reflection and understanding of the limits to and boundaries of the knowledge within the different disciplines and educational domains.

## Experiences with Bringing Social Perspectives into Engineering Education

Attempts to add and/or integrate social perspectives into engineering have been many and have followed different pathways. In recent Danish research in the Project on Opportunities and Challenges in Engineering Education in Denmark (PROCEED), studies have been conducted of how social challenges have been taken up and integrated into engineering education by interpreting and translating these efforts based on what we have identified as institutional response strategies.

Over a rather long period of time engineering education has been reacting to criticism that those responsible for technology and engineering have not taken seriously the critical role that technology plays in society, and consequently have not taken seriously the social responsibility of engineering. In relation to the idea of engineering as a profession serving societal and human needs, most engineering institutions have felt obliged to respond to such criticism. This has been done by including courses that are intended to provide engineers with social and ethical skills, ranging from the idea in the U.S. of having liberal arts requirements to provide engineers with the broad knowledge to make them good citizens, to more specific course requirements that teach about the role of technology in society and how engineers may handle eventual conflicting goals. The latter has included courses in the history of technology, engineering ethics, and, in Denmark, a special mandatory course about the philosophy and practices of engineering.

Along the same line of arguments that have made math and science into common courses, these social science-based courses on the role of engineers and technology have in most cases been provided as courses given to a large number of engineering students across different programs, and very often with only little connection with the engineering 'hard' topics that students take. The very few examples of integration that can be found have demonstrated that while the model with separate courses may in theory provide better teaching from a disciplinary point of view, it also gives rise to many of the problems of disconnectedness that these add-on topics and courses have experienced. In this respect the objectification of problems and solutions, following the core math and science courses, contrasts the discursive and actor-based teaching in the social science courses, and thereby digs even deeper the divide by enhancing the gap in superficial ideologies that does not fit well with how technologies operate in practice.

Besides the attempt to identify why and how it has been so difficult to insert social science-based teaching into engineering curricula, the studies in PROCEED have been carried out in relation to different contemporary challenges to engineering education that can be identified across Europe and the U.S. We have named these the environmental/climate challenge, the entrepreneurial challenge, the globalization challenge, the design challenge and the high-tech challenge. Without claiming that these cover all relevant aspects of what might be challenging the fields of engineering, nor that they are the key drivers of change within the different specializations and disciplines, we have found that these challenges and the identified response strategies have provided us with a quite broad and relevant set of archetypes for ways that engineering institutions choose to tackle the challenges. Four such archetypical strategies can be identified across the mentioned social challenges (Jørgensen and Valderrama 2012; Jørgensen et al. 2013).

1. In the first type of response strategy, an institution may identify a challenge as important for engineering practice, while at the same time denying it any influence on engineering curricula. This may entail highlighting the challenge as one among many important fields of engagement for engineers as responsible citizens and professionals. The challenge may be seen as something that should affect the attitude and orientation of engineers when solving problems, and with respect to this it might even be taken up in advertisements for engineering education and in competitions where students can demonstrate their creativity in problem solving. Still, the divide between engineering as rational problem solving and the politics of, for example, humanitarian design, sustainable solutions, and innovative ideas is maintained. The latter are not made objects of study within engineering, only objects of application.
2. In the second type of response strategy, an institution takes up the challenge by identifying new topics and disciplines that might help students in getting supplementary knowledge and competence as an add-on to their engineering training. These new topics and disciplines may come from fields of natural sciences, as in the case of biology, physiology, and medicine, or they may come from the humanities and social sciences in the form of ethics, organization, economy, business models, or psychology. These add-on contributions generally have their origins in other educational and institutional settings outside of engineering. While the idea of add-on topics has been very dominant in many response strategies, as it provides the flexibility to expand the competences of engineers, it has also resulted in two directly related problems: i) the integration between the engineering problem solving methods and the new approaches has been left to the students, and ii) the teachers of the add-on topics often have been placed in a conflict between adapting their teaching to be a part of engineering curricula and their own background and research options. This response strategy is very often seen when engineering programs include a course in design, a course in entrepreneurship, a course in communication, and/or a course in humanitarian engineering, which in several instances even may be followed by an optional

project assignment where the students can experience the challenge and get some basic, practical experiences.

3. A third type of response strategy operates with a more subtle and disciplinary change process in which the challenge results in the development and assimilation of new problem solving strategies that incorporate and translate aspects of the challenge into the instrumental perspective of engineering. This adds to the repertoire of analytical tools and defined problem solving methods and solutions that are presented to the students. It also contributes to the continued evolution of the technical disciplines in engineering, keeping them up to date with novel methods and cases. The critical aspect of this strategy is that the challenge may appear as a new set of tools and methods, after having been filtered and translated to meet the disciplinary structure and approach in the specific domain of teaching. In response to the environmental concerns in the public in the 1970s, many engineering programs, hitherto focusing on sanitation and water, responded to the challenge by expanding their teaching to include how to deal with pollution through handling the emission to air, soil, and water. They translated pollution threats into handling waste streams. In the field of wastewater treatment, this entailed new advanced processes for mechanical and biological treatment. The origins of pollution – often, extant technologies – were eventually addressed a decade later when cleaner technology strategies were developed that included addressing production processes and their use and handling of materials and energy. These perspectives entered engineering education as, for example, a new course in life cycle assessment methods, and new, less polluting processes added to the repertoire of existing methods of production. But overall, the challenge was effectively reduced to some new parameters in the optimization and choice of technologies, along with a few new courses.
4. The fourth and last type of response strategy combines and goes beyond the two former strategies by seeking new ways of integrating society and nature as an intrinsic part of technology, grounded in the view that technology is much more than just the application of math and technical sciences to subdue nature in service to human needs. Technology, in this perspective, is deeply entrenched in social development and must be understood as a product that integrates the social and the material. As a consequence, new disciplines like 'technology studies' and other interdisciplinary contributions play an important part in providing the new perspectives. As sociology, technical sciences, economy, and other classic disciplines tend to be bound by their framing of the difference between what is considered social and technical, they also have little to tell about technology in practical operation due to their partial view of the workings and impact of a technology. While it is easier to operate the distinction for existing technologies, where an established difference between function and impacts seem obvious, the need for an interdisciplinary approach is promising when design of new products and systems are at the center of engineering work. Here, the actors to be involved, the use qualities of an outcome, the properties and functions in question, as well as the problems to be solved, are less fixed, which suggests a more open-ended process, both creative and analytical.

This general presentation of the four strategies does not render the specific application of these less relevant, as a lot of the impacts and outcomes need to be identified in relation to the detailed transformations that follow from the individual cases. A complete picture is not possible in this context, but hopefully the few examples presented for illustration purposes may help underpin the general lessons learned from the study of response strategies.

## The Challenge of 'Expansive Disintegration'

In her book 'Retooling', Rosalind Williams concludes that the field of engineering has gone through a process of 'expansive disintegration' in the recent decades (Williams 2002). This process has challenged engineering schools and educational structures by taking away their dominance as the providers of professionals innovating and working with technology. At the same time it raises questions about the idea of a uniform entity known as engineering education, and built on, for example, the idea of a core curriculum and a specific science-based way of understanding technology in society. The field of technology has been expanding into all aspects of human life and society; at the same time, many new educational programs not belonging to engineering schools provide knowledge about technical topics that seem to be crucial to development in these areas of knowledge. There is a tendency within engineering to maintain a certain resistance to accepting social science and technology studies entering into engineering education in more prominent roles, rather than staying as add-on topics complementing, but not fundamentally changing the approaches in engineering. These factors led Williams to suggest that engineering schools risked losing their status as the institutional and ideological framework that governs engineering.

This perspective is tempting when seen in light of decades of problems with reforming engineering education, though it does pose other problems that often have been back-grounded in discussions of the role of universities in modern society. Engineering has had a continued discussion about the gap between the technical sciences and their relevance to the professional practice of engineers, which raises critical questions about the instrumental focus and narrow framing of engineering science and object worlds, as well as methods that maintain a technological hegemony (Bucciarelli and Kuhn 1997; Sheppard et al. 2009). But the same is true, if only in more limited ways, for a number of university educational programs. Even though academically trained economists, managers, administrators, lawyers, doctors, etc., increasingly dominate societal institutions, their roles in modern everyday life, their professional training, and the power exerted through their disciplinary knowledge still needs to be taken up more critically.

Another problem relates to the practical and material skills that – though increasingly lost to computer-based virtual problem solving – still are part of the training and professional approach in engineering. These critical problems related to the university educational system at large demonstrate that the job is not done by dismantling engineering schools without bringing some of the reform controversies in engineering to the fore.

Engineering schools and institutions have built a formidable institutional network, which leaves the idea of dismantling these institutions as a provocative, but also somewhat idealistic approach. As the engineering hegemony over technology nevertheless has slipped, the challenge and question remains about the direction of future developments of engineering and other technology-focused educations. Several institutional strategies can be observed to point in very different directions. Some tend to follow the idea of techno-science and invest heavily in the new high-tech areas, arguing for these to have huge innovation potentials and to point to futures technology. Others take seriously sustainability challenges, and focus on energy, green technologies, and solving environment and climate problems. Some take up new dimensions of entrepreneurship and/or design as part of reforming their engineering curricula. In this respect, the disintegration is showing in the form of diversity of institutional strategies.

## Socio-material Design – A New Core Element of Engineering?

The main argument in this chapter is centered round the new role that socio-material design approaches, which build on lessons from technology studies, can play in a reform of engineering education. This is not just a nice idea, but has been substantiated through a number of recent developments in engineering programs in the U.S. and Europe, for instance the Product Design and Innovation program at Rensselaer Polytechnics, Troy (USA), the Design and Innovation program at the Technical University of Denmark, Lyngby (Denmark), the Engineering Design program at Delft University of Technology, Delft (the Netherlands), and the new Sustainable Design program at Aalborg University in Copenhagen (Denmark).

Taking a design approach may entail rather different pathways for change, as the notion is very open for interpretation and has been taken up in very many different ways in public and professional discussions. A clarification of what is referred to as socio-material design is therefore needed.

First, socio-material design defines the role of the engineering designer as a professional able to stage, and navigate among and with, a number of different actors who have stakes in the processes of designing, producing, implementing, using, and eventually disposing of a technology.

Second, a design is in this perspective not limited to the materialized result, but to the process of involvement and the process of enrollment. A design is not just a product, a service, or a system (of products, operations, maintenance, and services) – it is the outcome of a networking process that brings the design artifact or result into being. In this perspective the design result is clearly not only the material thing, but its socio-material existence and application. It resembles the broad and economic definition of an innovation, but with much more emphasis on the design process as a professional process that involves a set of relevant and necessary actors.

Third, socio-material design builds on a thorough problem identification and analysis. Problems in design do not – even not in the case of an already existing design specification – just operate with problem solving based on already established concepts and methods. A fundamental aspect of a design process is to question specification, design briefs, and pre-selected concepts, as these may correctly state the design script from a single actor perspective but may overlook important problems and challenges with respect to other actors involved. In this perspective, any design process starts with the ability to ask questions and map the sphere of problem statements found among the different actors.

Fourth, design professionalism combines the ability to be creative with the competence of visualization, the ability to analyze a field of use, the employment of a repertoire of models and technical knowledge and known concepts, and the ability to analyze and synthesize the variety of problem-solution relations that define the space of socio-material outcomes.

Many of these dimensions are relevant to quite a large part of engineering education, but they also expand the needed knowledge and experience base that constitute a 'good' and well trained engineer by adding some of the dimensions that, while often defined as crucial to being an engineer, are also often seen as an implicit – almost magic – outcome of education without being addressed in the curriculum. These dimensions are not core to the ways students are taught to analyze and solve problems. Rather, understanding of the social aspects of making designs operational, as opposed to the technical means and methods needed, is assumed to result from a few project assignments and some rather general teaching in social and design topics.

There is a dilemma in re-focusing the core of engineering, as many engineering curricula are crowded with coursework. Consequently, any new topic or project assignment at first glance seems to reduce the math and technical part of the curriculum. This has resulted in a basically hopeless controversy over the loss of quality in engineering education, as measured by the number of topics and by the number of pages the students have to read. In most other professional settings, engineers would argue the need for analyzing and measuring the resulting outputs and competencies that different engineering educational styles produce. But when it comes to engineering education itself, the measure is based on input, not output.

Of course there are reasons for this situation. Such measures of practice are quite difficult to make, and it is even more difficult to relate the measured competencies to the individual, as engineers very often work in teams. Even worse, the coupling of the composition of educational programs with these results makes the measured relationship very complex. Also, engineering educational programs and institutions have a very meager tradition for discussing the relationship between professional practice and educational practice. Many teachers of engineering subjects may never have worked as practicing engineers, but have instead been recruited based on their research work.

What still makes socio-material design a potentially good alternative core of engineering education is not that this perspective is seen as a substitute to math and science in any banal way. Rather it is because it emphasizes competencies that better reflect those needed by engineers in professional practice. The math and science topics are as important as knowledge of the frames and boundaries within which engineering is operating – e.g., organizations, staging processes, ethnographic approaches to field studies, economic valuation, etc.

In all parts of engineering in all its variety, classic functions such as verification of solutions, building trust through references and documentation, and testing, testing, testing of new products, services, and systems are continuously crucial parts of engineering work. These do not lose their importance because more emphasis is oriented towards problem analysis and design processes. On the contrary, more focus on the variety of possible solutions and the open-ended character of design processes will also result in engineers becoming more aware of risks and vulnerabilities, as this will do away with the illusions of the one, objective, best way to solve a problem.

## The 'End' of Engineering – Or a Plea for Heterogeneity

There have been several critical contributions, in addition to that of Rosalind Williams, describing a change in engineering and indicating a fall from being the profession ruling technology and providing progress to society. Despite the criticism of such technocratic ideas of technology as an autonomous force guiding societal development, the dominant image among many politicians and in the public still may include some basic assignment of core contributions to be provided by technology. The same holds for engineering institutions when they try to portray the future role of engineering for society and sustainability (Millennium Project 2008; National Academy of Engineering 2004; National Academies 2009). The important role of technological visioning does render the idea of engineering's obsolescence rather problematic. The popular image may have pushed engineers away from the top of the most attractive trades and professions, but engineers are still assigned a number of specific roles nicely captured by the phrase, 'to solve this problem we may need an engineer', though it might remain unclear if this refers to a skilled technician or an engineer trained at a university.

While engineers may have lost their supreme role and influence, and other professions and educational programs, from science to humanities, have taken up technical subjects and produce professionals that both can innovate and operate specific areas of technology, just arguing for the 'end' of engineering would at the same time miss the importance of knowing and handling material objects and integrating the social and the material. Instead of 'ending' engineering, some of these skills, from being able to analyze material objects to knowing about the limits of one's professional models and concepts, are becoming more and more relevant to other fields of education, like economy, management, anthropology, etc. So perhaps engineering's need to embrace non-engineering ideas is complemented by the need for non-engineering fields to embrace engineering ideas.

Alongside the socio-material design approach other ideas have surfaced that try to produce a generally new focus for engineering. At the cognitive and conceptual level, Andrew Jamison has proposed the concept of hybrid imagination as a way to combine rational, analytical thinking with a critical and reflexive perspective. This approach attempts to support a new way of knowing and working for engineering students:

> A hybrid imagination can be defined as the combination of a scientific-technical problem solving competence with an understanding of the problems that needs to be solved. It is a mixing of scientific knowledge and technical skills with what might be termed cultural empathy, that is, an interest in reflecting on the cultural implications of science and technology in general and one's own contribution as a scientist or engineer, in particular (Jamison et al. 2011, p. 4).

This approach takes as a starting point a cultural critique of engineering practice, along with the monolithic reasoning that follows from the math and science based core of engineering. It provides – at a rather abstract level – a program that can be applied in engineering education as a way of thinking and a way to understand the need for combining very different modes of thinking and acting.

In a another proposal that involves more specific considerations of how to organize a new form of engineering programs, Louis Bucciarelli has proposed an engineering program that is grounded in the liberal arts, placing these disciplines in a much more important position in the curriculum and making them stronger and equal to the science topics (Bucciarelli 2011). Also, this vision presents new ways of opening up engineering education to become part of an exchange of knowledge with disciplines outside the field of technical sciences.

There might also exist other way to redefine the core of engineering than the proposed focus on socio-material design. This is still a topic to be explored through discussions and studies that take the gap between engineering practices and the specific and productive role of engineering teaching more seriously. Besides focusing on design as the candidate core of engineering work practices, another large field of engineering is related to technological consultancy, to planning of large technical systems, and to the construction of standardized procedures and measures, which all are fields in which complex social aspects, and their crucial role for engineering problem analysis and problem solving, tend to have been neglected. But to lay the foundation for these new ways of making engineering education a more heterogeneous trade, the approach taken with socio-material design at least provides an exemplary pathway for change.

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