THE ROLE OF SOCIAL SCIENCE IN ENGINEERING

Knut H. Sørensen

In an era that seemingly celebrates interdisciplinarity [Nowotny *et al.*, 2001] where technology is no longer the exclusive preserve of engineers one might imagine that it would be rewarding to review research into the influence that social science has had upon engineering. For a long time many have also argued that social science issues should be given more prominence in engineering curricula. More to the point, social studies of technology have repeatedly observed how important the understanding of the social world is to successful engineering. This emanates especially from the consistent reconceptualisation of technology as seamlessly sociotechnical, as an outcome of combining so-to-speak nature and culture (see, e.g., [Bijker *et al.*, 1987; Latour, 1988]).

Such observations raise questions about the modes of appropriation of social science that one expects to find among engineers. Broadly speaking, there seem to be two options. One is to adopt transdisciplinary collaboration so that engineers and social scientists work together as specialists from distinct professional fields. This may take the form of teamwork but it can also give social scientists the role of consultants or advisors. I will term this *the transdisciplinary mode of appropriation* since it involves combining knowledge from different recognised disciplines or professions. Transdisciplinary modes may also be confrontational in the sense of social scientists representing a critique of engineers' proposals and vice versa. Exchanges across disciplines and professions bring conflict as well as consensus [Sørensen, 2008].

The second mode of appropriation is where social science knowledge and competence is assimilated by the profession of engineers to become part of an increasingly hybrid form of engineering knowledge. Such appropriation may occur during the education of engineers, through what engineers read, from interaction with social scientists, etc. This I will call *the profession-based mode of appropriation*, since it takes place within an ecology of knowledge production characterised by the professional autonomy of engineers in which engineers remain the active and controlling party. The relative importance of these two modes, together with details about their features, will be discussed in this chapter.

The major barrier when assessing these issues is the fairly limited amount of research on engineers' appropriation and use of social science. The comprehensive literature on social studies of technology emphasizing social aspects of engineering has not been particularly concerned with the actual sources of knowledge on

Handbook of the Philosophy of Science. Volume 9: Philosophy of Technology and Engineering Sciences.
Volume editor: Anthonie Meijers. General editors: Dov M. Gabbay, Paul Thagard and John Woods.

the social aspects and the way in which such knowledge may be appropriated. Moreover, the field of technology studies have engaged in case studies of specific examples of technological development rather than in a broader examination of the education and work practices of engineers. For example, Trevelyan and Tilli [2007, pp. 305-306] conclude their review on research into engineering work by stating

> [t]hat there has been no recent, comprehensive investigation into the processes involved in engineering work as it is actually practiced. Few researchers have asked engineers what they do and none has asked where they acquired the skills they use; nor have we found any systematic research on the links between what is taught in engineering institutions, what graduates learn early in their careers, what training engineers undertake while in the workforce, and how any of this contributes to producing competent engineers.

While they overstate the problem, the main thrust of their argument is justifiable. The volume of research on engineers and engineering is not extensive and the available information about, and analysis of, the role of social science is even more limited. The dominant focus in the literature is the social status and professionalism of engineers, not their actual practice with respect to technology [Sørensen, 1998].

In addition, we face inherent theoretical and methodological difficulties when studying the role of social science knowledge in engineering. In Section 1, I shall briefly examine some of them because they are important for clarifying how the issue in hand — the influence that social science has on engineering — may be understood and discussed. This will serve as a backdrop to the exploration of the two main areas of information pertaining to the role of social science in engineering: education and work or design. Section 2, on education, will explore the place ascribed to social science in engineering curricula. I shall draw especially on a Norwegian study but will also review some programmatic papers about the kinds of skills engineers require. Then, in Section 3, I will briefly discuss the use of social science in the field of information systems design before turning to engineering work and design more broadly in Section 4. Section 5 summarizes the main arguments.

1 THEORETICAL AND METHODOLOGICAL ISSUES

Should we expect to be able to detect social science input in engineering and engineering design? Clearly, this a complex issue. How would we unambiguously identify a fact or an insight that identifies design or engineering as originating from the social sciences? A main achievement of historians of technology has been to show that engineering is an independent science, or rather a set of sciences, and not just applied natural science (see, e.g. [Layton, 1971]) or applied social science. Clearly, natural science does have a prominent role in the development of modern technology but new technology or solutions to engineering problems are not usually produced through straightforward applications of established natural science facts, theories and discoveries. The main point has been succinctly summarised in the critique of the so-called linear model of innovation (see Radder and Channell, both in this volume, Part 1, for a more detailed discussion). It is a critique that emphasizes that innovation involves autonomous creative acts directed at assembling a mix of relevant kinds of knowledge. Science may play a part as a supplier of such knowledge but not in every case, and the links between scientific knowledge and design choices have proven to be difficult to trace [Kline and Rosenberg, 1986].

Analysing the role of social science knowledge in innovation and engineering may be an even more complex task than in the case of natural science. Firstly, there are many different ways in which results from social research may be implemented, and such use may not always be constructive. For example, Weiss [1979] distinguishes five ways in which policy-makers make use of social science: (1) instrumental use where research results are used in problem-solving, (2) political, conflict-related use where research is used as an argument or weapon in a political controversy, (3) enlightenment because social science research leads users to conceptually re-orient or change their ways of thinking, (4) interactive use, where research is applied in combination with other information to provide a knowledge base for policy purposes and (5) tactical applications where research is used to create a feeling of change or where it becomes part of an "avoid or delay" strategy. The role of social science in engineering could display a similar variety of practices.

Secondly, social science knowledge claims, which are often controversial and unstable, are characterised by disagreement and are thus difficult to apply in a setting where one does not wish to take a stand on social issues. At a more basic level, social science representations may interact with and transform the very phenomena that are to be represented (see, for example, [Suchman, 2007]). This is the problem aptly characterised by Giddens [1976] as the double hermeneutic circle: social scientists interpret the world, but the world also interprets social scientists.

Thirdly, in general, the social sciences have not given priority to research that aims to be relevant to engineers and to their efforts to design and innovate. Thus, the availability of off-the-shelf social science knowledge applicable to engineering work, together with a bank of social scientists interested in interacting with engineers may prove to be a greater limitation than in the case of natural science. However, these problems should not be overestimated. Many social science-related issues or questions emerging from engineers' work may be tackled by drawing upon well-established social science knowledge or skills. For example, many engineers base their work on too simplistic assumptions about human behaviour, assumptions that may be disputed or rectified on the basis of fairly standard knowledge about decision-making, consumption or phenomena like cognitive dissonance. Overall, there is a range of situations related to technological design and other forms of engineering work that raise questions relevant to social scientists;

some that can be quickly answered and some that make it necessary to co-produce new social science knowledge with new engineering knowledge.

Fourthly, social scientists are often perceived by engineers to be critical conversationalists engaging in ‘philosophy’, a thing that is not appreciated in a profession which values, above all else, hands-on problem-solving engagement. From interacting professionally with engineers over a long period of time I know from experience that social scientists may be seen as unhelpful sceptics rather than as constructive team-workers. Similarly, many social scientists are critical of engineers whom they tend to find difficult to communicate with and insufficiently reflexive with respect to the effects of their work. Thus, collaboration is not easy.

We could, of course, sidestep the challenges discussed in this section by basing the analysis of the impact of social science on engineers’ own accounts of how and to what extent they make use of such knowledge. However, this would at best tell us about the instances where such use was explicit. It seems more probable to assume that if engineers really used knowledge gained from social science, this fact would tend to be rendered invisible in their accounts of developing new technologies because the social sciences are less prestigious than natural science. Social science contributions might consequently become prone to being overlooked or hidden because acknowledging the value of social science input might ultimately damage reputations. Such acknowledgement might even be thought to endanger the scientific status of engineering.

It is possible to have a good intuitive understanding of the social conditions of engineering performance without consciously drawing on social science research. For example, such knowledge may be mediated through the mass media, thus being appropriated from journalists’ reports rather than scientific accounts. Alternatively it may become a part of the standard secondary school curriculum. The point is that engineers may be affected by social science without being aware of that form of appropriation. The underlying problem is aptly summed up in the arrogant claim made by a Norwegian research director after a seminar when he stated: “We are all sociologists. We all read newspapers!”

In many accounts of successful inventions and innovation a good understanding of user needs and the social context is vital [Freeman, 1982; Bijker et al., 1987; Latour, 1987]. A classic example is Thomas Edison’s assessment of the competitive situation concerning gas when he embarked on the invention of electrical lighting. The system was designed by optimising the cross-section of copper power cables in relation to the price of gas and copper so that electrical lighting could be made cheaper than gas lighting [Hughes, 1985]. Similarly, the Norwegian effort to develop a technology to extract nitrogen from air in order to produce synthetic fertilizer was based on the engineer-entrepreneur Sam Eyde’s comprehensive study of the international fertilizer market and the decline in supply of guano [Sørensen and Levold, 1992].

One way of interpreting such observations emerges from Callon’s [1987] study of an early French effort to develop fuel cells for cars. He observed how engineers produced fairly complex social scenarios to support their project which led him to make the — admittedly polemical and overstated — claim that engineers are better at sociology than sociologists. While Callon correctly reminds us that engineers need to possess an awareness of social needs and interests where social scientists may be unable to offer useable knowledge, it is nevertheless something different from what concerns us here. Callon's claim raises the question of how engineers may learn to act as competent producers of social scenarios. Is this a skill inherent to engineering or is it a qualification that is developed through a mix of experience and exposure to social science observations?

A good place to start studying such issues is in the education of engineers. First of all, engineering curricula provide evidence of the extent to which social science is incorporated in the training of engineers. What is of equal importance is the fact that the education of engineers frequently gives rise to debates about what engineers need to know. Such debates would be interesting topics of study because they represent good opportunities to voice the need for change in the education of engineers.

2 WHAT ENGINEERS NEED TO KNOW

Comparative studies of engineers have shown substantial variations in a multitude of dimensions such as status, professional orientation, placement in industrial hierarchies and the relative importance given to theoretical and practical competence [Maurice *et al.*, 1986; Meiksins and Smith, 1996; Sørensen, 1998]. This reflects differences in the roles of engineers in national division of labour systems as well as in relation to historical traditions. Still, it seems that there are some similarities, like the strained relationship between theory and practice, between the perception of engineering as science-based as opposed to growing out of practical, industrial concerns (see also Banse and Grunwald's chapter in this Volume, Part I). This issue partly emerges from concerns about the social status of engineering. In most countries, having a scientific background is more prestigious than being versed in practical skills.

The matter of establishing what engineers need to know has been a controversial issue. Efforts in the late 19^{th} and early 20^{th} centuries to provide engineers with a professional status resulted in the combined challenge of acquiring scientific standing as well as being recognised as educated. This challenge was met in three main ways. In the French tradition, in which the Ecole Polytechnique is the paradigmatic institution, academic status could be achieved by heavily emphasising science and mathematics. The North-American tradition placed greater weight on making liberal arts courses a compulsory part of the engineering curriculum to achieve recognition as educated, while in Germany endeavours to turn engineering into a science with an academic status were successful [Kranakis, 1989; Lundgreen,1990; Manegold, 1978; Noble, 1979; Shinn, 1984].

The sociology of professions has compared engineering to professions like law and medicine and found engineers wanting with respect to autonomy and social status. It has been asked if engineers really constitute a profession. Within the context of this chapter another concern emerges from the consistent differentiation of engineers into specialist fields like mechanical engineering, civil engineering, chemical engineering, and so on, specialisations that often have their own professional societies. Moreover, as Bucciarelli [1994] shows, these specialists — trained in distinctly different ways — see technologies and define problems in specific ways that cannot easily be communicated across the educational divides. Nevertheless, for the purposes of this chapter, it seems appropriate to regard engineering as a single profession, at least in a national context, partly because engineers are educated similarly in similar types of institutions and partly because they are also organised into general engineering societies designed to help provide a common engineering identity. What is gained from employing the concept of professions is not just to remind of the phenomenon of education-based enclosures within the labour market but also to point to the existence of a regime of organising knowledge that differs from discipline-based patterns. Professions are characterised by outspoken theory-practice concerns involving efforts to strike a balance between the respective importance of professionals' experience and research-based knowledge.

It may be argued that the education of professionals mixes discipline-based knowledge with specialised professional knowledge. In engineering education, this mix has resulted in curricula that contain mathematics and natural science subjects in combination with several kinds of engineering science. Such broad input has provided what may be called polytechnical competence in individual engineers.

The term polytechnical is used to highlight the tradition of giving engineers a fairly broad-based education, involving introduction to the basic competence of several fields of engineering and with finally cultivating an area of specialisation. We may recognise this as a particular form of interdisciplinary education. Such interdisciplinary, polytechnical training of for example mechanical engineers would involve teaching them basic knowledge of civil engineering, electrical engineering, chemical engineering, and so on. This corresponded to the demand for less specialised, broadly competent engineers, which dominated in most countries in the early modern period. Social science and humanities subjects could be part of the broad knowledge base, in which case these forms of knowledge were integrated into the hybrid framework created along the lines of the polytechnical knowledge strategy. The result was an individualised polytechnical type of interdisciplinarity which was innately different from the type of interdisciplinarity characterised by specialists collaborating in teams [Sørensen, 1996].

Science, mathematics and the liberal arts have been used to strengthen the social status of engineers, as outlined above. Insofar as social science subjects were made part of engineering curricula, the underlying reasoning seems to have diverged. It was believed that engineers needed to know something about management and business. Subjects like economics, law and business administration were thus taught at many if not most institutions of engineering education. However, these fields of study were seen as peripheral even though many, if not most, engineers tended to embark on management careers, at least until the end of the 1970s [Sørensen, 1998].

A recent study on the changes in educational ideology with respect to the training of engineers at the Norwegian University of Science and Technology (NTNU, previously the Norwegian Institute of Technology) that took place between 1910 and 2006, provides detailed insight into these underlying considerations [Amdahl and Sørensen, 2008]. The higher education of engineers in Norway was initially particularly shaped by the German tradition adhered to at the Technische Hochschulen but after 1945 it was the US that was turned to for inspiration. The source material — containing the matriculation speeches of the Presidents of the Institute and the reports made by committees engaged in curricular reform — clearly indicates that there was ongoing dialogue with institutions devoted to the education of engineers in other countries. The observations made in this study should therefore have more general validity, even in view of the fact that Norway is a small country with fairly small industrial enterprises. This undoubtedly explains why the polytechnical ideal was probably dominant here for longer than in most other advanced economies. Large companies make better use of specialised engineers than small companies. However, in Norway just like in most other countries, the polytechnical ideal is in decline.

The traditional outlook on specialisation among those responsible for educating engineers in Norway was aptly described by the Institute's President Olav Heggstad in his matriculation speech of 1932:

> Here, you [the engineering students] will not be educated as specialists but will receive a comprehensive education in a broader professional field. For a time, there was a strong mood for specialisation across the institutes of technology. But this idea has increasingly been departed from among other things because, after the education has ended, it is not certain that the graduate engineers will find employment in their field of specialisation [Amdahl and Sørensen 2008, p. 55].

Later Presidents and curricular reviews emphasized that Norwegian industry consisted largely of small companies in need of engineers with broad areas of competence — polytechnical as defined above — rather than specialised. It was not until the 1970s that the importance of specialised knowledge among engineers was fully recognised.

The notion of the engineer as a general kind of practitioner was an indication that individually based polytechnical interdisciplinarity was the dominant mode of education. If the humanities or social sciences were to become integrated in engineering practice, this would have to involve adding such topics to the engineering curriculum. At the Norwegian Institute of Technology there were some social science topics in the curriculum when the Institute was established in 1910 but the scope was modest and the main focus was on certain aspects of economics and a little bit of law. For a long time, the presidents of the Institute mentioned the need for more such topics in their matriculation speeches. Usually they concluded — occasionally with remorse — that such needs could not be catered for. The need for social science-related subjects was not considered large enough to merit curricular space. Obviously the various presidents presented their considerations in different ways.

Firstly there was a set of responses that dismissed the need for more social science in the engineering curriculum and emphasized that technology represented a prominent cultural element in itself. President Alfred Getz eloquently formulated this point of view in his 1916 matriculation speech:

> And nevertheless, technology is truly a means of education. It is pure and ideal. Like the artist, the creative power of accomplishment of engineers resides in inner vision and, like the artist, the engineer also has to grapple with the fabric in order to fulfil the spiritually envisaged reality.

From this perspective, engineers could easily cope on their own without professional input from the social sciences. Their own cultural capacity would be sufficient to respond to the need of understanding social issues and concerns. Similar ideas have resurged from time to time as counter-arguments to accusations that engineers are narrow-minded cultural dupes (see, e.g., [Florman, 1976]).

Secondly, many presidents emphasized that later in their careers, often as managers, engineers would need additional skills like a knowledge of foreign languages, psychology, organisation theory, etc. Students should therefore seek to acquire such skills, but — unfortunately — they would have to do that in their spare time. There was no room for such enlargement of the engineering curriculum. This was also indicative of the perceived low status of social science.

A third set of concerns related to the impact of engineering on society and to the social responsibilities of engineers. Such issues were voiced from time to time from 1910 onwards but the plea became more persistent after 1970, clearly in response to discourse that saw technology as a potential social and environmental threat. In his matriculation speech of 1991 President Karsten Jacobsen went so far as to argue that the future of engineering would be shaped by the tension between technology and human concerns:

> It is no longer sufficient to know one's discipline; the technologist of the future has to enter the playing field with quite a different and more general value base and outlook than before, with an ability, will and training to face the consequences of this in practice — to see actions from a broader view — what we could call a holistic perspective — technological-ecological-human-aesthetic-economic. [Amdahl and Sørensen, 2008, p. 61]

However, at this point in time, specialisation had become the dominant theme underlying the education of engineers. It was not really believed that Norwegian engineering students should receive a much broader and comprehensive training in the social sciences and humanities to be able to act on the challenges outlined by Jacobsen. Rather than asking for new types of knowledge, Jacobsen and indeed later presidents, spoke about the issue in terms of interdisciplinary collaboration.

The students needed educational reform but this reform had to focus on instilling new virtues rather than on gaining new knowledge.

The new virtues called for included, of course, a broader outlook on engineering and greater sensitivity to the social and environmental impacts of the work of engineers. However, even more prominent in the presidents' speeches was the ideal that engineering students should be encouraged to become skilled in and willing to engage in interdisciplinary activities that also involved graduates from the humanities and the social sciences, and vice versa. As President Eivind Hiis-Hauge put it in his matriculation speech of 2004:

> No single person is able, with sufficient depth, to be interdisciplinary alone: it is the capacity to perform constructively and to be committed to working together with others in teams which gives results.

It was an appeal to students from all academic fields to be prepared for interdisciplinary collaboration.

If we return to the two modes of appropriation of social science in engineering proposed in the introduction, we can see that both are emphasised in the above quotation. For a long time, the presidents' speeches together with all the curricular reviews voiced the opinion that engineers should be able to cope with a broad spectrum of challenges including certain social science concerns on their own. In that way, they were emphasising what I have termed the profession-based mode of appropriation. Social science input were seen as potentially important by some, but ultimately it was given little curricular space and assimilated into the broad polytechnical education of the individual engineer. The switch to a more collective, heterogeneous kind of interdisciplinarity observed in the last decade has accentuated the transdisciplinary mode of appropriation of social science. In the end it may pave the way for a greater number of social scientists working together with engineers — and thus for social science in a distinct and visible form — within the framework of technological development. The critical question is, of course, whether this latter alternative has been realised? What modes of appropriation are most important to engineering education and the professional development of engineers?

The US-based Accreditation Board for Engineering and Technology (ABET) is important when it comes to the world-wide setting of standards for engineering education. Their lists of criteria do emphasize teamwork — with or without the prefix 'multidisciplinary' — the social sciences though tend to be referred to in an indirect and imprecise manner, like in the mention of the need for students to acquire 'a broader outlook' and understanding of the social, economical and political constraints on engineering work, together with an awareness of the importance of social responsibilities.[1] Both the social sciences and the humanities are mainly seen to contribute insight into the ethical, legal and social aspects of engineering — all the so-called ELSA concerns also present in the Norwegian situation. The

[1] http://www.abet.org/forms.shtml#Applicable_to_All_Programs (downloaded 30 August 2008).

ABET criteria therefore invite both modes of appropriation of social science without placing any great emphasis on either mode.

Recent discussions on engineering education include contributions that argue in favour of the importance of profession-based appropriation. For example, Vesilind [2001] claims that the traditional view of the encyclopaedic engineer should be maintained but changed — engineering should not just be seen as 'applied natural science' but also as 'applied social science'. Facets of this view seem fairly widespread in the international literature on the skills that are essential to practising engineers and ideas on how engineering education could be changed. Ravensteijn et al. [2006] suggest, for example, the need for engineers to be more communicative. Nguyen [1998] lobbies for communication skills in combination with many other competences related to the various business demands. Grimson [2002] and Robinson et al. [2005] emphasise that engineers need to possess a broader set of non-technical skills. In line with this, Jones [2003] argues that the image of the renaissance engineer might actually be an appropriate educational reform goal; but the main issue is this: what should be the components of appropriate encyclopaedic knowledge? On the other hand, Russell and Stouffer [2005] show how U.S. undergraduate civil engineering education is overwhelmingly dominated by technical subjects, with little indication that profound changes are taking place. This supports the impression given by the ABET list of criteria for the accreditation of such programmes.

The U.S. National Academy of Engineering has carried out extensive reviews into the situation of engineers in 2020. These discussions only relate vaguely to the potential role of social sciences with respect to engineering education and work. Interdisciplinarity is signalled as important and social skills are claimed to be important, which means that both modes of appropriation of knowledge of the social sciences are inherently present. However, the overriding impression made by the reports is the assumption that the engineering profession will continue to be largely self-sufficient, thus demonstrating that the profession-based mode of appropriation is given priority [National Academy of Engineering, 2004; 2005].

A different perspective is provided by Williams [2002; 2003]. She argues that during the last few decades, the former close link between technology and engineering has been broken. Technology is no longer exclusively the domain of engineers; engagement with technology has far outgrown any single professio. Williams' assertion has important implications, not just for engineers but also for social scientists who need to reflect much more about the implications of this change in relation to their own practices. Probably neither group yet fully grasps where this will lead; they may not even have discovered the ongoing change. If Williams is correct, the future development of technology will include interdisciplinary encounters of many kinds but the present developments, as enumerated above, are not promising in this respect. The education of engineers and of social scientists seems to be well entrenched in the established perception that the technical and the social aspects of modern society are worlds apart.

Williams identifies as a serious challenge what she perceives as the way in which the engineering profession is currently developing along two main lines. One camp is concerned with doing real engineering by designing and building useful things that actually work. The other camp, she observes, advocates a new emphasis on large technological systems and management:

> Both the design movement and the systems engineering movement seek to reclaim a distinctive identity for engineering: to proclaim that here is something engineers do that scientists and businessmen do not do. In the end, however, the reclamation efforts only underscore engineering's loss of identity. In both design and systems work, many people other than engineers are in on the act. In design today, engineering, programming, science, language, and art converge. In dealing with technological systems, it is even more obvious that engineers have to collaborate with political scientists, economists, lawyers and managers [Williams, 2003. p. B12].

On the one hand, it seems that Williams is correct to note that late modern technology is embracing an increasingly wider body of disciplines and professions. Consequently, engineering will become more and more engaged in broad transdisciplinary collaboration, also with social scientists and, for that matter, humanities scholars as well. Engineers seem to put considerable effort into preserving the boundaries of their profession and their professional influence, for example by giving priority to the profession-based rather than to the transdisciplinary appropriation of social science. How may such prioritising of profession-based appropriation be achieved and how may that shape the intake of social science knowledge and skills?

3 MAKING SOCIAL SCIENCE THEIR OWN? THE EXAMPLE OF COMPUTER SYSTEMS DESIGN

The area of computing, in particular the sub fields involving the design of information systems, may provide interesting insight into the way in which social science knowledge may be appropriated in engineering. To begin with, we should note that computing — in particular with respect to areas like information systems design, information systems analysis, and software engineering — does draw on methods as well as research findings from social sciences. It is commonly acknowledged that practitioners in these areas need to possess broader-based knowledge. Early examples are Vitalari [1985] and White and Leifer [1986] who argue that the knowledge base of systems analysis should be broad and should include a variety of technical and non-technical skills.

For such reasons, some argue that software or information systems engineering is not really engineering at all, but something quite different (see, e.g. [Davis, 1998, pp. 31-40]). Given the existing diversity within the loosely defined profession of engineering, such boundary work seems less fruitful. However, software or information systems engineering probably struggles more explicitly than most other fields of engineering with issues similar to those that concern social scientists. In this respect, engineers working with software and information systems will probably find that they are particularly engaged in the appropriation of knowledge and skills gained from social science, thus allowing us a better understanding of the processes and content of such intake.

Recent research confirms the early arguments to the effect that software and information systems engineers need broad skills, both technical and non-technical. Iivari *et al.* [2004] maintain that the distinctive competence of information system experts lies (1) in their expertise of aligning IT artefacts with the organizational and social context in which the artefact in question is to be used, (2) in identifying and specifying the needs of people who are supposed to use the system, (3) in organizational implementation, and (4) in the evaluation/assessment of these artefacts and related changes (see also Radder in this volume, Part V). While the emphasis may vary, such observations of the need to combine technical and non-technical skills seem commonplace [Goles *et al.*, 2008; Lee, 2005; Litecky *et al.*, 2004; Turley and Bieman, 1995]. In fact, the requirements are seen as quite comprehensive. Lee [2005, p. 90] summarizes this succinctly when he remarks that organizations 'expect their systems analyst to become all-round athletes who play every corner of the field'.

Such ideas are also used to argue that a broad education is required if IT specialists are to be properly prepared to combine technical and non-technical challenges in their professional practice [Brookshire *et al.* 2007, Dahlbom and Mathiassen 1997]. However, Brookshire *et al.* end up by proposing a fairly conservative curriculum comprising predominantly technical courses. Dahlbom and Mathiassen, on the other hand, suggest taking a much more radical step. They argue that

> [s]tudents of computing should develop the ability to ask serious questions about the social impact of computing and to evaluate proposed answers to those questions, and they must be able to anticipate the impact of introducing a given product to a given environment. [1997, p. 84]

What we observe in this literature is that there is a clear tendency to want to promote individualised polytechnical interdisciplinarity, which is similar to what we observed in Section 2. Even if these authors present their arguments in different ways, their main thrust is that computer professionals should be self-sufficient in terms of the competencies required to carry out IT work. Social science may be a resource, but it should be presented as something that is integrated into systems design or software engineering. In the final instance, the origin of social science input is rendered unclear through the insistence on profession-based appropriation. This is not, of course, a problem in itself. If indeed attainable, individualised polytechnical interdisciplinarity of such comprehensive scope is extremely demanding and therefore also risky with respect to the quality of the outcome.

Research areas like Human Computer Interaction (HCI) and Computer Supported Collaborative Work (CSCW) are definitively meeting places for scientists with diverse disciplinary backgrounds, including social science. The shared concern for developing more useful computer systems also produces a shared interest in the ways humans interact with computers, what strategies evolve from such interaction and how greater benefits can be achieved from computers. In early participatory computer system design efforts and trade union involvement, social scientists collaborated with computer scientists to organise participation and to establish methods that were helpful for workers to articulate their needs and requests [Ehn, 1988]. However, a main contribution that social scientists have made to HCI and CSCW has been to underline the complexities of human actions and the deep-rooted problems involved in predicting and stabilising human interaction with machines [Suchman, 1987; 2007]. Such critical interventions seem to have been made notice of, but their actual appropriation is less clear, probably because these kinds of insights are difficult to integrate into computer science methodology which, to some extent, depends on achieving some level of prediction and stability.

The reviewed literature about software and information systems engineering shows the presence of both modes of appropriation in the case of social science. However, it is particularly the discussion about the training of such engineers and the emphasis placed on a broad knowledge base that also includes strong non-technical components proving that even in this case where concerns for social issues are so prominent, profession-based appropriation dominates. Furthermore, what is appropriated from social scientists is, above all else, methodology. Some software and information systems engineers seem to want to perform their own social science type of investigations but mainstream approaches to the design of computer systems seem less aware that parts of their work — for example the modelling work practices of customers — could just as well be construed as a job for social scientists. When practitioners are asked about the competences they need to carry out their work, they tend to emphasize skills like communication and the understanding of people's needs. When asked how they can acquire such skills, they tend to point to their experience — not to any form of social science input [Sørensen *et al.*, 2007].

The potential complexity of the information system designing required to facilitate decision-making and to access the knowledge needed to make proper decisions, is considerable. In the long run, this may make the profession-based appropriation of social science inadequate. However, the challenges involved in establishing good practices based on transdisciplinary appropriation may be substantial, not least because of the fairly tight professional collaboration required to achieve accurate forms of knowledge integration. As Lagesen and Sørensen [2008] demonstrate, it is common to assume that communication practices may be separated from computer-related practices like programming, making the first a task for social scientists and the second a job for software specialists. However, Lagesen and Sørensen found that the claim made by software specialists to the effect that a knowledge of computers and programming is needed if they are to communicate properly with customers or product users was convincing. If social scientists are to be part of such a process they, like the software specialists, will need to engage in reciprocal profession-based appropriation. Thus, the issue is not perhaps so much that of replacing one strategy of appropriation with another as that of combining them.

However, at present, there is little doubt that the pursuit of profession-based appropriation dominates thanks to the prevailing position of individualised polytechnical knowledge performance. Is this situation more generally characteristic of engineers? Our analysis of engineering education does point in that direction but what may be observed from engineers working to develop technology?

4 WHAT SOCIAL STUDIES OF ENGINEERS AND DESIGN TELL US ABOUT THE RELATIONSHIP WITH SOCIAL SCIENCE

Probably the most comprehensive studies of engineers and engineering work are those that have emerged from the history and sociology of professions. A main finding was that the professional behaviour of engineers is characterised by less autonomy and a larger degree of collectivist culture than that which applies, for example, to medical doctors or lawyers [Gerstl and Hutton, 1966; Perruci and Gerstl, 1969; Ritti, 1971; Hutton and Lawrence, 1981; Zussman, 1985; Whalley, 1986]. Still, engineers have considerable autonomy as 'trusted workers' [Whalley, 1986], even if they work under managerial control, in particular with respect to resources and deadlines [Meiksins and Watson, 1989].

According to these studies, engineers are mainly engaged in a diversity of technical and non-technical work, unless they move into management, which used to be a common career move [Sørensen, 1998]. Since of the focus of these studies is professional behaviour, there is little substantive discussion of the actual content of engineering knowledge and thus of the modes of appropriation of, for example, social science. This even applies to most ethnographic studies on engineering work (see [Bucciarelli, 1994; Downey, 1998; Forsythe, 2001; Vinck, 2003]). Vincenti [1990], whose main concern is engineering knowledge, does not provide insight into such appropriation processes either (see also [Downey and Lucena, 1995]).

As already mentioned, management, business administration and economics are long-standing professional interests of engineers. Some such knowledge is a standard part of engineering curricula and many engineers become further educated in these fields. A combination of engineering knowledge, computer skills and knowledge about finance or management has become the basis of careers in consulting [Williams, 2002]. However, this trajectory substantially extends the idea of what constitutes engineering and more to the point, what is normally taken to constitute social science. Rather than being a good example of how the social sciences affect the work of engineers, it points to the development of a set of practices centred on the construction of mathematical or computer models in which technology and social issues tend to be represented only in a very abstract and oversimplified fashion.

For the purposes of this chapter, design remains a more interesting topic and one in which social science might be expected to be a potentially useful resource. In the previous section, we observed how some such influences could be traced in information system design. However, we also saw that this influence was largely attributable to computer scientists' profession-based appropriation of social scientific knowledge and methods. This raises interesting questions about the nature of such processes of appropriation in engineering design as well as about the kind of knowledge designers want.

It is tempting to assert that social scientists could present engineers with clearly defined design criteria related to user needs, the cultural conditions of domestication of new products, etc. To counter such ideas, Williams *et al.* [2005, p. 102] warn us about what they call the design fallacy, 'the presumption that the primary solution to meeting user needs is to build ever more extensive knowledge about the specific context and purposes of an increasing number and variety of users into technology design'. They base this warning on the problems encountered with linear thinking as discussed in Section 2 of this chapter. Still, designers tend to base their notions on certain ideas about future use and users [Akrich, 1992]. Where do such ideas come from?

There are many sources that can provide designers with information about users and with ideas about how products may be shaped [Walsh *et al.*, 1992; Williams *et al.*, 2005]. Arguably, social scientists are skilled at analysing the use and users that could produce insights that would be conducive to the development of new products. Increasingly, companies are using market research to inform their efforts with respect to design and innovation. However, such research seems above all to be used to identify potential groups of users/customers, for example according to gender, age, etc., which means that its impact on the work of engineers tends to be a point of departure in terms of design rather than in terms of informing concrete problem-solving efforts [Cockburn and Ormrod, 1993; Chabaud-Rychter, 1994]. Engineers have to use other resources to interpret what is needed to design technology that can be considered appropriate to targeted groups of users, like kitchen appliances for women or microwave ovens for young men. While there are ways to translate user requirements into design specifications (see the contribution of De Vries in this volume, Part III), these methods tend to be vague when it comes to defining what it is that users want.

The most common resource used to interpret user requirements is not social science but the personal experience, knowledge and taste of the designing engineers. For example, engineers involved in design are frequently observed to implicitly model the intended user after themselves or to invoke stereotypes [Berg, 1994; Oudshoorn *et al.*, 2004; Williams *et al.*, 2005]. Usability trials may be employed to test how a given design matches user needs and tastes, but most technologies are developed without such testing. Moreover, usability tests are generally undertaken by engineers.

Arguably, the study of users could amount to an area of interaction between social science and engineering knowledge. Experiments in participatory design have demonstrated the potential to provide better computer systems [Ehn, 1988] but such approaches are expensive and the results have not been convincing. A leading drawback is the widespread perception among designers that users are conservative, the implication being that participation needs to be limited to the shaping of the user — technology interface, while decisions about technology choice and emerging new practices are seen as the prerogative of designers [Hatling and Sørensen, 1998]. Williams *et al.* [2005] identify a range of other difficulties, for example the fact that user groups may change during the lifecycle of a product. A major challenge is the inherent instability of needs and tastes — what users want, may change as the technology in question develops. It may thus seem more tempting to employ a kind of trial and error approach than to carry out a comprehensive study of users as the backbone of design. In turn, this may make it less interesting for engineers to collaborate with social scientists, partly because they cannot provide the well-defined answers that engineers are looking for and partly because the experiments with potential users that could be undertaken to obtain some relevant input on the design process appear to be too expensive. Trial and error may actually be cheaper, at least if it can be organised on a small scale.

Clearly there are huge challenges attached to translating the — already existing or specially produced — knowledge gained from social science into design criteria, shapes and functions. What does the fact that an artefact is easy to use, that a system is efficient or that a machine is flexible actually mean? The challenge is well illustrated by Cockburn and Ormrod [1993]: how can a microwave oven be made attractive to young men? For example, why should one assume, as did the company, that the colour brown is more 'gender authentic' to young men than the colour white?

These challenges could be viewed as the appropriate tasks of interdisciplinary teams, combining the skills and competencies required to fulfil the relevant problem-solving. Such interdisciplinary practices combining the social and engineering sciences [Sørensen *et al.*, 2008] are not, however, widespread. Instead, as was observed with computer systems designers in the previous section, engineers seem to prefer a professional mode of operation which enables them to opt to independently access information and knowledge about social and cultural aspects mainly by drawing on experience and only occasionally by delving into material related to social science. For example, it is evident that books like those written by Suchman [1987; 2007] or Norman [1988] are being discussed in various design communities. Probably this has resulted more from engineers adhering to a profession-based appropriation of the work rather than to them engaging in interdisciplinary collaboration to combine ideas. Is that a problem?

Social scientists might be inclined to think so but if we try to favour one interpretation over the other we will run into difficulties. In the first place there is often dissent among social scientists themselves about how precisely social scientific research should be interpreted. Secondly, and more importantly, what is really at stake here is: the correctness of the interpretation or the quality of the resulting design? On whose premises do we base our decisions — those of the social scientists' or those of the engineers'? Does it matter if social scientists claim that engineers have made an incorrect interpretation?

From the point of view of engineers — and probably most people — what lies at the heart of the matter is the quality of the resultant design. To prove that a social scientist's interpretation is 'better' than an engineer's, we need to show that better interpretation leads to better design. Or, to put it more generally, that transdisciplinary appropriation is a more fruitful mode than the profession-based mode. There is no research available to help us to settle this point, so in a sense social scientists are left to prove their own worth.

Perhaps such proving is easier in areas like economics and accounting? Financial constraints and economic motives definitely underlie technological design but it is not easy to unambiguously translate technology into economic potential. To a certain extent costs may be predicted and much research has been done into project management, cost control, etc. inside and outside the field of engineering but this aspect of technological development also involves considerable risk as evidenced by the frequent overspending in many projects.

According to Thomas [1994], making cost calculations that are perceived by management to be realistic is a prerequisite to starting projects on the designing of new or improved technology. However, whether or not these calculations prove correct is a different matter; they often do not but by then the engineers who initiated the project, tend to have moved on to other projects. Thomas therefore concludes that the creating of new projects is more fundamentally a political-rhetorical matter, demanding skills in providing the right arguments and making convincing economic calculations, rather than something shaped by what might be termed the strict application of economic knowledge.

While it is not well described in the literature reviewed in this chapter, there is no doubt that many companies and laboratories put considerable effort into achieving cost control as far as technological projects are concerned. There are many different methods and tools available to support such efforts. Most engineers are no doubt concerned with economic issues, but ultimately they prefer a profession-based appropriated version, an engineering economics, to the skills and knowledge represented by economists and MBAs. In engineering stories, economists and MBAs are troublemakers rather than helpful parties. The actual influence on technological design and on the engineering work of professional economics may not therefore be so strong. Costs are important, economists are not.

When many engineers perceive economists and MBAs to be too conservative and too control-oriented, this probably reflects the different perceptions of the economic dynamics of technological development. In his study of wind turbine development in Norway, Solli [2007] shows how economists evaluated the economic prospects of wind energy on the basis of the notion that production costs were known and would be similar to the costs measured at any given time. The advice of the economists was therefore to say no to wind energy projects. Engineers involved in this technology favoured a more dynamic approach, arguing from the so-called learning curve effects that a considerable drop in production costs would occur because accumulated engineering experience would lead to much cheaper installations.

The fact that there has actually been a large drop in the cost of producing energy would suggest that, at least in this case, the engineers had a better grasp of the economic dynamics than the economists. However, the matter is more complicated than that, given the restrictions of the available national economic resources. The case demonstrates that also with respect to economics, engineers prefer profession-based appropriation, where some arguments go in their favour but do not necessarily win the day. For a thorough evaluation of the initial decision not to support wind energy technology, we would probably need the kind of transdisciplinary appropriation that results from engineers and economists debating the issue together and appreciating each other's arguments — whilst perhaps also taking on board other bodies of knowledge.

5 SOCIAL SHAPING VERSUS SOCIAL SCIENCE SHAPING OF TECHNOLOGY

Technology is always a social achievement, a material or mental representation of human activity. In principle, this makes the development of technology as much a challenge to social sciences as to engineering. If anything, social science research constitutes an effort to provide representations of human activities. However, there is no guarantee that such representations are useful or will indeed be used by engineers when they engage in design and technological development. As we have seen in this chapter it is rather the case that the relationship between the social sciences and engineering is problematic and unclear. Most studies of engineering work reveal little about how engineers appropriate and use social science. Engineers are probably not very concerned about this because the use of such knowledge is normally implicit and mediated. Social science is most commonly appropriated in a profession-based way, providing professional self-sufficiency and resulting in what I have termed individualised, polytechnical interdisciplinarity.

The acknowledgement that technology is socially shaped raises interesting questions about how the social dimensions are represented and mediated in engineering work and design processes. From accounts found in technology and engineering studies, it seems clear that the dominant form of such mediation is in the experience, knowledge, outlook, etc. of the involved engineers In a sense, it is the engineering body that is the main instrument of observing, learning and mediating of social aspects relevant to engineering work. The social sciences have a subdued and much less visible role which is difficult to assess.

Some of the features that produce this somewhat paradoxical situation have already been reviewed. Firstly it should be noted that most engineers show rather little interest in the social sciences, with the exception of the areas of management and economics which are perceived to be career-enhancing types of knowledge. Compared to the natural sciences, with which engineers engage heavily, the social sciences have less prestige and, probably, are more difficult to translate into useful design criteria.

Secondly, today, engineers and natural scientists tend to professionally dominate the development of technology. As a consequence, engineers (and probably also the natural scientists) tend to prefer to abide by their own profession-based appropriation of the social sciences — including economics — rather than to be involved in interdisciplinary collaboration with social scientists. As noted above, this appropriation process seems to be largely about the accumulation of experience — often from interacting with customers and user communities over a fairly long period of time [Sørensen *et al.*, 2007]. Presumably, there is also a kind of 'citizen effect' in the sense that some social science knowledge seeps in from news media and similar sources but this phenomenon is also difficult to access and assess in an empirical fashion.

Thirdly, as suggested several times throughout the chapter, the social sciences have not particularly set out to be relevant and useful to engineers. Teaching social science to engineering students never had much status; moreover, such teaching has tended to focus on ethical and other social concerns related to the possible negative effects of new technology. In that way the engagement of social science with technology and engineers has been doubly marginalised. It has remained external to the core social science concerns while possessing a kind of policing role that is not particularly appreciated by most engineers. However, it should also be recognised that substantial efforts have been made by groups of social scientists to actively engage in collaboration with engineers and to produce potentially relevant knowledge about many aspects of technology.

Nevertheless, it remains a problem that there is little if any empirical research that actually examines such efforts and investigates the role of social science with respect to engineering and the design and development of technology more generally. There is even a danger that the interpretations made in this chapter may underestimate or misjudge the influence of social science. To some extent, this is a methodological problem attributable to the dominant position of the profession-based mode of appropriation in the enactment of social science knowledge among engineers. This form of appropriation tends to reduce the impact of social science.

Another challenge is the argument that to engineers (and probably also to social scientists) the insight gained from social science may appear difficult to apply to the design and development of new technologies. When social scientists accentuate the complexity and instability of human cultures, which is what they tend to do (and with good reason), they provide explanations that engineers do not usually find helpful because they in their activities are more concerned about reducing complexity and constructing stable technological standards that will instigate development and problem-solving. Obviously, there are challenges and opportunities behind finding better ways to co-produce new social science and engineering science that may be integrated.

My own experience indicates that there is increasing interest among engineers to collaborate with social scientists to find ways to manage challenges that engineers experience as problematic and outside their professional area of expertise. New technologies may be rejected or may meet with resistance while their actual effects may be quite different from what was originally intended. When social scientists enter into such collaboration, they will probably discover a range of ways of interacting with engineering knowledge. Some problems, like policy conditions or public views about new technologies may be dealt with in a fairly isolated manner while others, like the need to analyse user requirements, may call for more integrated ways of working. The difficulties involved should not be underestimated. For example, the tendency among engineers to find doing more important than reflection and to demand constructive input rather than critical opposition, may mean that social scientists have to adjust their normal mode of operation or vice versa. To communicate and collaborate, one needs some insight into the knowledge of the other party if one is to acquire what Collins and Evans [2007] call interactional expertise — the capability to interact constructively with the experts with whom you are supposed to collaborate. It may thus prove fruitful — at least for some period — for engineers to pursue a profession-based appropriation of relevant social science, while social scientists concentrate on a profession-based appropriation of relevant engineering science, so paving the way for a productive transdisciplinary appropriation of both kinds of knowledge.

BIBLIOGRAPHY

[Akrich, 1992] M. Akrich. The Description of Technological Objects. In *Shaping Technology/Building Society*, W.E. Bijker and J. Law, eds., pp. 205-224. MIT Press, 1992.

[Amdahl and Sørensen, 2008] E. Amdahl and K. H. Sørensen. Den polytekniske kunnskapsideologien: Fra viten til dyd. In *Vitenskap som dialog - kunnskap i bevegelse. Tverrfaglighet og kunnskapskulturer i forskning,* K. H. Sørensen, H. J. Gansmo, V. A. Lagesen and E. Amdahl, eds., pp. 49-69. Tapir Akademiske Forlag, 2008.

[Berg, 1994] A.-J. Berg. A Gendered Socio-technical Construction: The Smart House. In *Bringing Technology Home. Gender and Technology in a Changing Europe*, C. Cockburn and R. Fürst-Dili, eds., pp. 165-180. Open University Press, 1994.

[Bijker *et al.*, 1987] W. E. Bijker, T.P. Hughes, and T. Pinch, eds., *The Social Construction of Technological Systems*. MIT Press, 1987.

[Brookshire *et al.*, 2007] R. G. Brookshire, R. Yin, S. Hunt and T. B. Crews. An End-User Information System for the 21^{st} century. *The Journal of Computer Information Systems*, 47 (3), 81-88, 2007.

[Bucciarelli, 1994] L. L. Bucciarelli. *Designing Engineers*. MIT Press, 1994.

[Callon, 1987] M. Callon. Society in the Making: The Study of Technology as a Tool for Sociological Analysis. In *The Social Construction of Technological Systems,* W.E. Bijker, T.P. Hughes, and T. Pinch, eds., pp. 83-106. MIT Press, 1987.

[Chabaud-Rychter, 1994] D. Chabaud-Rychter. Women Users in the Design Process of a Food Robot: Innovation in a French Domestic Appliance Company. In *Bringing Technology Home. Gender and Technology in a Changing Europe*, C. Cockburn and R. Fürst-Dili, eds., pp. 77-93. Open University Press, 1994.

[Cockburn and Ormrod, 1993] C. Cockburn and S. Ormrod. *Gender and Technology in the Making*. Sage, 1993.

[Collins and Evans, 2007] H. Collins and R. Evans. *Rethinking Expertise*. University of Chicago Press, 2007.

[Committee on the Fundamentals of Computer Science, 2004] Committee on the Fundamentals of Computer Science. *Computer Science. Reflections on the Field. Reflections from the Field.* National Academies Press, 2004.

[Dahlbom and Mathiassen, 1997] B. Dahlbom and L. Mathiassen. The Future of Our Profession. *Communications of the ACM*, 40 (6), 80-89, 1997.

[Davis, 1998] M. Davis. *Thinking Like an Engineer. Studies in the Ethics of a Profession*. Oxford University Press, 1998.

[Downey, 1998] G. L. Downey. *The Machine in Me. An Anthropologist Sits among Computer Engineers*. Routledge, 1998.

[Downey and Lucena, 1995] G. L. Downey and J.C. Lucena. Engineering Studies. In *Handbook of Science and Technology Studies*, S. Jasanoff, G.E. Markle, J.C. Petersen and T. Pinch, eds., pp. 189-204. Sage, 1995.

[Ehn, 1988] P. Ehn. *Work-Oriented Design of Computer Artifacts*. Arbetslivscentrum, 1988.

[Florman, 1976] S. C. Florman. *The existential pleasures of engineering.* St. Martin's Press, 1976.

[Forsythe, 2001] D. E. Forsythe. *Studying Those Who Study Us. An Anthropologist in the World of Artificial Intelligence*. Stanford University Press, 2001.

[Freeman, 1982] C. Freeman. *The Economics of Industrial Innovation*. The MIT Press, 1982.

[Gerstl and Hutton, 1966] J. E. Gerstl and P. Hutton. *Engineers: The Anatomy of a Profession*. Tavistock, 1966.

[Giddens, 1976] A. Giddens. *New rules of sociological method*. Hutchinson, 1976.

[Goles *et al.*, 2008] T. Goles, S. Hawk and K. M. Kaiser. Information Technology Workforce Skills: The Software and IT Services Provider Perspective. *Inf Syst Front* 10,179-194, 2008.

[Grimson, 2002] J. Grimson. Re-engineering the Curriculum for the 21^{st} Century. *European Journal of Engineering Education*, 27 (1), 31-37, 2002.

[Hatling and Sørensen, 1998] M. Hatling and K.H. Sørensen. Social Constructions of User Participation. In *The Spectre of Participation. Technology and Work in a Welfare State*, K.H. Sørensen, ed., pp. 171-188. Scandinavian University Press, 1998.

[Hughes, 1985] T. P. Hughes. Edison and Electric Light. In *The Social Shaping of Technology*, D. A. MacKenzie and J. Wajcman, eds., pp. 39-52. Open University Press, 1985.

[Hutton and Lawrence, 1981] S. Hutton and P. Lawrence. *German Engineers: The Anatomy of a Profession*. Clarendon Press, 1981.

[Iivari *et al.*, 2004] J. Iivari, R. Hirschheim and H. K. Klein. Towards a Distinctive Body of Knowledge for Information Systems Experts: Coding ISD Process Knowledge in Two IS Journals. *Info Systems J*, 14, 313-342, 2004.

[Jones, 2003] M. E. Jones. The Renaissance Engineer: A Reality for the 21^{st} Century? *European Journal of Engineering Education*, 28 (2), 169-178, 2003.

[Kline and Rosenberg, 1986] S. J. Kline and N. Rosenberg. An Overview of Innovation. In *The Positive Sum Strategy. Harnessing Technology for Economic Growth*, R. Landau and N. Rosenberg, eds., pp. 275-305. National Academy Press, 1986.

[Kranakis, 1989] E. Kranakis. Social Determinants of Engineering Practice: A Comparative View of France and America in the Nineteenth Century. *Social Studies of Science*, 19, 5–70, 1989.

[Lagesen and Sørensen, 2008] V. A. Lagesen and K.H. Sørensen. Re-locating software engineers: From technologists to communicators? Submitted to *Engineering Studies*, 2008.

[Latour, 1988] B. Latour. How to Write 'the Prince' for Machines as well as Machinations. In *Technology and Social Process*, B. Elliot, ed., pp. 20-43. Edinburgh University Press, 1988.

[Latour, 1987] B. Latour. *Science in Action*. Open University Press, 1987.

[Layton, 1971] E. T. Layton. *The Revolt of the Engineers: Social responsibility and the American Engineering Profession*. Press of Case Western Reserve University, 1971.

[Lee, 2005] C. K. Lee. Analysis of Skill Requirement for Systems Analysts in Fortune 500 Organizations. *The Journal of Computer Information Systems*, 45 (4), 84-92, 2005.

[Litecky *et al.*, 2004] C. R. Litecky, K. P. Arnett and B. Prabhakar. The Paradox of Soft Skills versus Technical Skills in IS Hiring. *The Journal of Computer Information Systems*, 45 (1), 69-76, 2004.

[Little *et al.*, 2002] S. Little, P. Quintas and T. Ray, eds. *Managing Knowledge*. Sage, 2002.

[Lundgreen, 1990] P. Lundgreen. Engineering Education in Europe and the U.S.A., 1750–1930: The Rise to Dominance of School Culture and Engineering Professions. *Annals of Science*, 47:33–75, 1990.

[Manegold, 1978] K. H. Manegold. Technology Academised. Education and Training of the Engineer in the Nineteenth Century. In *The Dynamics of Science and Technology. Social Values, Technical Norms and Scientific Criteria in the Development of Knowledge*, W. Krohn, E.T. Layton and P. Weingart, eds., pp. 137-158. Reidel, 1978.

[Maurice *et al.*, 1986] M. Maurice, F. Sellier and J.-J. Silvestre. *The Social Foundations of Industrial Power*. MIT Press, 1986.

[Meiksins and Smith, 1996] P. Meiksins and C. Smith, eds. *Engineering Labour. Technical Workers in Comparative Perspective*. Verso, 1996.

[Meiksins and Watson, 1989] P. F. Meiksins and J.M. Watson. Professional Autonomy and Organizational Constraint: The Case of Engineers. *The Sociological Quarterly*, 30 (4), 561-585, 1989.

[National Academy of Engineering, 2004] National Academy of Engineering. *The Engineer of 2020. Visions of Engineering in the New Century*. National Academies Press, 2004.

[National Academy of Engineering, 2005] National Academy of Engineering. *Educating the Engineer of 2020. Adapting Engineering Education to the New Century*. National Academies Press, 2005.

[Nguyen, 1998] D. Q. Nguyen. The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students. *Global Journal of Engineering Education*, 2 (1), 65-75, 1998.

[Nobel, 1979] D. Noble. *America by Design. Science, Technology and the Rise of Corporate Capitalism*. Oxford University Press, 1979.

[Normal, 1988] D. A. Norman. *The Psychology of Everyday Things*. Basic Books 1988.

[Nowotny *et al.*, 2001] H. Nowotny, P. Scott and M. Gibbons. *Re-thinking Science. Knowledge and the Public in an Age of Uncertainty*. Polity Press, 2001.

[Oudshoorn *et al.*, 2004] N. Oudshoorn, E. Rommes and M. Stienstra. Configuring the User as Everybody: Gender and Design Cultures in Information and Communication Technologies. *Science, Technology, & Human Values*, 29 (1), 30-63, 2004.

[Perruci and Gerstl, 1969] R. Perruci and J.E. Gerstl. *Profession Without Community*. Random House, 1969.

[Ravensteijn *et al.*, 2006] W. Ravensteijn, E. de Graaff and O. Kroesen. Engineering the Future: The Social Necessity of Communicative Engineers. *European Journal of Engineering Education*, 31 (1), 63-71, 2006.

[Ritti, 1971] R. R. Ritti. *The Engineer in the Industrial Corporation*. Columbia University Press, 1971.

[Robinson *et al.*, 2005] M. A. Robinson, P. R. Sparrow, C. Clegg and K. Birdi. Design Engineering Competencies: Future Requirements and Predicted Changes in the Forthcoming Decade. *Design Studies*, 26, 123-153, 2005.

[Russell and Stouffer, 2005] J. S. Russell and W. B. Stouffer. Survey of National Civil Engineering Curriculum. *Journal of Professional Issues in Engineering Education and Practice*, 131 (2), 118-128, 2005.

[Shinn, 1984] T. Shinn. Reactionary Technologists: The Struggle Over the École Polytechnique, 1880-1914. *Minerva*, 22 (3–4), 329–345, 1984.

[Solli, 2007] J. Solli. Bærekraftige kalkyler? Utviklingen av økonomiske argumenter om vindkraft. In *Mellom klima og komfort: Utfordringer for en bærekraftig energiutvikling*, M. Aune og K.H. Sørensen, eds., pp. 125-142. Tapir Akademisk Forlag, 2007.

[Suchman, 1987] L. Suchman. *Plans and Situated Action: The Problem of Human-Machine Communications*. Cambridge University Press, 1987.

[Suchman, 2007] L. Suchman. *Human-machine reconfigurations. Plans and situated action 2^{nd} edition*. Cambridge University Press, 2007.

[Sørensen, 1996] K. H. Sørensen. Den nye tverrfagligheten. Fra polyteknisk generalist til polyvalent spesialist. In *Perspektiver på tvers. Disiplin og tverrfaglighet på det moderne forskningsuniversitetet*, T. Dahl and K.H. Sørensen, eds., pp. 19-28. Tapir Akademiske Forlag, 1996.

[Sørensen, 1998] K. H. Sørensen. Engineers Transformed: From Managers of Technology to Technological Consultants? In *The Spectre of Participation. Technology and Work in a Welfare State*, K.H. Sørensen, ed., pp. 139-160. Scandinavian University Press, 1998.

[Sørensen, 2008] K. H. Sørensen. Dialog og tverrfaglighet som kunnskapspolitikk. In *Vitenskap som dialog — kunnskap i bevegelse. Tverrfaglighet og kunnskapskulturer i forskning,* K. H. Sørensen, H. J. Gansmo, V. A. Lagesen and E. Amdahl, eds., pp. 9-26. Tapir Akademiske Forlag, 2008.

[Sørensen *et al.*, 2007] K. H. Sørensen, V.A. Lagesen and N. Levold. Flytende profesjoner? Om organisering av kunnskap. In *Arbeid, kunnskap og sosial ulikhet. Festskrift til Olav Korsnes*, J. Hjellbrekke, O. J. Olsen and R. Sakslind, eds., pp.197-220. Fagbokforlaget, 2007.

[Sørensen and Levold, 1992] K. H. Sørensen and N. Levold. Tacit Networks, Heterogeneous Engineers, and Embodied Technology. *Science, Technology & Human Values.* 17 (1), 13-35, 1992.

[Sørensen *et al.*, 2008] K. H. Sørensen, H.J. Gansmo, V.A. Lagesen and E. Amdahl, eds. *Faglighet og tverrfaglighet i den nye kunnskapsøkonomien.* Tapir Akademiske Forlag, 2008.

[Thomas, 1994] R. J. Thomas. *What Machines Can't Do. Politics and Technology in the Industrial Enterprise.* University of California Press, 1994.

[Trevelyan and Tilli, 2007] J. Trevelyan and S. Tilli. Published Research on Engineering Work. *Journal of Professional Issues in Engineering Education and Practice*, 133 (4), 300-307, 2007.

[Turley and Bieman, 1995] R. T. Turley and J. B. Bieman. Competencies of Exceptional and Nonexceptional Software Engineers. *J. Systems Software*, 28, 19-38, 1995.

[Vesilind, 2001] P. Vesilind. A. Engineering as Applied Social Science. *Journal of Professional Issues in Engineering Education and Practice*, 127 (4), 184-188, 2001.

[Vincenti, 1990] W. Vincenti. *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History.* Johns Hopkins University Press, 1990.

[Vinck, 2003] D. Vinck, ed. *Everyday Engineering. An Etnography of Design and Innovation.* MIT Press, 2003.

[Vitalari, 1985] N. P. Vitalari. Knowledge as Basis for Expertise in Systems Analysis: An Empirical Study. *MIS Quarterly*, 9 (3), 221-241, 1985.

[Walsh *et al.*, 1992] V. Walsh, R. Roy, M. Bruce and S. Potter. *Winning by Design. Technology, Product Design and International Competitiveness.* Blackwell, 1992.

[Weiss, 1979] C. H. Weiss. The Many Meanings of Research Evaluation. *Public Administration Review,* 39 (5), 426-431, 1979.

[Whalley, 1986] P. Whalley. *The Social Production of Technical Work.* Macmillan, 1986.

[White and Leifer, 1986] K. B. White and R. Leifer. Information Systems Development Success: Perspectives from Project Teams Participants. *MIS Quarterly*, 10 (3), 215-223, 1986.

[Williams, 2002] R. Williams. *Retooling. A Historian Confronts Technological Change.* MIT Press, 2002.

[Williams, 2003] R. Williams. Education for the Profession Formerly Known as Engineering. *The Chronicle of Higher Education*, 49 (20), B12, 2003.

[Williams *et al.*, 2005] R. Williams, J. Stewart and R. Slack. *Social Learning in Technological Innovation. Experimenting with Information and Communication Technologies.* Edward Elgar, 2005.

[Zussman, 1985] R. Zussman. *Mechanics of the Middle Class.* University of California Press, 1985.