Engineering in Context

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Preface

In 1982 Barry Barnes and David Edge published a book entitled *"Science in Context. Readings in the Sociology of Science"*. Since then it has become a classic within the sociology of science. The intention of their book was to engage in a reflection on the relationship between the subculture of science and the wider culture which surrounds it. In this book we have been inspired both by their short and catchy title and their intentions. However contrary to Barnes and Edge the focus of this book is neither on science nor on technology but exclusively on engineers and what they do – engineering. Thus an important aim of this book is a better understanding of the contexts in which engineering activities are situated within the larger realm of human activities and the culture which surrounds them at the micro, meso and macro levels. In addition, the present book differs from Barnes and Edge's in the sense that we do not restrict ourselves to a merely sociological perspective. What we offer is a genuinely inter- and meta-disciplinary reflection by engineers, humanists and social scientists.

The book is the result of a European-American research project which was launched in Golden, Colorado, at the Colorado School of mines in April 2008. As a result of a three-day workshop, the structure of the book and the contributions of participants were agreed upon. In the project, 40 scholars from Europe and the United States took part, half of whom were present at the Golden workshop. Some of the questions that were discussed in Golden were: What do we mean by engineering in context? Isn't engineering always in context? What are the various contexts for engineering? Do these contexts impose themselves inevitably, or can one choose relevant contexts? How do these contexts create possibilities or impose limits? What are the implications of contextualizing engineering for the *Bildung* of engineers? We hope that the reader will find some illuminating material for reflection on the above contextual issues in our book.

We would like to emphasize the collective character of the book. This is reflected on two levels. First, in spite of our aim to write a scholarly book allowing participants a certain degree of freedom to pursue their research priorities, it has been a central concern for all of us that the book should present itself as a coherent and integrated whole. Second, the collective character of the book is reflected in the fact that a considerable number of the 28 chapters are co-authored.

As the book is meant to be a contribution to furthering the dialogue between engineering and philosophy in order to explore ways in which the humanities can contribute to self-development in engineering education through appreciation of the multiple contexts within which engineers increasingly work, these groups of academics are the primary audience for the book. In this way we hope that it may contribute to bridging the gap between the two cultures. However the book is also addressing a wider academic audience and may actually function as a means to achieve greater self-understanding for both teachers in engineering disciplines and for practitioners. Educational policy makers, both on a political and an institutional level, may also find valuable matter for reflection and inspiration in this book. We believe that, not least, the process of globalization compels engineering educators to rethink and to re-contextualize engineering education in order to educate a better and more rounded type of engineer. We finally hope that the book may inspire students of engineering as well as students of the humanities and social sciences who are interested in the challenges and complexities that a rapidly changing and globalized world pose for higher education in general and for engineering education in particular.

The structure of the book reflects our ambition to present the individual chapters in a logical and coherent way. At the beginning, there is an introduction which serves to frame the contents of the book but can also be read separately. The separate chapters are grouped into five main sections, the contents of which are presented and framed by a short introductory text for each section. An abstract and a number of keywords at the beginning of each chapter are intended to support the reader's overview.

In the first section, the notion of context is explored and questioned from the perspectives of philosophy and history. The second section is focused on engineering education. After a comparative analysis of European and US traditions, it explores the questions of the place of liberal education and humanitarian engineering in the training of young engineers, ending with a statement on diversity in engineering. Engineers are supposed to be designers: that is the focus of the third section – again starting with general and philosophical considerations, continuing with a historical perspective, and ending with more recent and very concrete examples like nanotechnology and sustainability. Section four explores some of the organisational contexts within which engineers work: enterprises, professional bodies, laboratories, the military. Trends in societal context form the fifth and final section, with contributions from diverse angles like art, religion, politics and environmental care.

The diversity of images and identities of the engineer, and the diversity of environments within which they work, is also reflected in the diversity of contributors to this book. Historians and philosophers meet with "hard core" electrical and aeronautics engineers. Backgrounds in literature meet backgrounds in business administration. Chemistry meets psychology. The reader may feel the original backgrounds in the angle and style of the different contributions. The European or the US origin of the authors may also be perceptible in the differences in the use of the English language. For the editors and the other contributors of the book, this variety of inputs was an enriching experience. In fact, it was also one of the starting premises of the project. We hope that the readers will feel and appreciate something of the experience we had when working on this book.

Acknowledgements

First we would like to express our gratitude to Carl Mitcham, Colorado School of Mines, who believed in, and whole-heartedly supported, the idea of the "Engineering in Context" project from its first announcement at a research conference entitled *"Bildung in Engineering – A Dream in the Heads of Humanists or a simple Necessity?"* in Herning, Denmark, 15 May 2007, and all the way through its different stages. We also thank him for his keen composition of our American team of authors. As one of the central gatekeepers within this field of study the project has benefited greatly from his many contacts. Without his support this project would never have come into being.

We would also like to express our gratitude to the Colorado School of Mines for generously hosting a 3-day kick-off meeting and workshop in April 2008. In particular, we wish to thank *the Hennebach Program in the Humanities, the John and Sharon Trefny Institute for Educational Innovation, and the International Network for Engineering Studies* for sponsoring the workshop.

Thirdly, we would like to thank the participating universities and institutions of higher education for their willingness to enter into the project and for giving the financial support allowing their respective project participants to travel to the workshop in Golden and the freedom to make their contributions to the project and to write their contributions to this book.

We are especially indebted to the following institutions for sponsoring the publication of this book, and we would like to convey our warmest thanks to them:

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- Dublin Institute of Technology (DIT), Ireland
- Katholieke Hogeschool Sint-Lieven, Ghent, Belgium
- Université des Sciences et Technologies de Lille, IUT "A" Lille, France

Finally we would like to thank our publisher, Academica, for a very fruitful collaboration. At this place we would also like to thank the editor Torben Bystrup Jacobsen for his kind and always careful monitoring of all the details and complexities in all the stages of the production of a well-crafted book. It would also be remiss of us

not to recognize the contributions of all our proof readers in helping us finalise this book. Because of the large number of scholars contributing from both Europe and the United States, as editors we have accepted as an editorial principle UK and US styles of language and spelling.

Steen Hyldgaard Christensen	Herning
Martin Meganck	Ghent
Bernard Delahousse	Lille

January, 2009

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General Introduction

The Challenges in Engineering and Society[1]

Steen Hyldgaard Christensen, Bernard Delahousse, Martin Meganck & Mike Murphy

The aim of this book is to gain a better understanding of the contexts in which engineering activities are situated within the larger realm of human activities. In dealing with context it immediately becomes clear that context is an inherently dialectical concept, since contextualizing in itself is dependent on definitions of what is perceived to be the relevant boundaries regarding both the education and the practice of engineering (see chapters 1, 2, 3, and 4). Contextualizing thus unfolds its inherent dialectics in the terrain between what "is" and "ought". In this way the quest for a re-contextualizing of engineering education and practice put forward in this volume inevitably is a value-laden enterprise and therefore not without a certain degree of controversy. It is concerned with both what engineering "is" and what it "ought" to be (see chapter 22). Ultimately a greater awareness and understanding of context should result in better preparation of engineers to render those contexts visible in their work, and consequently enable engineers to contribute to more socially robust and responsible endeavours (see chapter 20).

As contexts can either create possibilities or impose limitations, differing perceptions of context also contribute to creating controversies among engineering educationalists. The following two examples may serve as an illustration of the spectrum of what is perceived to be relevant contexts of engineering education. At one end of the spectrum, a report published by the Royal Academy of Engineering (2007) *Educating Engineers for the 21st Century*, argues in favour of a concentration on the technical context of engineering, "Universities must continue to teach "core engineering" and not dilute course content with peripheral subject matters". At the opposite end of the spectrum, Harvey Mudd College, California (2008), argues in favour of a widening of the context of engineering education in order "to educate engineers, scientists, and mathematicians, well versed in all of these areas and in the humanities and the social

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[1] The authors would like to thank Byron Newberry for stimulating and valuable comments on an earlier draft of this general introduction.

sciences so that they may assume leadership in their fields with a clear understanding of the impact of their work on society". In the following we address the first position, the limitations imposed by context. After that we address the second position or more precisely opportunities created by a widening of contexts.

Limitations imposed by context

Regarding the limitations imposed by context, many observers have gone so far as to speak of a crisis in engineering education, for example McIlwee and Robinson (1992), Copeland and Lewis (2004), Goujon and Hériard-Dubreuil eds. (2001), Ferguson (1977, 1993), Florman (1987, 1996), Bucciarelli and Kuhn (1997), Beder, (1997, 1999), The Institution of Engineers, Australia, (1996) and Williams (2002), to mention but a few. A number of arguments in support of this crisis position have an ideal typical character that can be presented by one or more of the following arguments:

1. The captivity argument
2. The cultural change argument
3. The identity crisis argument
4. The weak profession argument

The *captivity argument* put forward by Goldman (1991), Johnston *et al.* (1996) and Holt (2001) suggests that the engineering profession, in regard to both engineering education and practice, has been locked in a number of social and intellectual captivities which may be interpreted as a "fundamental usurpation of the intellectual and social dimensions of engineering as an autonomous discipline" (Goldman, 1991, p.121). Intellectually engineering has been subordinated to science. Socially engineering practice has been subordinated to a managerial agenda driven by the market. Engineers exercise their power only within that mandate. By internalizing the interests of either the company or the client, engineers thus become captive to the social process of technological action. For Goldman, technological action is a social process in which engineers participate rather than something which engineers do. Goldman´s argument fundamentally questions the characterisation of engineers as the primary agents of technological change. Moreover according to Johnston *et al.* (1996, p.1), "the result has been a serious limitation in engineers" capacity to examine the social meanings and effects of their work and to self-consciously reflect upon their practice and professional identity".

The *cultural change argument* is concerned with what is claimed to be a lack of diversity in the engineering culture. Especially in feminist research, the social norms of the engineering culture have been much debated in recent years, for example

Hacker (1981), Carter & Kirkup (1990), McIlwee & Robinson (1992) and Copeland & Lewis (2004). Increasingly, a shift in the way the underrepresentation of women is understood and explained has been advocated. Instead of problematising what could be seen as the qualifications lacking in women, the very culture of engineering is seen as the problem. Particularly, the dominant masculinity in engineering faculties and in the profession has been called into question. The main concern of this argument is that it makes it difficult to attract female students to degree programmes that will initiate them into this kind of culture. In chapter 25 in this volume it is noted that, "Currently there is a major initiative by the United States National Science Foundation to recruit women and girls into maths, science and engineering. It is known as Advance. One of the odd things about Advance is that it does not include in its purview the opportunity to encourage young girls in the early school grades to tinker". A dominant motivation for female students to enroll in engineering degree programmes appears to be that they have excelled in mathematics and physics courses prior to their decision to enter into an engineering degree programme, whereas the motivation of male students is predominantly an experience with and an inner urge to tinker. Here lies a major challenge in future engineering education as argued in chapter 10. However, this is only one aspect of the cultural change argument. More broadly, diversity in general is identified as the major challenge.

The *identity crisis argument* has been developed forcefully by Williams (2002) in her mighty analysis of the engineering profession (see chapter 19). She shows how the division of labour has destroyed the identity of the engineering profession. Williams argues

> *"What engineers are being asked to learn keeps expanding along with the scope and complexity of the hybrid world. Engineering has evolved into an open-ended Profession of Everything in a world where technology shades into society, into art, and into management, with no strong institutions to define an overarching mission. All the forces that are pulling engineering in different directions – toward science, toward the market, toward design, toward systems, towards socialization – add logs to the curricular jam".*
> (Williams, 2002, p.70)

Williams provides an illuminating description of the tensions in engineering education resulting in what she describes as a curricular jam. In extension Heywood (2004) argues that inevitably the engineering profession will develop into a plethora of grades, types and levels as technology has by far outgrown any single occupation. In terms of education, Williams continues that this

> *"means that the trend toward cramming more and more into the engineering curriculum runs in exactly the wrong direction. Few students will want (to) commit themselves to an*

> *educational track that is nearly all-consuming. What we now call engineering education should be lowering the threshold of entry, mixing itself with the larger world rather than trying to keep expanding its own world. Students are trying to do this mixing on their own, but in too many cases they are trying to pour new educational wine into old institutional containers".* (Williams, 2003, p.4)

If the result of the present situation is the education of engineers to very narrow specialisms, with a set of narrowly defined skills and competencies for pre-established jobs, then this kind of hyper-professionalism, runs exactly contrary to Braslavsky´s (2002) analysis of future educational demands where she stresses the importance of "educating active, rigorous and flexible individuals, rather than skilled workers for pre-established jobs". For Williams, the curricular response should be a convergence between the technological and liberal arts educating the engineering student both for life and flexible employment. According to Williams, "only a hybrid educational environment will… prepare students for handling... life in a hybrid world". Williams argues

> "*the convergence of technological and liberal-arts education is a deep, long-term, and irreversible trend. Students need to be prepared for life in a world where technological, scientific, humanistic, and the social issues are all mixed together. Such mixing will not take place if students have to decide from the outset that they are attending an "engineering school" as opposed to a "non-engineering school".* (Williams, 2003, p.4), (see also chapters 5, 6 and 8).

Williams further argues that if engineering schools only attract "faculty members and students who gravitate toward the technical problem-solving approach, then those students have an education that does not prepare them well for life experience". As pointed out by Heywood (2004), Williams' argument bears strong resemblances to some of John Henry Newman's core ideas regarding the value of liberal education put forward in his famous book "The Idea of a University". For Newman, the university is a hybrid educational environment which serves to educate students for life by means of "collegiality", "enlargement of mind" and "acquisition of a philosophical habit of critical thinking". Williams, like Newman, is concerned with skills and competencies and not primarily with content.

The *weak profession argument* may be interpreted in two different ways. In comparison with strong professions, such as medicine and law, the engineering profession may be described as a weak profession or a quasi profession for a number of reasons (Mitcham, 2008) (see chapter 18). However this is not the point we want to make here, rather we will interpret engineering as a weak profession that aspires to become a strong profession by promoting an ideology or a vision. In "The Engineer of 2020"

(National Academy of Engineering, 2004), the section titled "Our Image and the Profession" presents us with an optimistic picture of the aspirations of the engineering profession, one of which is to gain leadership and broad acknowledgement in society. "By 2020 we aspire to engineers who will assume leadership positions from which they can serve as positive influences in the making of public policy and in the administration of government and industry." However positive many of the ideals put forward in the "Visions of the Committee", they nevertheless are in stark contrast to the observations made by Holt (2001). Holt speaks of the

"inescapable condition of engineering in all ages; that is, patronage… First the patron or client establishes the intention, deciding on particular grounds what shall be done. Second, the patron provides the wherewithal to accomplish that purpose… Decisions about the market for engineered products, at once declaring opportunity and justifying commitment, are thus removed from engineering itself. It is the patron who energises professional work towards a specific goal, not what the engineer might know or can do". (Holt, 2001, p.498).

The point we make in outlining this argument is that there is another tension in engineering education. In aspiring for engineering leadership, should engineering educators primarily endeavour to educate technocrats or should they also aspire to educate public engineering intellectuals by means of supplementary science, technology and society (STS) studies for at least a limited number of philosophically minded engineers? Some might dismiss this as merely wishful thinking. However Bijker called for STS scholars to become public intellectuals (Bijker, 2003). As some engineers also have an STS degree, this might be the basis of a new kind of engineering public intellectual and hence a new form of engineering leadership. This approach also supports the identity problem issue for engineers discussed above. Bijker argues

"*that STS needs to make a further step and actively contribute to democratizing this technological culture: to show to a broad array of audiences – politicians, engineers, scientists, and the general public – that science and technology are value laden, that all aspects of modern culture are infused with science and technology, that science and technology do play key roles in keeping society together, and that they are equally central in all events that threaten its stability. It is therefore necessary that science and technology, in their explicit and implicit forms, be subject to political debate".* (Bijker, 2003, p.444).

This perspective is also linked to another tension within higher education generally, namely what should be the aims of the university. This tension was addressed by Wolff (1969) when he discussed what he termed the ideal type of the university of professions. He fundamentally questioned whether the university should serve as a training camp for professionals. Basically Wolff directed his criticism against the ideal type of the university of professions towards (1) its lack of autonomy, and (2) its lack of intellectual inquiry and critique. Today, when changes in the social distribution of knowledge production, academic capitalism and managerialism have undermined the autonomy of the university, Wolff´s first criticism appears dated whereas we argue that his second criticism is still valid. Delanty (2002) makes a similar point in speaking of cultural and technological citizenship and the way they should be linked. Delanty´s argument thus lies in the extension of Bijker´s call for public STS intellectuals and Wolff´s call for intellectual inquiry and critique. Delanty says that

> "*the domains of education and intellectual inquiry and critique relate to cultural citizenship, and the domain of research and professional training relate to technological citizenship. The fulfillment of these two kinds of citizenship is the social responsibility of the university. To find ways of linking these roles and cognitive frameworks into a communicative understanding of the university seems to be what the university needs to achieve today if it is to be able to take on the task of becoming one of the key institutions in the public sphere and in which citizenship is brought forward to new levels*". (Delanty, 2002, p.9).

Opportunities created by a widening of contexts

The crisis position presents a relatively pessimistic picture of the present context of engineering as residing almost entirely under the aegis of business. This is the bad news, however the good news is that engineering education is becoming increasingly more socialised (Williams, 2003). This means that engineering is becoming engaged with the pressing concerns of society, a fact which is likely to create optimism and new opportunities. Engineering educationalists and faculty members of engineering degree programmes are becoming more aware of the social responsibilities which should be highlighted in engineering education, not least because of the current accreditation criteria. Hence a more positive counterpoint to the crisis position is that globalisation, humanitarianism, sustainable development, green development, climate change, renewable energy etc. are beginning to become quite prominent issues in engineering practice and education (see chapters 15, 16 and 24). Accordingly there is more to engineering education than the crisis position would have it. Moreover, "re-contextualising" initiatives have occurred particularly in the US where specific programmes on "engineering in context" have been promoted, for example at the University of Virginia. The university describes its "Engineering in Context (EIC)" programme as providing *"engineering students with a culminating (capstone) experience in which they apply the engineering knowledge and skills they have acquired to address realistic problems in a multidisciplinary team environment. It emphasizes the importance of context (cultural, organizational, regulatory, environmental, economic, political,…) in identifying and defining problems, and the potential benefit and impact of engineering solutions. EIC capstone teams receive the financial, instructional and infrastructural support to bring a proposed solution from problem definition to final design and prototype testing".* (University of Virginia, 2007).

At the Colorado School of Mines and a number of other engineering schools in the US, the context of engineering has been widened to embrace the humanitarian context (see chapters 7 and 9). Degree programmes in "Humanitarian Engineering" have been established to help contribute to humanitarian relief work. This type of programme demonstrates that the context of engineering is not entirely resident under the aegis of business as Williams argues. It is noteworthy that this kind of endeavour is motivated by traditions of human idealism departing from "an ethical vision for the use of science and technology (initially in the form of medicine) to benefit human beings who may have previously been harmed by technology (at first in the form of military weapons" (see chapter 7 where this quote from Mitcham *et al.* is to be found). The opposite side of the coin points to a contextual dialectic. As argued in chapter 21, the profession and practice of engineering have historically evolved within a military context in "tandem with activities sponsored by military agencies and purposes". This dialectic corresponds to what Wolff called the ideal type of university acting as a social service station (Wolff, 1969), an approach which he criticized from the historical perspective of the war in Vietnam and the student unrest of the 1960s. From this perspective Wolff argued "surely it should be obvious that the academy must make its own judgement about the social value of the tasks it is called upon to perform. Even if the federal government wants war research or political stability studies or offer training, the professors and students of the university may decide that the government is wrong and that its desires should be resisted" (Wolff, 1969, p. 40). The perspective of the 1960s regarding engineering education is presented in chapter 22.

In current discussions of engineering education the global context is a major concern. However the meaning of globalisation is not always made explicit for which reason perceptions of globalisation move swiftly between "is" and "ought" (Newberry, 2005). Globalisation has both a descriptive and a normative meaning. Newberry argues that educational programmes that seek to develop a global perspective must endeavour to develop and convey a suitable normative meaning of globalisation,

"*if we give credence – as I do – to the assertion that there are serious, pervasive, and persistent problems and inequities that are potentially created or exacerbated via the current* *process of globalization, then simply providing our students with "global skills", skills desired by employers in order to bolster their competitiveness in the global marketplace, may not be sufficient from a moral point of view".* (Newberry, 2005, p.12).

Evidently the normative meaning of globalisation relates to the lives and motivations of engineers and the meaning and aspirations they attach to their life and work. According to Newberry such moral concerns relate to the education-for-life perspective in engineering studies. However the skills and competencies to be acquired by engineering students to become globally competent practitioners of their profession relate to the mode of collaboration in engineering practice. More specifically, they relate to working with people from different cultures in interdisciplinary, multidisciplinary or international contexts. According to Downey *et al.* (2006) these skills and competencies depend critically on the ability to work effectively with people who frame and define problems differently, including both engineers and non-engineers. This kind of collaboration has increasingly become a normal condition of engineering practice.

"Interactions with people from other countries are valuable because they are most likely (a) to draw boundaries around problems in different ways and (b) to judge problems to have distinct implications for their lives and careers. The key benefit in the ideal of learning to work productively with other cultures thus involves going beyond recognizing that engineering problems can be solved in different ways and mean different things to people holding different perspectives". (Downey *et al.* 2006, p.4).

The good news is that educational initiatives based on these premises, laid down by Newberry and Downey *et al.*, are currently gaining momentum in Australia, Europe, Latin America, and the United States. Moreover they have a strong resonance within accreditation criteria for engineering degree programmes both in the US and in Europe (see chapter 5).

The emergence of globalisation as a new normative context in engineering

It would need a specific historiography of the idea of globalisation to sort it out in detail, but it seems that globalisation as an explicit term appeared only in the very last few decades. The word "global" and related terms are, for example, rather sparingly used in Hans Jonas' *Das Prinzip Verantwortung* (1979), even if implicitly the global effects of modern technology are one of its major themes. Among the reasons why traditional ethics appeared insufficient for dealing with the effects of a technological society, Jonas mentioned the ambivalence of technology, the worldwide extension of the effects of technology, and the very new theme "the survivability of the human race" where the main threat is human action itself (Jonas, 1987): questions which are now clearly linked to the idea of globalisation. Other aspects of the actual conception of globalisation, like poverty and development, are on the contrary less to the fore in Jonas' analysis. However one of the major merits of Jonas' work is, undoubtedly, that technology became a theme of ethical reflection in a way other than it had been until then.

In many aspects, engineers do not differ much from the rest of society with respect to the evolution in awareness and conception of the idea of globalisation. As themes like climate change, food and energy sufficiency, and sustainable development gain more attention in society, so they do in engineering circles. And this inevitably also changes the normative environment for engineering. One symptom of this may be that environmental and safety issues appear in the ethical codes of engineering organisations almost simultaneously with the growing awareness of these themes in society at large, i.e. mainly since the 1970s. Now, as far as they can be distinguished from others, they constitute almost half of the 14 "Grand Engineering Challenges" for the 21st Century, as listed by a group of experts gathered by the U.S. National Science Foundation (The National Academies, 2009).

Like many other groups, engineers appear in the chain of causalities leading to global problems. They also belong to the groups from which remedies for these problems are expected. Yet – and again this may be compared to other groups – when practically dealing with their immediate stakeholders (such as clients, employers, authorities), these themes often remain unmentioned or hidden. Except in projects which focus directly on questions of environment or development (see e.g. chapters 9, 16 and 24 of this book), global issues mainly figure in the background of engineering work – represented either by official norms and standards or by general evolutions in public perception as boundary conditions within which to work.

One of the obstacles in raising the consciousness level of global problems is that some of their manifestations are not directly perceptible to the human senses. One may take here as examples ozone depletion or the greenhouse effect. They are calculated and implied rather than experienced directly (Achterhuis, 1992). And the more directly observable consequences may, in the individual cases where they occur, not be univocally attributable to these general tendencies: skin cancers and tropical storms also happen without depletion of the ozone layer or without global climate change. Dealing with statistical data may be difficult due to the short period for which data are available, and to difficulties in the communication of relevant methodological keys for the interpretation (see e.g. the discussions following Von Storch *et al.*'s criticism of the "hockeystick model" in climate studies (2004)). The probably inevitable feeling of uncertainty surrounding such data may moreover be fostered by some participants in the scientific debate, and as a result the acceptance of "scientific" conclusions can often be dependent on trust. The history of public awareness of risks linked to smoking or to asbestos are classical examples of this, and the climate change debate is no exception in this regard. Occasionally, engineers have seemed to be reluctant to accept that environmental debates have an objective or real value. Their reluctance may have to do with a kind of confidence or value-ladenness inherent to the training and professional activity of engineers, or alternatively with the immediate interests which were at stake for themselves and their employers.

In two ways, however, the involvement of engineers in environmental issues differs from that of most other individuals and groups. A first way is in the gathering and treatment of information. The development of measuring devices and strategies, participation in research programs and the development of mathematical models are challenging intellectual and professional tasks. To the extent that engineering work often requires a reliable reduction of complex situations to manageable data and theories, climatological and environmental studies may very well fall into the realm of the affinities and competences of engineers. However such models may have to include factors which are more difficult to forecast, such as local or worldwide trends in economic development (the occurrence of economic crises, the economic evolution of developing countries), political factors (the election of leaders wanting or not to give priority to environmental factors; the outcome of international negotiations) or the rate and kind of technological innovations (e.g. the development of nuclear fusion power) – factors engineers often feel uncomfortable with, certainly in the past. An awareness of the cultural and even political values hidden in climate change models may complicate (and at the same time be necessary for) working with such models (De Vries, 2001).

A second way in which engineers – more than other citizens – have the capacity to exert an influence is the development and deployment of specific technologies which are less "globe-consuming": be it really new products, products efficiently replacing existing products, or products for mitigating, treating or repairing damage caused by other activities. The development of technologies for environmental care, in academia as well as in industries, brings environment into the realm of accepted engineering activities, whereas a few decades ago, drawing attention to environmental problems was often seen as a threat to industry, and hence challenging for engineering. Interference of political or commercial instances may occasionally hamper the introduction of these new technologies, but they can as well stimulate them. Beside their possible role in the development and production of these technologies, engineers should be to the fore in informing the public about the various consequences or likely outcomes – philosopher Etienne Vermeersch mentioned this as one of the prime responsibilities of engineers in society. And because of their acquaintance with technology, engineers may be among the "early adopters" of these products, and hence function as trendsetters. In the late 1990s, the German Wuppertal Institute for Climate, Energy and Environment calculated that, at that very moment, the state of the art could deliver technologies which were four to ten times more efficient (or less consuming) than the ones commonly used at that time. If professionalism entails taking pride in delivering state-of-the-art products and services, engineers (in the past generally perceived as part of the problems) could well become a vital part of the solutions required.

Broadening competencies in the organizational context

The above-mentioned "Grand Engineering Challenges" for the 21st century, identified by a panel of experts at the request of the U.S. National Science Foundation, have been subsumed under four themes: sustainability, health, reduction of vulnerability, and joy of living. Obviously these themes not only address engineers as professionals and as citizens, but they also concern administrations and private organisations employing engineers and producing artefacts and/or services as well as engineering educationalists, economists, politicians, to name but a few authorities necessarily involved. New facets of engineering have already emerged in recent years, such as "humanitarian engineering" (see chapters 7 and 9 in this book) or "environmental engineering" (see chapter 16), in which engineers devote their technical competencies and their sense of civic responsibility to an altermondialist ("another globalisation is possible") type of commitment. Nevertheless the fact remains that a vast majority of engineers throughout the world are employed in an organizational context, whether private or public. In this context, the modern engineer, as highlighted throughout this book, is no longer "the "self-absorbed loner with a one-track mind" depicted by Braham (1992); he is one of the multiple actors, including customers, employers, colleagues, public authorities, etc. working together in close interaction (see chapters 17, 19 and 20 in this volume).

As a result of the globalization of the economy, fast-changing technologies – particularly in the fields of ICTs and biotechnologies – and the constant evolution of our western societies, the industrial paradigm has considerably changed. New forms of work organizations have appeared, such as multidisciplinary project teams or networking cellular enterprises, entailing broader competencies on the engineer's part, like teamwork, communication and behavioural skills. Companies make their production systems more flexible by concentrating their activities on their core business and outsourcing the less profitable ones to SMEs or to low-income countries. Total quality management procedures are now generalized to ensure the safety and reliability of products to satisfy the customer, thus requiring more controls and paperwork. Product-oriented policies are replaced by customer-oriented ones with their focus on delivery times, high quality, after-sales services, wide product ranges, etc. thus rendering engineering work far more complex and the engineer's workload more stressful (see chapter 19).

Identifying or predicting the knowledge, competencies and skills that will be required of tomorrow's engineers is therefore a difficult task, even though there seems to be a consensus in the current literature on the engineering profession that, beside the traditional scientific and technical skills, a "socio-cultural approach" is highly needed. By this, A. Kolmos (Christensen *et al.*, 2006) means that the social sciences and the humanities are core components in the engineer's formation in that they can help him/her develop specific skills, dispositions and habits to exercise a self-critical reflection (see chapter 20). However, if the needs of companies regarding engineering competencies may converge with the needs of society on a number of fundamental criteria, e.g. technological expertise, creativity, leadership, good communication, life-long learning abilities, environmental awareness, etc., they diverge on other crucial points. Society needs autonomous engineers with a sense of responsibility and reflective skills that enable them to be critical of what they or their firms are doing and how they are doing it. Autonomy, responsibility and reflectiveness are also publicly valued by companies, but in practice they are often closely demarcated or perverted: the engineer's autonomy is increasingly impaired by all kinds of controls and bureaucratic procedures; his/her loyalty to the organization often conflicts with his/her responsibility toward society or even his/her profession, despite occasional cases of whistleblowing; as for reflectiveness, it is generally instrumentalised by the enterprise as practice-oriented reflection in order to solve a problem or improve a method.

Actually the main point of divergence between companies and society at large concerns the way profits are used. Society insists that profit should be used for the common good, i.e. sustainability, health, reduction of vulnerability and joy of living (which are the main themes of the Grand Engineering Challenges mentioned earlier), whereas organisations privilege a profit-for-profit's sake perspective for shareholders and CEOs. The excessive financialisation of organisations has led to a harsh global competition which severely affects employees at all levels as well as populations all over the world, e.g. in the USA and in Europe: it has contributed to the generation of dramatic restructuring movements in the industrial world, with a host of company mergers and relocations resulting in millions of lay-offs, which now also affect engineers and executives. The worldwide economic crisis which broke out in 2008 may be the chance for our society to reconsider its model of development and introduce new policies centred on inter-generational and inter-national equity. Among the actors of this profound mutation, the engineer certainly has a key role to play provided he or she has developed the relevant reflective competencies.

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Section 1

Contextualism in Engineering

Introduction

Sylvain Lavelle

The issue of context in engineering is no doubt one of the most central and controversial topics in the studies of technology. On the one hand, context is an old issue if one views engineering as an activity adapting technical objects and projects to particular material and social conditions. On the other hand, it is a current issue if one considers the context to be at the heart of contemporary philosophical, historical and social reflections upon technology. Whatever the viewpoint, any attempt to characterize engineering as a core activity of the "technology-in-society" must, as far as possible, choose a position on what can be termed "the question of context".

The integration of some context elements into the dynamic of technology raises the question of the factors impacting or shaping its complex development. Technology can be viewed as a dynamic process of design, production and use of technical artefacts for which engineering appears as a core activity. Engineering design is largely about working with constraints, many or most of which can be described in quantitative terms. However context does not come so nicely arranged, rather it is described in a variety of qualitative terms and this fact alone makes absorbing it into a design method all the more difficult. The requirement for the internalisation of the context is itself context-dependent in the sense that it is particularly evident in a time of "globalisation" and "democratisation" of technology. This historical evolution requires indeed the engineers to take into account a variety of background information related to global or local events, trends, habits, identities or claims. In this respect, a context can be defined in terms of emphasizing the economic, social, cultural or environmental aspects.

The methodological status of the context is of much importance as regards the methods used in philosophy, in history or in the social sciences in order to construct the very object of the engineering studies. Most of the domains of philosophy had a "turn" in their history: a linguistic turn, an empirical turn, and then – among others – a contextual turn. The issue of context is now duly identified in philosophy as a topic called *contextualism* whether in the field of logic, epistemics or ethics. However, the "contextual turn" is less conspicuous in the field of technics, despite some crucial contributions both in phenomenological and analytical philosophy.

In a way, it is social studies applied to engineering that have long paid more attention to the contextual factors which contribute to the shaping of technology. The methodological approach of social studies on engineering (Option 1) is that of the "social construction" of technics, or socio-technical "externalism". The basic idea is that engineering is an activity that is shaped during its whole process, from requirements gathering to design and on to the use of technical artefacts, by a set of external social factors forming the context. The alternative methodological approach (Option 2) is that of technical "internalism" supporting the opposite idea of a proper and inner technical development. Thus, in this view, engineering is an activity that is shaped only by internal technical factors and remains so regardless of the context conditions.

It seems pretty daring to sustain Option 2 on technical contextualism, since nobody would deny that engineering is an activity that is shaped by some external social factors. The simple fact that the technical artefacts, as products, are dependent on the requirements and expectations of the users gives an idea as to the legitimacy of social shaping. However, it is no less daring to sustain Option 1, at least in the strongest version, if one suggests that technology is *entirely* shaped by a set of social factors. In this case, indeed, it would be almost impossible to make a difference between a set of material constraints ("internal") and a set of social influences ("external").

A third methodological choice (Option 3) in the approach to technical contextualism consists in exploring a range of possibilities located in between the two radical opposites (Option 1 and Option 2). This line of research requires that engineering studies scrutinize the *context sensitivity* of engineering, that is, the extent to which the various activities of engineering are shaped by some contextual elements. For instance, if one takes the stage of design as the most strategic phase of the engineering process, the context sensitivity should concern the early stages of engineering design.

The third approach or set of options on technical contextualism raises several questions :

1. Can engineering as a multi-dimensional activity be defined and identified in an accurate manner, considering its multiple parts and relations between these parts?
2. Can we reach a common or coherent methodological definition of the context that would be relevant for the whole scope of the engineering studies?
3. Can the technical activity of engineering be conceptually and empirically separate from its context, and, more precisely, from its economic, social or cultural context?
4. Can the stages or phases of engineering be isolated so that one can assess the impact of the context on each of them, or their impact on the context?
5. Can we identify some convergences in the variety of methodological approaches of the relations of engineering to its context?

The articles gathered in this section attempt to answer in their own way, mainly from a methodological perspective, some or all of these questions.

Byron Newberry, in "The Dialectics of Engineering", intends to clarify the notion of engineering which, as a multi-dimensional activity, can appear quite confusing. The dialectics of engineering are defined as tensions pulling the engineering enterprise in opposite directions, or ways in which engineering seems to be at odds with itself or with our perceptions of it. The dialectics of engineering is characterized by four themes : dialectics of scope, of identity, of purpose, and of method. As stated by Newberry, it is difficult to define engineering accurately, as a unified profession or role, provided with some clear general objectives, or with a common method. Several examples of such dialectics are given in the belief that they represent some of the key issues upon which any deeper understanding of engineering hinges.

Andrew Jamison, in "The Historiography of Engineering Contexts", contrasts and discusses three ideal-typical approaches to engineering contexts – economic, social, and cultural. He also reviews the historical "story-lines" on which the different approaches are based, namely those of innovation (economic), construction (social) and appropriation (cultural). The storyline of economic innovation emphasizes the commercial, or business, contexts of science and engineering. That of social construction emphasizes the role(s) played by scientists and engineers in building, or constructing, social institutions. Finally, the storyline of cultural appropriation emphasizes the ways in which science and engineering contribute to broader changes in cultural values and behaviour. The contribution of Andrew Jamison is all the more interesting as it draws both on research work in the history of technology as well as on his teaching experience with engineering students.

Peter Kroes and Ibo van de Poel, in "Problematizing the Notion of Social Context of Technology", address the classical problem of the relationship between technology and society. The basic dilemma concerns the main direction of influence between technology and society, with positions ranging from the idea that technology determines its social context to the opposite. A common assumption is that one can distinguish between technology and its social context, whereas this assumption is very questionable. The authors discuss the notions of technology and of context and explore whether the context of something can always be interpreted as a wider system that contains the thing under consideration as a subsystem. Then, they suggest that, for technology as process or as product, a conceptualisation that relegates all social elements of technology to the context is inadequate. Furthermore, the distinction between technology and its social context becomes even more problematic for socio-technical systems.

Sylvain Lavelle, in "Technology and Engineering in Context : Analytical, Phenomenological and Pragmatic Perspectives", explores the variety of definitions of the context and of the relations between a technological activity and its contexts. The basic idea is that a context is a property of the relationship between the individuals and their environment and can be defined as a milieu, a culture or a situation. In philosophy, the approach to contextualism has developed in most domains, but it did not result in a "contextual turn" in the philosophy of technics. However, a comparison between the two competing traditions of contemporary philosophy, the analytical and the phenomenological, highlights the assumptions and the implications of a technical contextualism. A more pragmatic perspective enables one to elucidate the role of technical paradigms or matrices, but faces the limits of any intercultural stance. This overview calls for a more questioning approach to the role of cultural backgrounds and to the context sensitivity or significance of technical objects and projects.

Chapter 1

The Dialectics of Engineering

Byron Newberry

Abstract: Dialectics of engineering are here defined as tensions pulling the engineering enterprise in opposite directions simultaneously, or ways in which engineering seems to be at odds with itself or with our perceptions of it. We offer several examples of such dialectics in the belief that they represent some of the key issues upon which any deeper understanding of engineering hinge. The introduction highlights an initial dialectic of scope that is encountered when it comes to studying the activity of engineering – that the closer it is scrutinized, the less well-defined engineering seems to become. The following section features dialectics concerned with engineering's identity. These include the enigma of engineering's simultaneous ubiquity and obscurity in society, the question of engineering's status as a distinct profession, and the tensions between the technical and organizational roles of engineers. Next, dialectics of engineering's purpose are highlighted, including a comparison of engineering ideals with practical realities, and a outline of engineering's equivocal contribution to societal understanding of technology. Finally, a dialectic of method is presented which contrasts the inward-focused nature of engineering methods with the outward-focused nature of engineering's purposes.

Key words: Engineering Profession, Engineering Method, Engineering Management, Technological Literacy, Public Perception

Introduction

This book is predicated on the assumption that *engineering* is an activity that ought to be studied and understood, in no small part because of its critical role in the creation of modern technology, technology which we know has transformational power for both the natural and social structures of our world. But engineering is not some external agent exerting its influence from the outside. It is endogenous to the world upon which it acts. It is an emergent process that coevolves with, and is inseparable from its medium. And this makes the study of engineering both fascinating and complex.

It is fascinating because of engineering's fundamental provenance in human nature, expressed succinctly in the title of Henry Petroski's book (1992), *To Engineer is Human*, and in the words of Billy Vaughn Koen (2003), who writes, "[T]he engineering method is coterminous with any reasonable definition of the human species." To truly understand engineering, therefore, is to understand something essential about humanity.

But this essentiality is also what complicates the study of engineering. When viewed as a most basic characteristic of human nature, the activity of engineering cannot be easily excised and examined in isolation from the larger ecology of human action. Like all ecological elements, it is inextricably coupled with its surroundings. At a very high level we might be able to create serviceable definitions of what it means to be an engineer, or to describe the products of engineering and the reasons for their creation. Such definitions of *engineering* are abstractions that we use to aggregate particular aspects of human activity for purposes of conceptual manipulation. But as we begin to dig to deeper levels of understanding, we get the feeling that the more we learn about engineering, the less plainly we can demarcate it. The more we study its causes and effects, the less clear are the distinctions between them. This is because, to use the words of Levins and Lewontin (1985), "abstraction becomes destructive when the abstract is reified and when the historical process of abstraction is forgotten, so that the abstract descriptions are taken for descriptions of the actual." That is, if we investigate *engineering* as if it were an actual ontological entity, we are destined to be unsatisfied with the result. Thus we have a *dialectic* tension in the study of engineering – a fundamental antagonism in which our examination of the contents of the engineering box, so to speak, dissolves the box and intermixes the contents with its surroundings.

Engineering is characterized by such dialectic tensions at many levels. They exist in overarching questions, such as those concerned with engineering's ultimate goals. They also exist in more narrow questions, such as those concerned with the technical methods engineering employs. Our aim in this chapter is to illuminate some of these dialectics – these ways in which engineering appears to be at odds with itself, or with our perceptions of it. We do this in the belief that grappling with them is central to refining our larger understanding of engineering. The list of dialectics discussed herein is not exhaustive, nor are they all necessarily unique to engineering. But when taken collectively, we hope these examples will shed some useful light when it comes to understanding *engineering in context*.

Dialectics of Identity

Omnipresence contra Invisibility

I have elsewhere used the *Shoemaker's Elves* fairy tale as a metaphor for engineers (Newberry 2007). Like the elves' role in the making of the shoemaker's shoes, engineers play an instrumental role in the design and production of nearly all the artifacts of life in a modern industrial society. A citizen of such a society is hard-pressed to touch or use anything during a typical day that is not either itself engineered (e.g., an appliance), or else was made available via engineered systems (e.g., a tomato purchased at the grocery store). And like the elves, the engineer's role in the existence and availability of many of these artifacts remains largely a mystery. Samuel Florman (1996) calls engineering the "anonymous profession." By this he literally means that modern engineers, unlike their historical counterparts – Henry Ford, say, or Thomas Edison – are rarely famous; that is, the public does not generally know the names of the engineers who have designed and developed the latest technologies that are so prominent in our lives. Rather, technologies are seen as the products of teams of nameless, faceless engineers. This observation is echoed in an article titled, "The Invisible Engineer," in which Gary Downey *et al.* (1989) write that in the 20th century, "Engineers lost their visibility as individuals and became instead corporate men buried within organizations."

Engineers are also anonymous in another, perhaps more significant sense. When surveyed, people often correctly associate engineers with the production of certain iconic technologies – such as vehicles, bridges, spacecraft, computers, and electronics. But those same surveys indicate that people do not know much about what engineers actually do. Nor do people necessarily realize engineering's role with respect to the existence of the vast remainder of artifacts and products that are less iconically technological, such as paper clips or toothbrushes. So not only are engineers anonymous as individuals, but what they collectively do at work, and how that translates into the resulting technologies, products, and goods, is also largely unclear. "Our culture's lack of attention to the artifacts and people of engineering," writes David Goldberg (2006), "causes it to misunderstand engineering education, engineering practice, and engineers themselves in important ways." We might say that engineers and engineering are largely opaque to the public. Like the proverbial black box, raw materials go into engineering and artifacts come out, but no one really knows what goes on inside. "Though ours is an age of technology," writes Petroski (1992), "the essence of what engineering is and what engineers do is not common knowledge." This lack of knowledge is true even of many nascent engineers. As an engineering professor, I meet frequently with high school students and their parents. These are students who have generally made up their minds to study engineering and are primarily trying to decide which school to attend. You would think that the decision to pursue a particular career would be based on a good understanding of what that work entails, but surprisingly one of the questions I'm most frequently asked is some version of, "What is it that engineers really do?"

This lack of clarity about engineering work, however, is not limited to the general public. Sociologist Robert Zussman (1985) spent time shadowing engineers at work in order to help fill a void he perceived in the academic studies of the engineering profession. "Although there is broad convergence around the idea that what engineers do is analytically important," writes Zussman, "there is little consensus as to what they actually do…" And Downey et al (1989) highlight the lack of definitive scholarship on the modern engineering profession, not only from sociologists, but also from historians and philosophers.

Unified Profession contra Diverse Occupations

In many countries, including mine (the USA), engineers widely consider themselves to be part of a *profession*. When an occupation is considered a profession, it connotes a somewhat privileged status in society. Professions are thought of as doing work critical to the well-being of society, work that requires a high level of education and expertise, and work which is worthy of a measure of prestige. Further, professions are often regulated to ensure that only those qualified are permitted to practice, and that the practice is governed by both procedural and ethical rules aimed at protecting the interests of the society which the profession serves. These rules, in turn, are the purview of the professionals themselves; that is, because of their expertise, professionals are allowed the autonomy of specifying their own constraints. As a result, professionals tend to see themselves as having obligations to society that may transcend the necessities of their particular jobs. In short, a profession comprises practitioners of a discipline having a formal, shared set of qualifications, ideals, and obligations.

But engineering's status as a profession is complicated. Much of that complication is due to the staggering diversity of engineering disciplines and occupations. This is compounded by differences worldwide in educational criteria and regulatory constraints. For example, if we examined the work of a biomedical engineering researcher, a civil engineering construction manager, and an electronics sales engineer, we would likely find little in common between their technical knowledge, their daily work activities, their work environments, their work objectives, or their employer types. If they are employed in the USA, for example, only one of the three is likely to be professionally licensed. Requirements for professional licensure for engineers vary by country, ranging from the non-existent to the strict. In the USA, certain types of engineering work require licensure, but most do not, resulting in approximately 80% of engineers being unlicensed. Most unlicensed engineers employed by industry in the USA have accredited academic engineering degrees, which assures some minimal educational commonalities. Yet in the USA, as well as in many other countries, companies are free to employ people in jobs titled "engineer" without regard to academic credentials. In France (Didier 1999), "almost half of the people working as engineers in corporations are not graduate engineers, but self-taught. The practice of an engineering profession is neither controlled nor regulated by French law." It is also likely that in some companies employees with neither the title "engineer," nor any formal engineering education, perform work substantially indistinguishable from that of engineers. In a related vein, at my own university there is a professor of electrical and computer engineering who holds no degrees in engineering – his educational background is in physics. Yet his theoretical knowledge and practical experience with electronics allow him to hold an engineering title and to teach engineering. And quite likely he could qualify for many engineering jobs within the electronics industry.

Among other differences, the three engineers used in the example above would probably not share membership in a common professional organization – in fact, one or two of them may not belong to any such organization at all, despite the fact that engineering organizations proliferate. Florman (1987) highlights the consistent failure of any efforts to establish organizational unity across engineering disciplines. The reason, he concludes, is because the engineering community does not have "any discrete message." The goals, interests, and concerns that both drive and constrain engineering are as diverse as the underlying technical subject matter. Rosalind Williams (2003) writes, "Engineering has evolved into an open-ended Profession of Everything in a world where technology shades into science, art, and management, with no strong institutions to define an overarching mission." This divergence of engineering disciplines, and the cross-boundary diffusion between engineering and non-engineering fields, occurs both in engineering as a whole as well as within individual disciplines. In an article aptly titled, "Electrical Engineering's Identity Crisis: When does a Vast and Vital Profession Become Unrecognizably Diffuse," Paul Wallich (2004) discusses electrical engineering's rapid divergence in many directions, some of which blur the boundaries with other fields such as biology, physics, or computer science. Wallich's article seeks, *with little success*, to identify the common thread that binds together the diversity of people who call themselves electrical engineers – to define what it means to be one. Given this trouble establishing what it means to be an electrical engineer, it is no wonder that it may be difficult, if not impossible, to identify a coherent nucleus of attributes that is general enough to apply to all engineers *yet* specific enough to unequivocally differentiate them as a distinct professional group (at least in a more meaningful sense than as a "profession of everything").

Technoscientist contra Businessperson

In his book *The Ancestor's Tale*, biologist Richard Dawkins (2004) tells of salamanders that inhabit the mountains that ring California's Central Valley. The salamanders, it is believed, migrated (over time) south from the northern end of the valley, following the two mountain chains that line its east and west sides – the valley itself is inhospitable to the creatures. By the time the salamanders arrived at the southern end of the valley, where the mountains rejoin, the east-west divergence had resulted in the evolution of two separate species that do not recognize each other and will not interbreed. The interesting point, however, is that if we start with one of the species at the southern end, follow its path back north along one side of the valley, and then proceed down the other side of the valley back south again, we will find a continuum of interbreeding salamanders bounded on either end by the two distinct southern species. Thus, while these two species appear clearly demarcated when viewed in isolation from their context, there is no such clear demarcation when the context is restored – that is, there is no way to determine where one species ends and the other begins.

I recount this story as a metaphor for engineering. Engineers are employed at all levels of responsibility within organizations, from the lowest level technical work to, in some cases, corporate CEO. A rank and file engineer doing basic technical tasks will interface seamlessly with his or her team leader. The team leader has some supervisory responsibility for several engineers, but will also be intimate with the technical details of their work. That team leader will also interface seamlessly in the other direction with a department head, say. The department head manages the budgets and schedules of several teams, in addition to overseeing the programmatic and technical objectives of the department. The department head in turn reports to a program manager, and so forth up the line. At each level both the business and technical aspects may be equally important – the main difference is in the level of abstraction with which they are engaged. The low level engineer will certainly be cognizant of the importance of budgets, deadlines, and other business objectives, but will typically engage them only in fairly abstract ways. The technical issues, on the other hand, are very concrete for that engineer. At a program manager level, the business issues are engaged much more concretely, while the technical issues are engaged at a much higher level of abstraction.

It is temping to conclude that someone who has risen from the engineering ranks to the CEO level of a big corporation has ceased to function as an engineer and is now employed in some other capacity. We might say the CEO has become a completely separate species from a low-level engineer. But as with the chain of salamanders, it is difficult to say where along the continuum between the two one crosses the line from being an engineer to being something else. Or rather than crossing a clear line of separation, perhaps one goes from being a whole engineer to being a fractional engineer, with the fraction gradually decreasing as non-technical responsibilities accrue. Or, does the attempt to separate the technical from the business miss the mark altogether with respect to characterizing engineering? Is Goldberg (2006) correct when he writes, "The businessperson who says that engineering is 'mere technology applied to the needs of business' could more accurately be told that modern business is merely the application of the engineering method to the design of commerce?"

These questions highlight a long-standing tension between engineers' technical and organization roles. Is engineering primarily about providing technical expertise or is it about accomplishing business or societal objectives with respect to technology? Are engineers technicians or technocrats? Are they labor or management? The answers are not easily forthcoming. In fact, this tension extends into the realm of engineering education. In the USA, for example, engineering education has long been heavily invested in the technical and scientific elements of the curriculum. But this emphasis is constantly challenged by voices from the engineering community that would prefer to see more attention given to developing engineers' organizational leadership skills and business acumen (e.g., NAE 2004, Duderstadt 2008). This tension has only been heightened in recent years in the context of engineering's adjustments to globalization.

Dialectics of Purpose

Ideals contra Realities

The mission statement of the Institute of Electrical and Electronics Engineers (IEEE), one of the world's largest engineering societies, states, "IEEE's core purpose is to foster technological innovation and excellence *for the benefit of humanity*" (IEEE 2008). Likewise, the mission statement of Cal Tech, one of the world's leading engineering education and research institutions, states, "The mission of the California Institute of Technology is to expand human knowledge and *benefit society* through research integrated with education" (Cal Tech 2008). This same overarching idealism – pursuing the benefit of humanity/society – is common rhetoric for engineering organizations and institutions worldwide. This is not surprising coming from a discipline that aims to be a profession in the fullest sense. But is there substance to these claims? Against them is the reality that the benefits proffered by engineering accomplishments are almost always attended by some measure of undesirable side effects or unintended consequences. We might even be able to name some products of engineering that have not worked to any reasonable public benefit all. In many cases, benefits may be distributed inequitably, accruing to one group at the expense of another. For reasons such as these, public opposition can and does arise in response to various engineering projects or products. It is also important to note that the majority of engineering work is carried out by private firms aiming most explicitly at financial success, not humanity's benefit. Some see engineers as being captive to these private interests, and thus limited in their ability to make good on any overarching professional ideals (Goldman 1991, Noble 1977).

So how might engineers reconcile tension between their overarching ideals and a somewhat different reality? One way is in the interpretation of what it means to *benefit humanity*. "No one claims technology is omnipotent or omnibenevolent," writes Sunny Auyang (2004). In engineering, "the underlying philosophy is usually utilitarian." Benefit, therefore, comes to mean *on balance*. We can accept a dose of negative in return for generating a greater dose of positive. Of course, as with all utilitarian thinking, the crux of the matter lies in how we choose to define positives and negatives, and in what (often incommensurable) values we assign them. Tradeoffs have always been a staple in engineering, but they are conceived most often in terms of balancing quantifiable technical parameters within the details of a design. But how do engineers ensure favorable tradeoffs at the far more consequential – yet often far less tangible – level of wide-ranging societal benefit/detriment? If their highest ideal is societal benefit, and if societal benefit is a complex and contested concept, then we might imagine engineers being heavily engaged in discourse about it. But in the view of many observers, such is not the case. "If Socrates' suggestion that the 'unexamined life is not worth living' still holds," writes Langdon Winner (1986), "it is news to most engineers." Winner softens that acerbic statement (slightly) by noting that there are exceptions. But his broad contention that engineers as a group are largely unreflective about their work remains intact, and it is shared by others. Richard Devon (2004), for example, writes that "it is still easier for engineers to understand a lot about how a technology works as a technology, while having a limited understanding of its possible uses and its social and environmental impacts."

It can be argued whether or not engineers are really as unreflective as these claims would have it. But even if they are, does being unreflective mean that engineers are indifferent, or that their mission statements are simply fodder for lip service? Not necessarily. "Every engineer I have ever met," writes Florman (1987), "has been satisfied that his work contributes to the communal well-being, though admittedly, I had never given much thought to why this should be so." Florman is suggesting an axiomatic presumption, perhaps instinctive to many engineers, that their work is organically beneficent, at least in a utilitarian sense. Engineers tend toward pragmatism, a belief in progress, an action orientation, and, of course, an affinity for technology. "Engineering is an inherently constructive profession," writes Goldberg (2006), "attempting to make a better world through change." Many engineers may tend to view engineering work as operating like a Smithian *invisible hand* that inexorably promotes the collective benefit. From that viewpoint, reflection may seem largely superfluous –

what is important is action. Of course, whether engineers realize it or not, the belief that technological progress will invariably work, in the manner of an invisible hand, for the collective good, is a disputed claim. So even if engineers might be absolved of any general indifference towards the broader implications of their work, allegations that their views are too limited may still be levied. Whatever the case, it is clear that significant tensions exist between engineering's ideals and the realities of engineering practice and technological development. This dialectic is a fundamental dynamic that must be grappled with in any quest to understand engineering in context.

Technological Understanding contra Technological Concealment

It is a widely accepted premise that the public needs to be more technologically literate for a variety of reasons that will benefit both individuals and society. For individuals, technological literacy will enhance the potential to acquire technology related jobs (Barus 1989), to make wise consumer choices, and to participate in public discourse about the pros and cons of technologies. Society benefits from having a skilled workforce capable of sustaining technological industries, as well as from having a citizenry capable of making informed contributions to public policy (Wacker 1991).

If there is a need for the increased technological literacy of people in our society, then it would seem patently obvious that engineers could and should play a vital role in helping to fulfill that need. After all, engineers are collectively the group most intimate with the workings of technologies. Toward that end, many engineering professional organizations have become active in seeking ways to promote technological literacy. The IEEE, just to give one example, recently launched an initiative called "Technological Literacy Matters!" Aside from the societal benefits, the engineering profession has more selfish motives for promoting technological literacy. The profession is generally aware of its own public invisibility, which has led it to undertake efforts, such as the annual National Engineers Week in the USA, to enhance understanding of engineering and technology. This also aids in filling the educational pipeline with young people having the interest and preparation to pursue careers in engineering – a crucial issue for the profession.

But with respect to the causes of technological illiteracy, an influential NAE/NRC report (Pearson & Young 2002) makes the following statement: "Most modern technologies are designed so users do not have to know how they work in order to operate them." The key word is *designed*. If technologies are black boxes which people learn to use without any real understanding, and if that is a leading cause of technological illiteracy, then engineers are in some sense the architects of that illiteracy. Albert Borgmann (1984) coined the term *device paradigm* to describe much of modern technology. The device paradigm suggests that modern technologies are designed specifically to enhance the ends of the technology (such as ease of communication in the case of the telephone) while removing the means from view as much as possible. "The concealment of the machinery and the disburdening character of the device go hand in hand…A commodity is truly available when it can be enjoyed as a mere end, unencumbered by means." Because of the powerful marketability of *ends unencumbered by means*, engineers have been proficient and prodigious in making the concealment of means a reality, and they do so as an explicit design goal.

We are all familiar with the term *user-friendly*, which we apply to a technological product that is easy to use and to understand. But when we say easy to understand, we do not mean it is easy to understand the underlying technological principles. Rather we mean it is easy to understand how to get it to do what we want it to do, and this often is purposely divorced from any knowledge of those underlying technological principles. In fact, the design trend is toward technologies that will do what we want them to do with less and less explicit input or manipulation on our part. Take for example the ideas of Donald Norman (1998), a proponent of human-centered computer technology. He writes, "Today's technology imposes itself on us, making demands on our time and diminishing our control over our lives. Of all the technologies, perhaps the most disruptive for individuals is the personal computer. The computer is really an infrastructure, even though today we treat it as the end object. Infrastructures should be invisible: and that is exactly what this book recommends: A user-centered, human-centered humane technology where today's personal computer has disappeared into invisibility."

Norman echoes Borgmann in pointing out that technology imposes a cognitive burden on us, one which we are generally happy to relieve if possible via user-friendly, invisible technologies. But whereas Borgmann – a philosopher – views that trend with uneasiness, Norman – an engineer – celebrates it as a worthy objective. The more invisible the technology, the less the user has to know about it, and the more successful the designer. Such design goals can stem from a positive desire to enhance the user's experience and productivity. On the other hand, sometimes such goals are couched more negatively as palliatives for users' ignorance. An article in the EETimes (Wallace 2006), an industry newspaper for electronics engineers, states that technology "wants--and needs--to become transparent, if not completely invisible to today's techless, clueless consumer." The article refers to such designs as *invisible facilitation*, which it says "is rapidly emerging as the design rule of the day." The article implies that the *techless, clueless consumer* – i.e., technologically illiterate consumer – is a problem to be solved. But the solution strategy in this case is not to educate consumers about technology, but rather to increasingly design technology to cater to consumers' low level of technological knowledge. This notion of designing to compensate for users' ignorance is illustrated, for example, in Inagaki's (2004) discussion of automation for transportation technologies: "[I]n cases of non-professional operators, such as private car drivers, it would not be sensible to assume that their levels of knowledge and skill are high. Their understanding of machine functionalities can be incomplete, or even incorrect."

The intentional design for concealment of means is pervasive. In addition to terms such as *user-friendly* and *black box*, other familiar terms which convey the notion of usability without understanding – and which are pursued during design as desirable things – include *plug-and-play*, *turnkey system*, *human-centered design,* or *user-centered design*. The great irony – the key to this dialectic – is that even as engineers recognize the need for, and work to promote technological literacy, in the context of their actual work they are caught in a spiral that works against that objective. The more engineers make their designs user-friendly, the less users need to know about the underlying technology. But the less users know about the underlying technology, the more they demand increased user-friendliness. And so on.

A Dialectic of Method

The General contra the Specific

In his *Metaphysics*, Aristotle writes, "Actions and productions are all concerned with the individual; for the physician does not cure man, except in an incidental way, but Callias or Socrates or some other called by some such individual name, who happens to be a man." That is, while physicians may value a general ideal (health) or work toward a global objective (curing the sick), their actions are always local and specific. Engineering's general ideals perhaps include such things as progress, efficiency, or improvement in the quality of human life. And global objectives might include such items as providing energy, transportation, communications, and the like. In practice, however, engineering concentrates on the local and the specific. Localization manifests itself in two primary ways in engineering, one circumstantial and the other methodological.

Circumstantial localization – or particularity – exists by virtue of the fact that solutions to engineering problems are always local and never universal. Engineering concentrates "on what is possible in narrow localities of the universe and definitely not everywhere" (Jarvie 1966). For example, if engineers design a suitable drinking water distribution system for a small town, they have not solved the problem of drinking water distribution for all people everywhere. The solution for the one town is particular; it depends on the particularities of, among many other things, the nature and quality of the local water source, the geography of the locale, the size of the town, the size of the town's budget, the engineers' inherent preferences for some materials and techniques over others, and the capabilities of local construction firms. This is not to suggest that there is no universal engineering knowledge. Certainly, much of the knowledge and reasoning that went into the design of the one drinking water system can also be applied to the design of other such systems. Nevertheless, the application of that engineering knowledge is always "concentrated on local conditions and their transformation," conditions "which might be absolutely unique" (Poser 1998). To take another example, the engineer does not solve the problem of communications, except in an incidental way, but rather solves the problem of communicating a specific type of information, at a specified rate and fidelity, between specific types of points. In fact, engineering cannot address generalized or abstracted problems. The fundamental object of engineering is to meet a set of specifications. And as the very word implies, specifications define the concrete and particular manifestation of a problem.

Hand-in-hand with this circumstantial localization of the problems with which engineering is concerned, engineering practice invariably attacks those problems by engaging in methodological localization, a form of reductionism. Not only is it the reality that each engineering problem is unique, but at all levels within the solution process, from overall system analysis, to the minute detailing of individual components, forms of reduction prevail. In order to cope with real world complexity and uncertainty, engineers invariably isolate, subdivide, and simplify. This reduction is what allows engineers to be successful. Carl Mitcham (1997) writes, "[I]t is not only permissible to ignore complex subtleties, but better to do so." In Larry Bucciarelli's (1994) analysis of engineering design, this notion of methodological localization surfaces time and again. "Object world stories," he writes, in reference to the domain of thought, actions, and artifacts comprising design, "work better with fewer elements; abstraction and reduction go hand in hand in this business. Sparseness characterizes a good, workable model." Reductionism, he concludes, "is the essence of technique within object worlds." Similar observations also appear in Walter Vincenti's (1990) account of engineering. He writes, for example, "Such successive division resolves the airplane problem into smaller manageable subproblems, each of which can be attacked in semi-isolation."

By their very nature, both types of localization help engender a mindset that is restrictive rather than expansive, exclusive rather than inclusive, convergent rather than divergent. Earlier we mentioned that engineers are sometimes accused of being unreflective with respect to the broader implications of their work. It should be no wonder that people who are constantly engaged in the solution of concrete, particular, and finite problems, and who habituate themselves to solution methods that discretize and simplify those problems, are not as a rule always and instinctively cognizant of the more abstract and potentially generalized effects of those solutions. We might posit that when engineers visualize an overall problem as a collection of relatively independent subproblems, each of which has been simplified and idealized, they nonetheless believe that they are manipulating actual components of external reality. This opens the engineer to a criticism, articulated for example by Larry Hickman (2001). When resolving a complex problem into component parts for the convenience of achieving a solution, it is a mistake, according to the criticism, to view those parts as somehow unique and absolute, existing independently of the process that led to the parts being identified and isolated – i.e., it is a mistake to view the use of a particular taxonomy of parts as somehow logically inevitable and necessary. This criticism is echoed by Levins and Lewontin (1985), who suggest that this biases solutions by favoring problems that are amenable to being reduced in the preferred ways.

The danger lies in the potential to foster a belief that engineering methodology follows a rigidly deterministic and logical path, rather than recognizing the biases, contingencies, and subjective decisions that skew the process toward the expedient achievement of specific, narrow objectives. As Koen (2003) suggests, engineering solutions always provide the right answers, just not always to the same questions that were initially asked. In other words, the way in which engineering problems are parsed in the solution process can serve to alter the problem itself. This has ramifications for the previously-discussed dialectic of engineering's ideals versus the realities of engineering practice and technological development, which this dialectic tension – and sometimes disconnect – between engineering's globalized objectives and its localized methods can exacerbate.

Conclusion

In sum, the core thesis presented here is that in one sense engineering can never be finally understood because it is neither discreet nor static. Nonetheless, engineering can be usefully investigated and those investigations can broaden our understanding – not just of engineering but of humanity in general – and we suggest that taking a dialectical approach can be beneficial. In making their case for the use of dialectical thought in biology, Levins and Lewontin (1985) write, "Things change because of the actions of opposing forces on them, and things are the way they are because of the temporary balance of opposing forces." Thus, they conclude, biological study advances with the investigation of these dialectical tensions. Likewise, we posit that many of the key entry points for our investigations of engineering are precisely at such points of dialectical tension. It is important, for example, to understand the dynamic arising from the tension between the increasing dependence of society upon engineering and technology and the simultaneously decreasing understanding by society of that same engineering and technology. It is important, for example, to understand the dynamic arising from differences between what engineers say they are trying to accomplish, or think they are trying to accomplish, and what they actually do accomplish, or what we perceive them to have done. In this chapter we have not even attempted a full assessment of these or any of the dialectics mentioned – those concerned with our study of engineering, those concerned with engineering's identity, those concerned with engineering's purpose, and those concerned with engineering's methods – space has permitted only the briefest of discussions (and no discussion of others that might be identified – "performance/capability contra risk" is one that comes easily to mind). But hopefully this chapter has served to frame some of these key conundrums that challenge our understanding of engineering in context. The subsequent chapters of this book will explore engineering in more detail from a variety of angles. In the process, many will encounter and grapple with various aspects of one or more of these dialectics.

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Chapter 2

The Historiography of Engineering Contexts

Andrew Jamison

Abstract: The chapter contrasts and discusses three ideal-typical approaches to engineering contexts – economic, social, and cultural – and reviews the historical "story-lines" on which the different approaches are based. The story-line of economic innovation emphasizes the commercial or business contexts of science and engineering, while the story-line of social construction emphasizes the role(s) played by scientists and engineers in building or constructing social institutions. A story-line of cultural appropriation emphasizes the ways in which science and engineering contribute to broader changes in cultural values and behavior. The chapter draws on a recent introductory survey to the history of technology and science (*Hubris and Hybrids*) that the author has written together with Mikael Hård and experiences in teaching "contextual knowledge" to science and engineering students.

Key words: Contextual Knowledge, Innovation, History, Sociology, Science, Technology, Hybrids, Technological Determinism, Social Constructivism, Cultural Appropriation

Introduction. On the Contexts of Engineering

One of the main difficulties in discussing the contexts of engineering is that engineering, like science and art and other forms of human creativity, has had a range of different meanings, or functions in history. It can therefore be useful to attempt to distinguish, in an ideal-typical fashion, some of the more significant meanings of engineering, since they have led to quite different understandings of engineering contexts and what might be termed contextual knowledge (see Table 2.1).

Table 2.1: The Meanings of Engineering

Meaning	economic, commercial	social, professional	cultural, human
relevant contexts	companies, corporations, markets	cities, nation-states, societies	movements, communities, cultures
story-line	innovation	construction	appropriation
forms of contextual knowledge	innovation studies, economic and market analysis	science and technology studies, sociology and philosophy of science and technology	cultural studies, history of science and technology, technology assessment

On the one hand, engineering has meant the transformation of "inventions" into "innovations" by means of what is customarily thought of as an evolutionary process (e.g. Basalla, 1988). Unlike Darwinian evolution, however, innovation is a process of not so natural, that is to say, artificial selection; and the interesting questions in relation to engineering contexts thus revolve around where the selection takes place, who is doing the selecting, and for what reasons.

The aim of this kind of engineering through the centuries has been to develop things of commercial value, be they products, tools or means of production, from one or another creative act, to turn, we might say, inspiration into perspiration. More specifically, the ambition has been to make money or accumulate wealth, or attain what are now called property rights, from commodities based on a scientific or technical discovery. This can be considered the economic or commercial meaning of engineering, and, at the present time, there is a strong tendency for this meaning or function of engineering to dominate all the others.

For while the importance of engineering for business or commercial purposes can certainly not be denied, there are other meanings that are at least of equal importance, if not more so. Indeed, it can be suggested that the dominance of the commercial or economic meaning of engineering has led to a relative neglect of what might be termed the social and cultural meanings of engineering.

Many forms of engineering are intrinsically social, in the sense that they are attempts to apply technical ingenuity to the solving of social problems and/or the resolution of social conflicts.

The aim of this sort of engineering has been to provide a kind of structural, or what is often referred to as "infrastructural" coherence to a unit of social organization, be it a city or a nation-state or a society. It has usually involved one or another form of system-building, or network-making, by which various component parts, both technical and non-technical, are brought together into a larger coordinated effort.

The interesting questions in relation to contextual knowledge in this sort of engineering revolve around the social sector or domain in which these processes take place and the particular kinds of competence or expertise that are required. In this form of engineering, the task has generally been to transform an idea, plan, design, or vision into material, or artifactual manifestations, and by so doing, help to "fix" a problem or resolve a conflict that has been identified as socially significant. This can be thought of as the social, or professional meaning of engineering.

Even less recognized than the social in relation to the dominant economic meaning is a third ideal-typical meaning of engineering, which can be characterized as cultural, and which represents the ways in which people have cooperated with one another to learn how to deal with the fundamental challenges of human life. This meaning has been given far less attention than the other two, due perhaps to its intrinsic diversity and variety, as well as to what might be called its "situatedness" or particularity; it is hard to aggregate or theorize about these forms of engineering, but they are nonetheless of central importance for many areas of human existence, particularly in relation to education and health care and environmental protection. The interesting questions in relation to engineering contexts revolve around the processes of what might be called collective knowledge-making, or cultural learning, and, more specifically, the capacity to use technologies in beneficial, or appropriate ways. This can be considered the cultural, or human meaning of engineering.

Distinguishing the contextual understanding of engineering in this way draws on many years of teaching science and engineering students at various universities in Scandinavia, most recently at Aalborg University in Denmark.

Contextual Knowledge at Aalborg University

Like many other universities that were created in the 1970s, under the influence of the student movements of the times, Aalborg University has attempted to develop a more "relevant" form of education than was then being offered by the established universities. From the outset, Aalborg University has based all of its undergraduate teaching programs on a combination of problem and project-based learning, with formalized courses playing a subsidiary or supportive role. For the most part, the students are taught their subjects by carrying out semester-long projects in groups, and the task of the teacher is to advise the students, rather than instruct them.

In the science and engineering fields, project work in the first year has included, since the early 1980s, a certain amount of what has come to be referred to as contextual knowledge. The particular way in which this knowledge is taught and included in the student projects varies from field to field, and has also varied from year to year, depending on who is doing the teaching, and, not least, on the relations between the main, scientific/technical advisers, who are responsible for the project work as a whole and the contextual advisers, who, for the most part, come from outside the particular field of study. Most of the contextual advisers have a social scientific and/or humanities education, and there has thus been a wide range of approaches to contextual knowledge that have been presented in the supportive courses that are given, and then put to use in the student projects.

The most common approach to contextual knowledge has been to provide a kind of supplementary, or add-on knowledge, usually aimed at offering the students knowledge of some of the “market” conditions that affect their particular engineering or scientific field. Typically, the lectures and advising focus on managerial issues and “entrepreneurship”, and the project work often involves one or another form of market analysis of the particular technical or scientific product that the students are learning how to design and/or build in their projects.

A second approach that is used in Aalborg provides more of a complementary or extra-curricular knowledge, offering students an opportunity to reflect on the underlying values and paradigmatic assumptions of their scientific-technical field as a way of preparing for their future professional roles. The courses usually offer an introduction to the philosophy and/or sociology of science and technology, presenting the different schools, or positions, as well as some of the methods of analysis that have been developed in science and technology studies. The social construction of technology, or SCOT, approach, as developed by Wiebe Bijker, has been especially popular (cf. Bijker, 1995). In the project work, the students are often encouraged to use these ideas to consider the ways in which scientific and engineering knowledge is produced, or constructed, within their fields.

A third approach, and one that has been used recently in the educational programs in biotechnology, nanotechnology and medialogy, is to connect, as much as possible, the technical-scientific components of the project work to broader contextual issues, and to mix something of the more instrumental ambition of the market-oriented approach with the reflective ambition of the professional approach. In the lectures the students are introduced to the cultural history of science and technology and to some of the public debates that have taken place in relation to science and technology. Students are also introduced to political and ethical issues associated with science and technology, and the contextual advising of their project work is seen as a way for them to learn how they might address and, at best, assess the political, cultural and/or environmental implications of their particular scientific-technical project.

In the following sections, the historiographic story-lines on which these different approaches to contextual knowledge are based will be briefly presented and compared.

The Economic, or Commercial Approach

Since Karl Marx based his influential theory of political economy on the central role of the "means of production" in historical development, it can be suggested that the dominant approach to the history of engineering contexts has focused on the relations between engineering and the economy. This story-line, as it has been developed by historians during the past 150 years, has, to a large extent, been a history of material science-based progress, and, more specifically, emphasized the role of science and engineering in economic growth and development.

It has directed attention primarily to the activities of companies and corporations, since they are generally considered to be the main sites, or contexts, in which market-oriented technological development, or economic innovation takes place. The relevant contextual knowledge in this form of history-writing is almost exclusively economic and managerial.

Although engineering had long been seen as having an economic significance, it was the so-called industrial revolution of the late 18th century and the broader experience of industrialization that stimulated historically-minded analysts to bring that economic significance into their narratives. Karl Marx was the most influential of a new breed of economic historians in the mid-19th century, who focused attention on the role of science and technology in economic life. Trained in philosophy and active in politics, Marx brought to his historical writings an eschatological ambition and an abstract terminology that helped give them an enormous impact both on academic life, as well as in the broader society.

Marx saw in the coming of modern industry and in the use of science and engineering in the economy an epochal shift in human history:

"For the first time, nature becomes purely an object for humankind, purely a matter of utility; ceases to be recognized as a power for itself; and the theoretical discovery of its autonomous laws appears merely as a ruse so as to subjugate it under human needs, whether as an object of consumption or as a means of production". (Marx, 1973/1857, pp.409-410).

The capitalist mode of production, as Marx characterized it, had its material base in the orientation of science and technology to the commercial marketplace. Science and engineering played a fundamental, "revolutionary" role in modern industry: "by means of machinery, chemical processes and other methods, it [modern industry] is continually transforming not only the technical basis of production but also the functions of the worker and the social combinations of the labor process" (Marx, 1976/1867, p.617).

While putting production on a scientific basis, industrialization also created, according to Marx, divisions among workers, and led to a new class of workers "whose occupation it is to look after the whole of the machinery and repair it from time to time, composed of engineers, mechanics, joiners, etc." In Marx's words, "This is a superior class of workers, in part scientifically educated, in part trained in a handicraft; they stand outside the realm of the factory workers…" (Ibid, pp.545-6). Scientists and engineers had been given a fundamental role to play in the economy, but at the same time, they had been forced to give up their independence and apply their knowledge and skills to the requirements of the commercial marketplace, and work alongside the "ruling class" rather than the working class.

Marx's insights into the economic significance of science and engineering, and his contextual understanding of industrial society have been highly influential in shaping the modernist belief in science-based progress, what might be called the dominant discourse of engineering. They became an important part of the political consciousness of those who created social-democratic and communist parties, and they also formed a central part of economic history, as it developed in the late 19th and early 20th centuries as a kind of hybrid academic field combining economics and history.

One of those who helped turn the Marxian insights into a story-line of economic innovation was the Austrian Joseph Schumpeter, who coined the term "creative destruction" that has since provided an underlying narrative trope, or metaphor for science-based industrial development. "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process." he wrote toward the end of his life in *Capitalism, Socialism and Democracy*. And at the core of the evolutionary process that was capitalism was the process of innovation that "incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one" (Schumpeter, 1975/1942, pp.82-83).

Drawing on the work of a Russian economist, Nikolai Kondratiev, Schumpeter developed a model of business cycles, or "long waves", in which the process of innovation played a central role (Freeman and Louca, 2001). Schumpeter's ideas have been formative for the ways in which economists and economic historians have since come to characterize the contexts of science and engineering.

At the beginning of each wave, a cluster of radical innovations – textile machines and the steam engine in the first wave, railway locomotives and the telegraph in the second wave, the telephone, airplane and the automobile in the third wave, atomic energy, synthetic chemicals and the transistor in the fourth wave – help propel a new upswing in industrial expansion as they are spread, or diffused in the economy. New companies and branches of industry, based on the radical innovations, grow up to replace the companies that had come to dominate the previous waves.

This extremely influential story-line can be said to provide a foundational narrative for innovation studies, as it developed in the 1980s as a sub-field in business management and economics. At both macro, micro and meso levels, a historiography of engineering contexts has developed that is based on the story-line of economic innovation.

On the one hand, there have been a number of major, programmatic works, written both by economists and historians, telling the story of industrialization in general, in overarching terms, according to the story-line of innovation. One of the most influential early works was *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*, by David Landes (1969), which placed technological innovation at the center of an ambitious historical narrative. Writing in the context of the 1960s, when more theoretically-minded economists, such as Walt Rostow and John Kenneth Galbraith, were emphasizing the importance of science and engineering in the contemporary economy, Landes rewrote the history of industrialization as a series of technological revolutions.

Rostow and Galbraith were followed in the 1980s by several, more theoretical works of "evolutionary economics", such as *An Evolutionary Theory of Economic Change*, by Richard Nelson and Sheldon Winter (1982) and *Technical Change and Industrial Transformation*, by Giovanni Dosi (1984). At a time when Asian countries were beginning to overtake Western economies in many branches of industry, not least in electronics and communications, the innovation story-line took on political importance, and it was at this time that innovation studies became an established academic field, leading to a second level of historiography, recounting the stories of what might be called the institutions of innovation and the dynamics of what started to be called national systems of innovation.

Christopher Freeman's analysis of the Japanese system of innovation, *Technology Policy and Economic Performance: Lessons from Japan* (Freeman, 1987), was a central text in this regard, pointing to the importance of strong ties, or linkages between companies, government agencies, and universities in Japanese economic development. The idea of a national system of innovation was applied in Denmark, as well, by a group of economists at Aalborg University, who told the story of Danish industrialization as a process of creating an "agricultural-industrial complex" or development block, drawing on particular kinds of engineering activities (Lundvall ed., 1992)

Since then, at an institutional, or meso level of analysis, economists and historians have discussed systems of innovation, both in particular countries, economic branches and fields of science and engineering. There are now departments of innovation studies at many business schools and management departments, and the story-line of innovation has come to provide the dominant way in which engineering contexts are discussed, both in the historical and broader academic literatures.

There is also, of course, a more popular historiography of engineering contexts in the large number of works on particular "success stories" – of products, companies, and individual inventions, that is, at a micro level of analysis.

The ways in which these stories are told, on all three levels, follows a typical pattern, which can be characterized as a form of technological determinism, according to which new, radical innovations – in our day, primarily in information technologies, genetic engineering, the Internet, and nanotechnology – are claimed to be the central factors behind economic growth and development. Engineering in this story-line is seen to be exclusively market-oriented; successful innovations are those that have a major economic impact, and the relevant contexts of engineering are those companies, corporations, business networks, or larger systems of innovation in which markets are found or created for economic innovations in the marketplace. All those forms of engineering that are not market-oriented tend to be neglected or ignored.

The Social, or Professional Approach

While economists and economic historians, and the stories of innovation that they like to tell, tend to dominate both the public understanding, as well as the academic study of engineering contexts, a second significant story-line or narrative approach has emerged within the field of science and technology studies, or STS. The roots of this work can be traced back to some of the early historians of engineering in the 19th century, such as Samuel Smiles, who wrote biographies of the bridge-builders and railway engineers who constructed the industrial society, as well as to social theorists, such as Max Weber, who was one of the first to consider some of the social factors that were involved in the engineering profession.

Weber emphasized the processes of rationalization and bureaucratization that were at work in modern societies, and which had a major influence on engineering, especially perhaps in what are now called infrastructural projects. He also wrote about the underlying values, or norms of behavior in many areas of social life, linking social activity to what he termed an underlying ethical system, or ethos. His famous book, *The Protestant Ethic and the Spirit of Capitalism* (1904) stressed the religious, or moral basis of engineering in the interest in technical improvement that was so much a part of the new forms of Christianity that emerged in the Protestant Reformation of the 16th century.

As with the story-line of innovation, the historiography of construction includes both a macro, or discursive level, at which overarching principles of social structure and organization are discussed (from the "iron cage" or rationalization process of Max Weber to the technological rationality of Herbert Marcuse and the power discourses of Michel Foucault), a micro level, at which particular projects are carried out, and an intermediary, or meso level of "infrastructural" engineering, or large technical systems, as they are sometimes called. The relevant contexts in this form of historiography depend on the level of story-telling, but they tend to be abstract social structures at the macro level, individual actors and networks of individuals at the micro level, and institutions and social organizations at the meso level.

Since the 1980s, the French philosopher and anthropologist Bruno Latour and the Dutch engineer turned sociologist Wiebe Bijker have been among the most active in developing the story-line of construction. Latour has emphasized the ways in which engineers have constructed "actor-networks" that bring together human and "non-human" elements in their various projects. It is, as he has characteristically put it in the title of one his books, a kind of "aramis, or love of technology" that forms a kind of core meaning of engineering work, and the kind of contextual knowledge that he has been so influential in developing has focused on the ways in which this love has been put into practice, not always with positive results.

Wiebe Bijker and the American Thomas Hughes, on the other hand, have provided a number of case studies of key "system-builders" or network-makers, seeking to uncover the ways in which engineers through their professional activities actually go about shaping social institutions and organizations. Hughes has contrasted the "networks of power" that were involved in the development of electricity systems in Europe and the United States (Hughes, 1983), and Bijker has elucidated the social interests and technological frames that were at work in a number of different fields of engineering (Bijker, 1995).

The story-line of construction emphasizes social processes rather than economic ones, and its story-tellers employ a language or vocabulary of sociology and social history to recount their tales of networking, negotiation and mediation. The stories that are told in this form of contextual knowledge are often carried out in bureaucratic organizations and at the interface or meeting place between the worlds of business, government and academic life, or what are increasingly referred to as the contexts of "governance".

The engineer is seen as a professional "actor" involved in the construction of a technologically mediated reality. The expertise or professional competence of engineers is thus not seen as purely technical or scientific; there is also a kind of social competence, or social capital that is necessary and this kind of contextual knowledge is thus seen, as in Aalborg, as an important part of the professional expertise of an engineer.

The Cultural, or Human Approach

While the economic meaning of engineering is by far the most dominant, the social, or professional meanings have become ever more influential in recent years, especially in the arenas of policy-making and government. Both focus on the production of science and technology, and have tended to disregard all of the other forms of engineering that involve what Mikael Hård and I have termed the "cultural appropriation" of technology and science (Hård and Jamison, 2005).

A main source of inspiration for this story-line was the American writer Lewis Mumford, especially his classic work, *Technics and Civilization*, from 1934 and his two-volume *The Myth of the Machine*, written in the 1960s. Mumford was one of the first to discuss the cultural preconditions for modern science and technology, and to explore the long process of cultural preparation prior to the scientific and industrial revolutions. He was also one of the first to discuss the cultural consequences, and, not least, the forms of cultural resistance and opposition to science and technology.

For Mumford, engineering, or what he termed "technics" was driven by two contradictory human, or cultural forces, which he termed democratic and authoritarian. Democratic technics was a shared engineering competence, a use of technology for the common good, and it was, he argued, the basis for many, if not most positive human achievements (Mumford, 1966). Authoritarian engineering, or technics, on the other hand, was the use of science and technology by those in power to oppress or dominate others. Later in his life, he became one of the main critics of the so-called military-industrial complex in the United States which he saw as a new kind of authoritarian engineering, what he termed the megamachine (Jamison and Eyerman, 1994).

More recently, the British cultural historian Raymond Williams has written about the relations between technology and broader processes of cultural transformation in a number of books that have contributed to the creation of the academic field of cultural studies. Williams emphasized how the idea of culture, at least in the British context, had emerged in the 19th century as a "record of our reactions, in thought and feeling, to the changed conditions of our common life… Its basic element is its effort at total qualitative assessment." (Williams, 1958, p.285)

Another influential writer was the literary historian, Leo Marx, who was a pioneer in investigating the artistic and literary representations of science, technology and engineering in his important study, *The Machine in the Garden* from 1964. Marx's student, David Nye, has been one of the most prolific contributors to the story-line of appropriation, in a series of books on the ways in which electricity and other forms of power have been used in different ways by different people. His recent book, *Technol-*

ogy Matters, provides a highly readable introduction to this way of discussing engineering contexts (Nye, 2006).

This third kind of engineering takes place in very different contexts or social locations than the other two, often in what are characterized as social and cultural movements rather than in established or formalized institutions and organizations. Understanding these contexts of engineering brings out the ambivalence, or mixed meanings of science and technology in human history, and the ways in which engineering has often had to be carried out at the "grass-roots" in informal and temporary public spaces, in order to provide alternatives to the dominant approaches.

Historically, these forms of engineering have been a part of broader political struggles, from the religious struggles of the 16th century through the social movements of the 19th and 20th centuries and into the present. The forms of engineering that took place in these movements involved processes of hybridization or creative eclecticism, by which engineering skills and knowledge were combined with others forms of thought and action. One of the founders of interior design, William Morris, was, for example, an active member of socialist organizations, as well as a professional artist and designer. In the anticolonial movements of the early 20th century, especially in India, Western-trained scientists also joined forces with political activists to resurrect traditional forms of engineering, or what are sometimes now called indigenous technology, that became important parts of the liberation struggle. Similarly, in the environmental movements of the 1970s, grass-roots forms of engineering provided "utopian" or radical examples of appropriate technology that have since developed into significant branches of industry (Dickson, 1974).

Particularly influential was how, within the context of the opposition to nuclear power, many professional scientists and engineers joined forces with environmental activists to experiment with alternative forms of energy. In countries like Denmark, as a part of the movement against nuclear energy, an organization for renewable energy was created that provided a space, or cultural context in which people could learn how to build wind energy power plants and solar panels (Jamison *et al.* 1990). Like similar activities in other countries, these forms of grass-roots engineering were a kind of democratic technics, and like other movements today, in organic agriculture, alternative health care, sustainable design and architecture, they open engineering to popular, or public participation.

Conclusions

An understanding of the contexts of engineering should include all three of the ideal-typical forms that I have discussed in this chapter. There is a strong tendency in most programs of science and engineering education to exaggerate the importance of economic, or commercial contexts, as part of a political program of supporting engineering for purposes of economic growth. Even the social and professional contexts are often discussed in market-oriented or business terms, while many of the cultural contexts in which more alternative forms of engineering are carried out are all too often neglected or ignored. There needs to be a much better balance between the different forms of contextual understanding and a much greater appreciation of the value and importance of each of these – and all the other – meanings and functions of engineering.

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Chapter 3

Problematizing the Notion of Social Context of Technology

Peter Kroes & Ibo van de Poel

Abstract: Issues about the relation between technology and its context, especially its social context (society), have been high on the agenda in the philosophy of technology and in STS. One of the bones of contention concerns the main direction of influence between technology and society, with positions ranging from the idea that technology determines its social context ("technological determinism") to the opposite ("social construction/shaping of technology"). A common assumption underlying many if not most positions that have been developed is that it makes sense to make a distinction between technology and its social context. In this chapter this assumption will be questioned. We will discuss first various general meanings of the notions of technology and of context and will briefly explore whether the context of something can always be interpreted as a wider system that contains the thing under consideration as a subsystem. Thereafter we focus on two different interpretations of technology, namely (1) technology as process, and (2) technology as product (as a collection of technical artefacts). We will argue that in both cases a conceptualisation of technology that relegates all social elements to the context is inadequate. Finally, we also argue that the distinction between technology and its social context becomes problematic in the case of socio-technical systems whose functioning depends not only on technical but also on social subsystems.

Key words: Context, Technology as Process, Technology as Product, Dual Nature of Technical Artefacts, Socio-Technical Systems

Introduction: Technology and its Social Context

The background ("context") of this inquiry into the meaning of the notion of social context in relation to technology is the long-standing discussion within the fields of Philosophy of Technology and of Science and Technology Studies (STS) about the interaction between technology and its wider context, in particular the social context (society) in which it is embedded. The main issue at stake is how to interpret the dynamics of technology and society. Is technology the main driving force behind the evolution of society, or is society driving the way technology develops? According to one position, known as "technological determinism", technology as an autonomous force determines the evolution of society (see for instance Winner, 1977). At the opposite position, known as "social construction/shaping of technology", we find the idea that society determines the way technology develops (MacKenzie and Wajcman, 1985; see, for instance Bijker, Hughes, and Pinch, 1989; Bijker and Law, 1992). In between we find positions that there is no dominant driver at all, that technology and society are mutually influencing each other and that the main direction of influence may vary from case to case. According to these positions, the interaction between technology and society has to be interpreted as a form of co-evolution (Rip and Kemp, 1998; Leonard-Barton, 1988; Latour, 1993).

Studying the dynamics of technology and society presupposes that technology and society can be conceptually separated. In this contribution, we will argue that this is often more problematic than assumed. Our aim is to show that technology cannot be separated conceptually from the social world because social processes or phenomena are constitutive (definitive) of technology. So a conceptualisation of technology that relegates all social elements to the context is untenable.

The Notions of Technology and of Context

Before we can proceed any further with analyzing the relation between technology and its context, we have to face up to the ambiguities in the meaning of the key notions "technology" and "context". The notion of technology is used in very different senses. Mitcham (1994), for instance, distinguishes between four different manifestations of technology, namely, technology as object, as knowledge, as activity and as volition. For some of these meanings the idea that technology has a context does not make much sense at first sight (e.g. for the idea of technology as volition). Here we will focus on two meanings of technology for which the notion of context appears to make sense, namely on

1) technology as process (activity): technology as the collection of processes of designing, developing, producing, maintaining and disposing of technical artefacts, and

2) technology as product (object): technology as the collection of technical artefacts, that is, what comes out of technology as a process in so far the latter is restricted to the design, making and maintenance of technical artefacts.

Generally speaking technological processes as well as technological products may be said to have contexts. Note that, when we speak of technology and its context in the following, we are referring to the contexts of individual technological processes or individual technical artefacts, not the contexts of the whole collections of technical processes or artefacts (it is not clear whether the latter notions make sense at all).

The meaning of the notion of context also raises questions. The notion derives from the Latin *contextere* which means "weaving together". In linguistics it refers to the weaving together of words such that the meaning of a word or expression is partly determined by the passage or discourse of which it is part. More generally, the notion of context stands for the "interrelated conditions in which something exists or occurs"[1]. The context of something is its environment, setting or background that contains all elements that are somehow relevant for the thing involved in the sense that they condition its being or occurrence. As in a fabric, the context of an object or event contains everything with which it hangs together and with which it is interrelated. Depending on the nature of the thing involved and the criteria for relevance, a context may contain physical, social or cultural elements or combinations thereof.

A problem that arises with regard to the above account of the notion of context is whether the context of a thing may always be taken to be a broader *system* of which that thing is a part or sub-system. The loose definition of a system as a set of elements with relations between these elements implies that this is the case, since the context of a thing was characterized above as that which contains anything with which it is interrelated. However, the notion of context appears to be a broader concept than that of a larger, encompassing system. Take the example of a power supply system that malfunctions because a crucial element is hit by a meteorite. Surely, the meteorite is an important element from the physical context (environment) of the power supply system; it conditions its being (functioning) to a high degree. But it seems far-fetched to take the power supply system to be a sub-system of an encompassing system that contains at least as elements the power supply system and the meteorite. From the point of view of the functioning of the power supply system, the meteorite is a disturbing factor originating from the "outside", that is the context, of the power supply system. Meteorite and power supply system do not form a system in the sense of an integral whole. From a purely physical point of view, the physical objects involved in the power supply system and the meteorite may be taken to be a physical system (albeit a very short-lived system), just as for instance the solar system. It would be a mistake, however, to treat such a physical system as a system of the same kind as the power supply system, since the latter is a functional system, whereas the former is not. In the following we will assume that the notion of context is broader than that of an encompassing system; so, the context of a thing does not by definition constitute a

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[1] See http://www.merriam-webster.com/dictionary/context, accessed August 15 2008.

system such that that thing may be considered to be, in some relevant way, a subsystem of that system.

The above account of the notion of context of something is based implicitly on a distinction between what belongs to the "inside" of that thing and what belongs to its "outside" or context (environment). For some kinds of objects, such as physical and biological systems, this distinction can (sometimes but not always) be taken in its literal sense as what is inside a spatial boundary and what is outside that boundary. But when it comes to the context of more abstract entities, such as technology, the inside-outside distinction is just a metaphor. It does not refer to a physical or spatial boundary, but rather to a conceptual boundary. What is conceptually definitive (constitutive) for the thing under consideration belongs to its inside and the rest belongs to its outside world. This means that how the thing under consideration is conceptualized is crucial for drawing the distinction between it and its context. The notion of the context of something has a well defined meaning only from a certain perspective, one which determines what kind of conceptualisations are adequate or useful and which ones not. The context of a human being qua biological organism is different from the context of that human being qua social being. The context of a power supply system, qua physical system, is different from the context of that power supply system qua technical system. So, when discussing the context of technology we have to be clear about what kind of entity technology is, that is, how we conceive of technology.

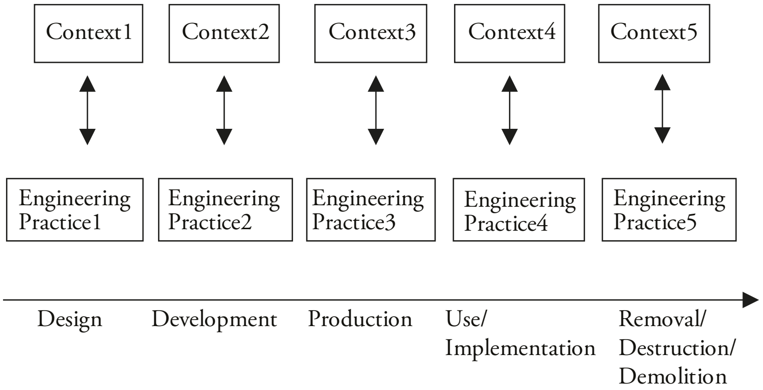
As we remarked above, we will focus in the following on two different interpretations of the notion of technology, namely technology as process and technology as product.

Social Context of Technology as Process

Technology as process may be taken broadly in the sense of all processes, scientific, social, economic, cultural etc., that concern the evolution/development of technology, more in particular processes that concern the creation, production, diffusion, use, maintenance and disposal of (services including) technical artefacts. This notion of technology as process includes by definition social processes (e.g. the diffusion of technical artefacts is in part a social process of adopting the use of those artefacts). In this sense of technology as process our original problem of the relation between technology and its social context loses much of its meaning. Here we will focus on technology as process in a much more narrow sense, namely on the development of new technical artefacts and/or new technical procedures; in other words, technology as a process refers to the changing state of the art of technology. For technology as a process in this more narrow sense it is not so evident that it refers to social processes; for instance, technology development in this sense may be taken to be mainly driven by the development of (advances in) scientific knowledge or considerations of effectiveness and efficiency.

Technology as a process in this narrow sense is intimately related to processes that take place in engineering practices, in particular to processes in engineering research, design and development practices. From a lifecycle perspective, however, engineering practices may also be involved in other phases of technical objects (systems). All these engineering practices are embedded in wider social contexts (see Figure 3.1). So the problem of the relation between technology as a process and its social context may be analysed in terms of the relation between the various engineering practices involved in the life-cycle of a technical artefact or system and the social contexts of these practices. Clearly, this interpretation of technology as a process complicates the problem of the relation or interaction between technology and its social context. Many different engineering practices may be involved in the life cycle of a technical artefact, as well as different social contexts (with, for instance, different stakeholders). There is no reason to assume that the interactions between these various engineering practices and their social contexts will be all of the same kind, that is, that all interactions run primarily from the engineering practices to their social contexts or the other way around.

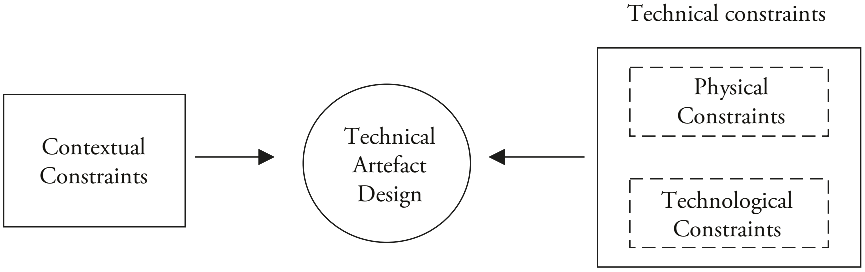
Figure 3.1: A lifecycle view on engineering practices and their contexts



In this interpretation of technology as process the interaction between technology and society may show a variety of forms. It is to be expected that, depending on the case at hand and the phase in the life cycle of a technical artefact one is looking at, different pictures of the interaction between technology and its social context may emerge, ranging from clear cases where technical developments drive social change through cases where there is mutual interaction between the two to cases of social shaping of technology.

Roughly speaking, it may be claimed that technological development takes place between two poles, one of which is defined by what is technologically feasible and the other by what is socially desirable. Tensions between these poles are the main driving forces of technology as a process. A view along these lines has been proposed by Kroes (1996). His analysis of the determinants of technological change focuses on the design phase because, during this phase, the decisions are made that determine the final form of the new technical artefact. The model that he proposes distinguishes between factors that constrain the engineering design of a technical artefact from the outside, called "contextual constraints", and those that constrain the design practice from within, called "technical constraints". The contextual constraints cover a wide range of different kinds of constraints; some of them are derived from the primary function of the artefact to be designed, others are related to safety constraints and constraints about costs, and again others may be related to constraints on resources available to the designing engineers, etc. The technical constraints derive from what is physically possible and what is in a given situation technically feasible (see Figure 3.2).

Figure 3.2: Model of contextual (external) and technical (internal) constraints in design



This model, however, shows serious shortcomings when it comes to the issue of the relation between technology and its social context. It is based on the assumption that the factors that determine the development of technical artefacts in engineering design practice may be neatly distinguished into contextual (social) and technical ones, that is, into external and internal factors. But what is technologically possible (the technological constraints) may depend heavily on social factors (for instance, on decisions to invest in technological research during a design project). It assumes furthermore that in engineering design practices, decisions about properties of the artefact to be designed are made on the basis of some form of technological or, more generally, instrumental rationality which, even in the case of conflicting requirements, dictates how trade-offs are to be made and what the optimal solution is. In other words, the model assumes that technology as a process may not only be separated from the social processes that take place outside of engineering practices, but also from the social processes that take place inside those practices. But as Bucciarelli (1996) has convincingly argued, engineering design practice itself is a social practice, and social processes of negotiation between different participants may impact significantly the outcome of design processes. This means that social processes are endemic to technology as a process as we have interpreted that notion here, and that therefore any meaningful conceptualisation of technology as a process will need to contain social elements.

The same point can be made in another way. We have associated technology as a process closely with processes that take place within engineering (design) practices. So the question whether technology as a process can be separated from social contexts boils down to the question whether engineering practices can be separated from social contexts, in particular in the sense that engineering practices can be shielded off from any social influences. But that seems impossible given that the notion of a practice itself is usually interpreted in terms of social processes. Take, for instance, the following definition of a practice by MacIntyre (1984, p.187):

"By a 'practice' I am going to mean any coherent and complex form of socially established cooperative human activity through which goods internal to that form of activity are realized in the course of trying to achieve those standards of excellence which are appropriate to, and partially definitive of, that form of activity, with the result that human powers to achieve excellence, and human conceptions of the ends and goods involved, are systematically extended."

According to this interpretation, social processes are constitutive for a practice. They play an essential role in practices, and therefore it makes no sense to assume that it is possible to isolate practices from social influences in general. This also applies to engineering practices and thus also to technology if it is interpreted as a process that takes place within engineering practices.

Note that, in MacIntyre's definition, reference is made to "goods internal" to a practice. In addition there are, according to MacIntyre, external goods that are characteristic of the social institutions in which practices are embedded. Such social institutions are, MacIntyre claims, necessary for the survival of practices. Practices in other words are always embedded in some broader social context, at least according to MacIntyre. The same applies, one might assume, for engineering practices.[2]

Where exactly the line between internal and external goods, or more generally, aspects of a practice has to be drawn may be a matter of debate. What our analysis shows, however, is that the distinction between internal and external aspects of engi-

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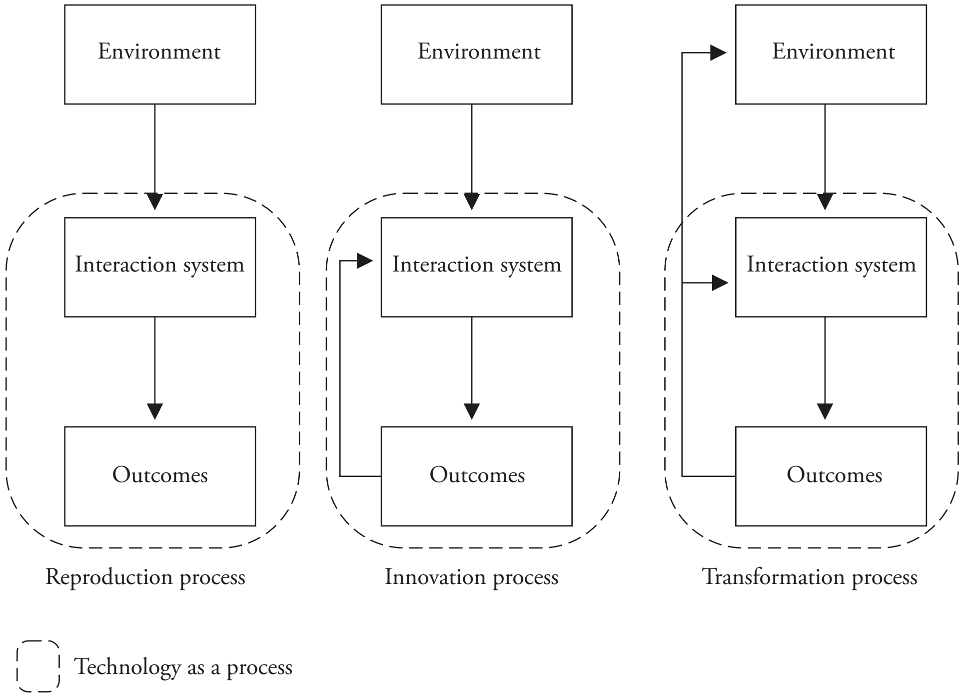
[2] Note that not all practices in Figure 3.1 are practices according to the definition of MacIntyre. Using a nail clipper is according to MacIntyre for example not a practice.

neering practices does not run parallel to technical and social aspects (factors). Social processes are an integral/internal aspect of technology if technology is conceived of as a process in the way proposed here.

Figure 3.3: Types of processes of technological change in relation to technology as a process and its environment (context)



The foregoing means that even if technology is interpreted as a process that is partly social in nature, it still makes sense to distinguish between technology and its wider context. A theory of technological change that illustrates this possibility has been developed by Van de Poel (1998). He distinguishes between the interaction system in which technological development takes place and the wider environment or context of this interaction system. The interaction system is usually characterized by a so-called technological regime, i.e. by a set of rules that are followed by the relevant actors in developing and further improving a technology.

Following Boudon's (1981) conceptualisation of processes of social change, Van de Poel distinguishes between three types of processes of technological change (see Figure 3.3). In reproductive processes, the environment sets the boundary conditions for technology as a process and there is no feedback from the outcomes (among others the technological artefact designed) to either the interaction system or the wider environment: this will result in a reproduction of the technical artefacts designed. In innovation processes, experiences with the technological artefacts designed are fed back to the interaction system leading to improvements and a cumulative pattern of innovation, but without interaction with the wider environment. In transformation processes, the environment does not just provide boundary conditions but becomes part of the dynamics of technological change.

Processes of transformation are especially interesting for our current purpose because in these the boundary between technology as a (social) process and its wider context may become fluid. Transformation processes are characterized by a reaction of the environment to the outcomes of technological development. One might expect such a reaction for example if a technology turns out to be more dangerous than expected (for instance because it uses or contains toxic materials). In some cases, the environment might react by setting new boundary conditions for technology as a process, for example by enacting new legislation. What might also occur is that actors who initially belonged to the environment of the interaction system now become part of it. In Dutch water management, ecologists have for example acquired a role in the design of dikes and barriers, when they were initially outsiders belonging to the context. If such outsiders become part of the interaction system in which technology is developed, this is usually associated with a transformation of the technological regime. Changes in the boundary between technological processes and their wider context may thus trigger technological change. The direction of influence might also point in the other direction. Technological change might "invite" outsiders to become involved, for example because the technological change requires new knowledge in order to arrive at successful designs, knowledge that is unavailable in the current interaction system.

The above account suggests the following conclusions. First, the distinction between internal and external factors of engineering practices does not run parallel to the distinction between technical and social factors. Second, it makes sense to distinguish between technology as a process that is partly social in nature and its wider context. Next, the dynamics of technological change can in some cases be understood in terms of processes in which the context provides boundary conditions but is not part of the dynamics of technological change (innovation processes). Finally, in some more exceptional cases the context can become part of the dynamics of technological change, possibly resulting in a shift in the boundary between technology as a process and the wider context and usually triggering a transformation of the technological regime (transformation processes).

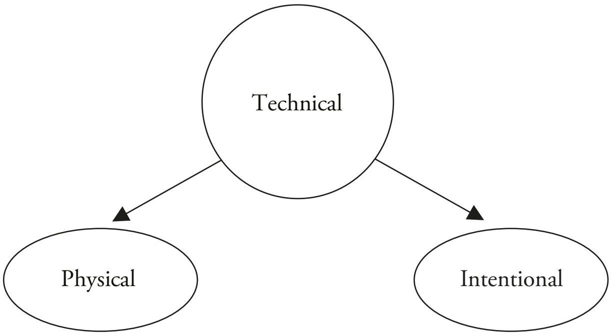
Social Context and Technology as Product

We now turn to technology as product, that is, to technology as a collection of technical artefacts. Is it possible to separate technology in this form conceptually from its social context? At first sight this seems to be no problem. We simply take a technical artefact, such as a nail clipper, and consider it by itself, as a technical artefact, irrespective of what people do with it and of how it affects the behaviour of people and irrespective of how it is embedded in and interacts with social contexts. We may analyse the physical structure of the nail clipper, its overall function and the functions of its parts and how it works, without taking into account any social context. We even may separate the nail clipper conceptually from its physical environment and consider it to be a closed physical system with no interaction with its environment. According to this line of thinking, technology as a product may be taken by itself, independent of any specific context, particularly of its social context. So, for technology as product the assumption that technology may be conceptually separated from any social context makes sense. Or so it seems.

On closer inspection the above line of thinking turns out to be untenable. The reason is that if we take technical artefacts to be physical constructions with a technical (practical) function, a conception of technical artefacts that is more or less standard (explicitly or implicitly) in engineering contexts but also in user contexts, then technical artefacts turn out to have a dual nature (Kroes and Meijers, 2006). If the object referred to as a "nail clipper" is taken to be a physical object, then it may be conceptually separated from its physical (and social) environment. But that object, as a physical object, is not a nail clipper; more generally, it is not a technical artefact. As a physical object it has no technical function and therefore cannot be a technical artefact as defined above. Since we are not interested in that object as a physical object but as a technical artefact, we have to take into consideration also its technical function. If we do so, then it follows, as we will see shortly, that technology as product cannot be conceptualized in a way that involves no social phenomena at all. This illustrates the importance of what was pointed out earlier, namely that the perspective we adopt with regard to an object is crucial for the conception of the context of that object. The context of an object that is considered to be a physical system is different from the context of that "same" object considered as a technical artefact.

The reason why technical artefacts cannot be separated conceptually from social phenomena has to do with the dual nature of technical functions. It is not our intention to go here into the details of theories of technical functions (see, for instance Vermaas and Houkes, 2003), but it may be observed that the functions of technical artefacts are on the one hand related to the physical properties and capacities of artefacts, on the other hand to human intentions. Technical functions cannot be grounded solely in the physical properties or capacities of technical artefacts, since that raises serious problems with regard to malfunctioning technical artefacts. Neither can they be grounded solely in human intentions, for such a theory cannot account for the fact that a given technical artefact cannot perform any arbitrary function. Thus technical functions are grounded in the physical domain (physical capacities) and in the intentional domain (the domain of human action). This means that technical artefacts have a dual nature (see Figure 3.4). The dual nature of technical artefacts implies that technical artefacts cannot be considered in isolation of a context of intentional human action. If we assume that the kind of intentional human action in which the functions of technical artefacts are grounded is of a social nature, then it follows that objects cannot be considered to be technical artefacts without taking into account some social phenomena. This in turn implies that not all social phenomena can be treated as belonging to the context of technical artefacts.

Figure 3.4: The dual nature of technical artefacts



So, independently of whether technology is interpreted as a process or a product, we reach the conclusion that it is not possible to draw a demarcation line with technology on the one side and its social context on the other. The reason is that the definition of technology as a process or a product involves reference to social phenomena. Social phenomena are conceptually definitive of technology (or, in ontological terms, constitutive of technology). Technology, whether it is taken to be a process or a product, is inherently social. This means that the idea of a strict boundary between technology and social phenomena loses its meaning. This conclusion, however, should not be misunderstood. The fact that some social phenomena are definitive (constitutive) of technology, and therefore cannot be relegated to the context of technology, does not mean that this is the case for all social phenomena. If we assume, for instance, that certain social phenomena in the practices of design and/or use, such as collective function assignments, are definitive (constitutive) for a particular technology and are therefore internal to technology, then other social phenomena in those or other practices (such as power relations among participants in design practices) may be taken to be external to technology. As we remarked before, the distinction between internal and external with regard to technology does not run parallel to the distinction between technical and social factors. Our conclusion that it is not possible to draw a boundary between technology and social phenomena only states that it is not possible to treat all social phenomena as belonging to the context of technology, since some social phenomena are definitive or constitutive of technology.

Social Context and Socio-technical Systems

There is yet another reason, apart from the ones discussed already, for reconsidering the fruitfulness of the idea that all social aspects may be treated as belonging to the context of technology, that is, as being external to technology. Consider, for instance, a traffic light at a road crossing; its function is to regulate traffic. The functioning of that traffic light is based not only on the functioning of the technical hardware of the traffic light but also on the behaviour of the road users. Only when these users obey certain rules, such as stopping for a red light, will the traffic light be able to perform its function of coordinating the behaviour of road users at the cross roads in a successful way. In other words, the function of regulating traffic can be performed only by a combination of well-functioning technical hardware and well-functioning "social software". For any technical artefact its operation manual may be considered to be its software. What is special about the case of the traffic light is that the "manual" of the traffic light includes social rules (that may be enforced by law). So if we take the traffic light to be the system of technical hardware together with the rules of how to use that technical hardware in a successful way, then the traffic light may be considered to be a socio-technical system. It is a hybrid system consisting of technical and social elements (for more information about socio-technical systems, see Kroes *et al.* (2006)).

There are many socio-technical systems around. Examples range from traffic lights through civil air transport systems to energy supply systems. These systems have in common that they consist of a combination of technical objects, social objects such as laws and organizations and human beings (usually in the role of operators or regulators). They can perform their function only on condition that apart from the technical hardware the appropriate social infrastructure is in place. The technical and social infrastructures have to match for the whole system to function properly.

Socio-technical systems themselves are usually embedded within wider (social) contexts and the idea that they may interact with these contexts does not raise any specific problems. It is when we look "inside" these socio-technical systems and try to conceptualize the relation between their technical and social subsystems that things start to become more problematic. Is it possible to separate these technical and social subsystems unambiguously? If so, how are we to conceptualize the way these two subsystems interact? May the social subsystem be taken to be the social context of the technical subsystem or the other way around? It is not clear how these questions are to be answered.

An analogy with a computer may be helpful to illustrate some of the problems involved. Surely, the hardware of a computer can be considered independently of the specific software that is installed on it. But does it make sense to consider the software as part of the context of the computer as a piece of hardware, or vice versa, to consider the hardware as part of the context of a piece of software? Both the hardware and the software may be considered to be incomplete technical artefacts: the hardware cannot perform its function without the software and the other way around. Hardware and software together form a complete artefact with a function (or set of functions). Similarly it may be the case that the technical and social subsystems of socio-technical systems are incomplete artefacts and have to be considered together since they form an integral whole just as a computer. Both may be taken to be essential subsystems, and from that perspective it seems rather odd to treat the social subsystem as the context of the technical system. Correspondingly, it may be questioned whether the interaction between the technical and social subsystems of a socio-technical system may be modelled as a form of interaction of technology with its social context.

Conclusion

We have briefly analysed various meanings of the notions of technology and of (social) context. We have argued that, if we conceive of technology as process or as product, technology cannot be separated conceptually from all social contexts. The notion of technology in these two meanings inherently refers to social processes. This means that an assumption underlying a number of models of the interaction between technology and its social context (society), namely that with regard to this interaction all social processes (aspects) may be located in the context of technology, does not make sense. We have also argued that the distinction between technology and its social context is problematic for socio-technical systems.

Finally, a caveat. Our analysis does not warrant the conclusion that it does not make sense to analyse interactions between technology as process or product and specific social contexts (for instance, to study the influence of changing cultural norms and values on technology). Since not all social phenomena are definitive (constitutive) of technology, social phenomena may be taken to be part of the context of technology. This opens the possibility of studying the interaction of technology with its social context in so far as the social phenomena involved are not definitive (constitutive) of technology. That is and remains an interesting field of study. What does not make sense, however, is to consider technology in splendid isolation of all social contexts.

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Chapter 4

Technology and Engineering in Context: Analytical, Phenomenological and Pragmatic Perspectives

Sylvain Lavelle

Abstract: A context should not be viewed as a mere "environment", but rather as a property of the *relation* between the individual and his environment. A context can be a milieu, a culture or a situation shaping the dynamics of technology, the process of which includes the phases of design, production and use of technical artefacts. The integration of context elements in the process of technology is now considered as a legitimate and ordinary claim within the work of engineers (see the "Context-Sensitive Design"). Contextualism is an approach that has developed in most of the domains of philosophy (logic, epistemics, ethics), but which did not result in a "contextual turn" in the philosophy of technics. It is worth comparing the two competing traditions of contemporary philosophy, the analytical and the phenomenological, in order to better understand the assumptions and the implications of a *technical contextualism*. Then, a more pragmatic perspective enables one to elucidate the role of *paradigms* or matrices in technology and engineering, but faces the limits of comparison, discussion and translation of these matrices, as suggested in radical contextualism. Finally, this comparative overview calls for a more questioning approach upon the role of cultural backgrounds which locates at the crossroad of these competing philosophical traditions.

Key words: Contextualism, The Dual Nature of Artefacts, The Triple Nature of Artefacts

Introduction

The question of the context and its role in the process of technology and engineering is both an old issue and a current issue. It is an old issue if one considers engineering to be different from science in that it aims at adapting the technical objects and projects to particular material and social conditions. However, it is also a current issue if one considers the context to be at the core of the contemporary theoretical and practical reflection upon technology, as regards notably the relationship between the structure and the function of technical artefacts. The request upon the internalisation of the context is particularly strong in a time of "globalisation" and "democratisation" of technology which requires the engineers, whether designers or producers, to take into account the peculiar cultures, values and claims of various communities of users. One can take the example of the Context-Sensitive Design (CSD) as defined by the Department of Transportation of an American State: "the art of creating public projects that meet the need of the users, the neighbouring communities, and the environment. It integrates projects into the context or setting in a sensitive manner through careful planning, consideration of different perspectives, and tailoring designs to particular project circumstances". It seems that the integration of the context elements within the process of technology and engineering provides a more open view on the relationship between design, production and use of technical artefacts.

The research on the definition, the structure or the function of the context has developed in the fields of Artificial Intelligence, Cognitive Sciences, Computer Science and Engineering[1]. However, the theoretical and practical stake of scientists and engineers is mainly to work out the context modelling and reasoning in using the formal tools of logic and mathematics. Philosophy as such can be inspired by such studies, though it has a proper stake, namely, to question the relevance of these formal tools as regards the experience and significance of technics for human beings. Philosophy has long addressed the issue of context, now duly identified as an option called *contextualism* (Preyer and Peter, 2005), whether in the field of logic, epistemics or ethics. However, the "contextual turn" in philosophy is less conspicuous in the field of technics despite some eminent and crucial contributions[2]. Thus, if the main streams of contemporary philosophy, the phenomenological and the analytical, have both contributed to a philosophy of technics, they have addressed only partly and recently the issue of the context. This evolution raises the philosophical question of *technical contextualism*, which can be viewed to some extent as a different option to those carried out in the classical opposition of universalism and relativism. Now, within the range of technical agency (design, production and use of technical artefacts), it is advisable to concentrate on *engineering design* insofar as it seeks to anticipate the use context of a technical artefact in elaborating some models of contexts.

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[1] See the international "Context Conferences" 2003-4-5-7.

[2] Annis, "A contextual theory of epistemic justification", 1978; Cohen, "Knowledge and context", 1986; Ihde, *Technology and the Lifeworld,* 1993; Unger "Contextualanalysis in ethics", 1995; Braun, *Technology in Context*, 1998; Barwise and Perry, *Situations and attitudes*, 1999; Böme, *Ethics in Context,* 2001; Jason, "Context and logical form", 2000; Maesschalck, *Normes et contextes*, 2001; Preyer and Peter, *Contextualism in Philosophy*, 2005.

Therefore, the questions raised by the option of technical contextualism are the following: (1) What is a context (milieu, situation, culture) as a factor impacting both technical and social process of technology and engineering? (2) How far can one model or interpret the context elements, and can the representation, the intention and the anticipation by the engineers be sufficient given the variety and the evolution of the use contexts? (3) Can we specify the assumptions and implications of a "contextual turn" within the streams (analytical, phenomenological, pragmatic) of contemporary philosophy of technology and engineering? (4) Is a paradigm (or cultural matrix) as elaborated in the philosophy of science a relevant notion in the philosophy of engineering, and how far can a matrix be commensurable with or translatable into another matrix? (5) What is the role of the cultural frames of reference in the significance of technical artefacts, and are the concepts of Background and Intentionality illuminating for this issue of significance?

Firstly, it is essential to delineate the scope of the methodological options and questions raised by technical contextualism (*Technology, Engineering and Context*). Secondly, it can be illuminating to draw several perspectives on the integration of context by presenting the contributions of three main streams of philosophy (*Analytical, Phenomenological, Pragmatic Perspectives*). Finally, this overall comparative view calls for a more questioning approach on the role of intentionality, background and significance which locates at the crossroads of these competing traditions (*Intentionality, Background and Significance*).

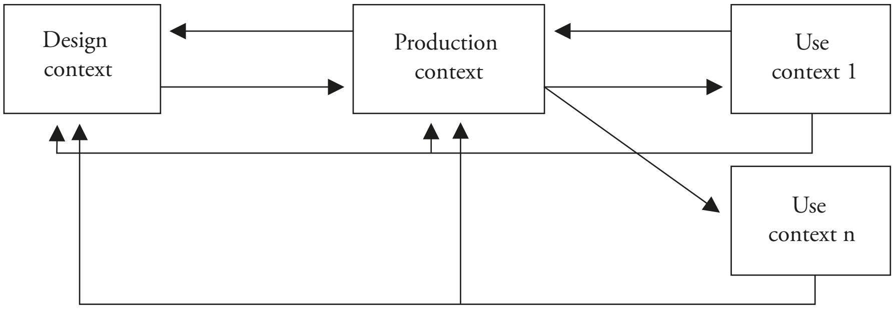
Technology, Engineering and Context

Engineering can be viewed as a core activity of technology characterized by the process of design, production and use of technical artefacts. There are several reasons for the *internalisation of the context* in engineering design: match of offer and demand, adaptation to change, efficiency of the process, assessment of the impacts, integration of social claims, etc. The internalisation of the context in engineering design is often focused on the *use context*, although the notion of context is much broader and more complex than that of use context. Indeed, the *design process* and the *production process* form a context for the users, the *production process* is also a context for the *designers,* and the converse.

In this respect, if almost anything can be a context, the philosopher or the agent reflecting upon the context can experience a sort of "context vertigo". One may say that there is an inscrutability of the context almost in the same way as there is an inscrutability of the reference (Quine) in the philosophy of logic. In fact, *contextualism* in philosophy does not equal *relativism*, which overlaps to some extent with radical contextualism: the integration of some elements of the context in the dynamics of technology, at the different phases of engineering, and especially of engineering design, does not imply, indeed, that all the rules, procedures, norms and values are relative. Anyway, as Verbeek points out,

> *"reality cannot be entirely reduced to interpretations, language games, or contexts… The facts that technological artefacts can be conceived as constructions, always exist in contexts, and are interpreted by human beings in terms of their specific frame of reference do not erase the fact that systematic reflection can be undertaken of the role that these contextual and interpreted constructions play concretely in the experience and behaviour of human beings"* (Verbeek, 2005, p.113).

Figure 4.1: Schematic representation of the context relativity



A *context*, in the broadest sense of the word, can be defined as a temporary or permanent background, be it material, natural, artificial, social or cultural, shaping the modalities (necessity, obligation, possibility…) of human thought, conduct and taste from the point of view of cognition, volition, action, judgement, experience and significance. There are then three basic meanings of the context: (1) context as a *milieu,* (2) context as a *culture* (3) context as a *situation*. Of course, there can be some relations between these three concepts of context: for instance, when Mr. Smith, who has worked for thirty years as an operator in a car industry (*milieu*) and has developed a set of professional abilities (*culture*) has car trouble on a country road and has to repair it by himself (*situation*).

One can identify several types of relations (R) between an activity (A) and a context (C) which is composed of several elements (E). If we take the example of car design in the industry "World Motor", here is the set of strategic contextual elements which might be identified as relevant for a technical project to be implemented:

Relations (R) between an activity (A) and the context (C)	**Example: Elements (E) of the context (C) in the activity (A)**
R1: activity shaped by the context R2: activity shaping the context R3: activity shaping and being shaped by the context R4: context sensitivity R5: strong context sensitivity R6: weak context sensitivity R7: cognitive relation R8: active relation R9: volitional relation R10: judgmental relation R11: experiential relation R12: perceptual relation R13: emotional relation	E1: growing demand for cars E2: increasing cost of oil E3: growing CO_2 pollution in the atmosphere E4: users demanding cleaner and cheaper cars E5: users trusting World Motor company E6: users caring about work conditions within car plants E7: shareholders ready to invest in new car technologies E8: competitors exploring new car technologies (gas, air, …) E9: weak inner financial resources for innovation

The important point is that a context should not be viewed as a mere "environment", but rather as a property of the *relation* between the individual and his environment.

The research on context modelling and reasoning suggests several methodological approaches of the concept of context (Zacarias, Pinto & Tribolet, 2005): (1) *Technological / engineering approach*: a context is (a) the collection of relevant conditions and surrounding (b) that make a situation (c) unique and (d) comprehensible. (2) *Psychological / cognitive approach*: a context is (a) a state of the mind (b) with no clear-cut boundaries (c) consisting of all associatively relevant elements and (d) which is dynamic. (3) *Analytical positive approach*: (a) Context is a form of information: it is something that can be known (b) Context is delineable: what counts as the context elements of an activity can be defined. (c) Context is stable: although the precise elements of a context representation may vary among different activities, they do not vary among instances of the same activity. (d) Context and activity are separable: the activity happens "within" a context, the context describes features of the environment where the activity takes place. (4) *Phenomenological / experiential approach*: (a) Context is a relational property among objects or activities: the issue is not that something is part or not of the context, but that it may be or not contextually relevant to some particular. (b) Context is dynamic: rather than delineating or defining context in advance, the scope of contextual features is defined dynamically. (c) Context is relevant to particular settings, instances of action and particular parties of that action. (d) Context and activity are not separable: context is embedded in activity and arises from it.

One can summarize the main differences between the analytical and the phenomenological approaches as follows:

Analytical approach	**Phenomenological approach**
Form of information	Relational property
Delineable	Dynamic
Stable among the same activity	Relevant to particular actions
Context / activity separable	Context / activity not separable

This diagram concentrates on the main points but remains quite rough if one considers, for instance, that both analytical and phenomenological perspectives provide for some *relational* approaches of the context. It is worth comparing further these two perspectives in order to get a better idea of their contribution to a possible "contextual turn" in the philosophy of technics.

Analytical Perspective

The analytical philosophy of technics is more concerned with the concrete work of engineers than with an ontological interpretation "à la Heidegger" of the phenomenon of technology. Analytical philosophy, and especially that developed by John Searle (Searle, 1997), has no doubt contributed to promote a more "down to earth" philosophy of technics, sometimes termed as an "empirical turn". In this respect, it appears as a relevant ground for the reflection on the structure and the function of technical artefacts (Kroes, 2003; Kroes & Meijers, 2006), even if it remains concerned with the more general question of the relation between man and the world (Searle, 1983). Furthermore, the analytical perspective emphasizes the role of human intentions and anticipation in the design process, as related to some specific social uses, demands, or claims, in paying more and more attention to the issue of the context.

Within the analytic philosophy, Friedrich Rapp appears in retrospect as one of the founding fathers of a more engineering-oriented philosophy of technics. He stated that

> *"the concrete material artefacts, and the procedures by means of which they are brought about and put to use, make up the kernel of modern technology. Without reference to the engineering approach and the processes of research and development derived from it the dynamics of modern technology can hardly be explained.* ***This does not imply that cultural, social, or economic factors are irrelevant. But their concrete influence is always shaped by the state of engineering****"* (Rapp, 1981).

Peter Kroes also suggested that "an artefact acquires its concrete shape during the design process and, therefore, the design process is the appropriate place to study the influence of various factors of change in artefacts" (Kroes, 1996). However, it is necessary to distinguish between (1) an *internalist* model: technology is an autonomous system that develops according to some inner logic or dynamics, (2) an *externalist* (contextualist) model: technological change is determined by contextual constraints such as economic or social factors. It seems that the design process in engineering gathers both internal and external constraints, so that the shaping of technology depends on several factors: the flexibility of the constraints, the kind of technology employed (micro, macro, experience-based), the product or process innovation involved, the kind of artefact, the kind of change, the history of an artefact (the phase in its life cycle), and the way an artefact is embedded in society.

Kroes *et al.* have investigated further according to an analytical method, the role of contextual factors in engineering design (Kroes *et al.*, 2006b). They use an *empirical basis* which gathers several assumptions collected through a dialogue with some experts of engineering design: (1) The combination of the product being designed, the design process, and the design context is important in all cases. (2) Designers change both the characteristics of the product being designed and of the design process. (3) Interactions between designers and stakeholders in the design context are crucial for the design project because of the influence of changes in the design context on decisions about the design process and the product being designed. (4) Design phases are the major structuring principles of design processes in practice and take long periods of time.

A *design situation* is then a combination of the state of the product being designed, the state of the design process, and the state of the design context at that moment. It is a combination of the set of values of all properties describing the product being designed, the set of values of all properties describing the design process and the set of values of all factors that influence the product being designed and its design process. It is then a more encompassing notion than that of *design context*, which is the set of factors influencing the product being designed and the design process at a certain moment.

The analytical approach makes a special effort to term the aspects or components of the engineering process in order to ground the analysis on an accurate and adequate lexicon. For instance: a *product being designed* is the product during the design process; a *property* is a characteristic of the product being designed; a *factor* is an external influence on the characteristics of the product being designed or of the design process. As suggested by the authors,

> *"properties of a design process describe, for example, members and characteristics of a design team, characteristics of a designer, and design aids like methods and computer support. Examples of factors are other processes than the design process in the lifecycle of a product being designed, stakeholders, a company quality handbook, competitors, patents, and the situation of the market".*

A *design relation* is a relation between properties and factors, whereas a *design process* is a finite sequence of design activities necessary to obtain the desired goal, and a *design task* is a task to meet the design goal at that moment, starting from the current design situation. A *design activity* is a transformation towards the design goal at that moment, carried out by a designer, causing a transition of the state of the product being designed or of the design process. In comparison, the *goal of design activity* is the creation of a desired representation of the product being designed having a desired state.

A design situation can be defined as a state, but also as a *state transition* which can evolve over time and be influenced or impacted by external factors of the context:

> *"A design situation can be changed into another design situation by one or more actions. Designers can change the state of the product being designed and of the design process.* ***Stakeholders can change the design context****. Stakeholders are actors in the design context who have an interest in the product being designed or the design process, such as consumers, users, production managers, logistic managers.* ***The design context can also be changed by interactions between designers and stakeholders****".*

The interaction with other communities suggests that the activity of engineering design is open to the influence of non technical factors.

The problem in the analytical perspective on technology and engineering is the emphasis on the possibility of *modelling the context* and especially the relation between the external factors and the internal process[3]. Thus, the reflective assessment of a design situation in the analytical perspective developed by Kroes *et al.* is made quite formal because of the option on modelling. Yet, it seems that the conditions of

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[3] "To further increase the usefulness of (the) model for supporting communication between designers (from several disciplines) and for supporting interaction between designers and stakeholders in the design context, the descriptive model must be refined and extended. A major extension is *the explicit modelling of the designers and stakeholders and their characteristics as individuals and as groups*" (Kroes *et al.*, 2006b)

possibility for dialogue between designers or between designers and stakeholders require more subtle an analysis than that which the formal operation of modelling can offer ever. Indeed, the modelling of the context equals an analytical reduction of the context elements likewise precluding any attempt to remain faithful to the complexity and the uncertainty of human behaviour, communication and interpretation. The analytical perspective, at least in this attempt to model the context elements, does not really tackle the possible *experiential or cultural gap* between the designers and the stakeholders.

It can be illuminating to present the contribution of another tradition, that of the phenomenological philosophy, at least to ensure that it can offer a relevant perspective on the relationship between the various communities and cultures involved in the technological process.

Phenomenological Perspective

The phenomenological philosophy of technics has long been dominated by the thought of Martin Heiddegger (Heidegger, 1993) and his epigones, such as Albert Borgmann (Borgmann, 1987), or, to a lesser extent, Jacques Ellul (Ellul, 1956). But this now classical thought is questioned by an inner development of phenomenology which can be called a "post-phenomenology" as regards its distance to Heiddegger and its reference to Husserl or Merleau-Ponty. Don Ihde as a leader of this stream within the phenomenology of technics is also one of the philosophers who addressed quite directly the issue of context in technology and engineering (Ihde, 1990).

For Ihde, human beings are unthinkable apart from a relation to the world which they continually experience and in which they realize their own existence. In the classical phenomenology of Husserl, the concept of *intentionality* designates the relation to the world which is grounded in and characterized by the consciousness of the individual. But, as stated by Ihde, the relation to the world can be mediated by things, objects or artefacts, so that the latter are not neutral "intermediaries" between humans and the world, but some genuine "mediators"[4]. The technical mediation between humans and the world is not an intrinsic property of the artefact itself, but a property of the relation between humans, technology and the world. The general intentionality relation in Ihde's can be expressed as follows, through a condensed

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[4] Here lies the later-developed critical idea of co-shaping (Verbeek, 2005) suggesting that the subject and the object constitute each other and that the environment with which they are involved codetermines in which ways they can be present to the world and each other. For instance, a train coshapes the way in which a landscape is present to human beings; a telephone coshapes the way human beings relate to each other.

formulation: *Human-Technology-World*. There are several possible variations of this general intentionality relation: embodiment, hermeneutic, alterity and background relations.

(1) Variant A (*embodiment relations*): (Human-Technology) → World
e.g.: wearing glasses

(2) Variant B (*hermeneutic relations*): Human (Technology-World)
e.g.: reading a thermometer

(3) Variant C (*alterity relations*): Human → Technology-(-World)
e.g.: operating a machine

(4) Variant D (*background relations*): Human (-Technology / World)
e.g.: automatic thermostats

Technology is no doubt a *cultural instrument* as shown by the operation of technology transfer from a cultural context to some other cultural contexts. Thus, the transfer of technology shows that the context of signification of a technical artefact may differ relative to the type of practice in the recipient culture. One can identify a double set of contextual involvements: on the one hand, the involvement of the artefact within its immediate use context ("The artefact is what it is in relation to that context"); on the other hand, the juxtaposition of a larger cultural context ("The artefact is what it is in relation to this cultural field"). Moreover, technology is characterized by a phenomenon of *multistability* which refers to the polymorphy of perception, like in the Necker cube, the form of which can change according to a *Gestalt* shift in the perception of the object. Then, the multistability of objects can be observed at the sensory level (*micro-perception*) as well as at the cultural level (*macro-perception*).

In fact, the multistability of technical artefacts, in allowing a major role to the context, limits the importance of the designer's intentions in the design process:

"*The designer's intentions play only a small part of the subsequent history of the artefact. It was, after all, Nobel's intention in the invention of dynamite that it be used for mining and the benefit of humanity. Design, in the history of technology, usually falls into the background of a multiplicity of uses, few of which were intended at the outset. At an even deeper level, this multiplicity of uses reveals a… phenomenological clue that must be followed.* ***There is no "things-in-itself". There are only things in contexts, and contexts are multiple***" (Ihde, 1990, p.69).

This (post-) phenomenological account of the context role is an acute critique of any philosophical attempt to foster the designers' intentions and anticipations of the contexts of use[5]. Now, one can ask whether the multistability can be itself limited by the growing stability of the uses of artefacts within a community of users:

"*the multistability of things makes it difficult to anticipate the eventual character of the mediation, and thus to explicitly anticipate it in the design process. But this anticipation is not impossible… Wherever conventions are already in place concerning particular objects, some stability has arisen in the multistability. Within design theory, extensive attention has been paid to such 'stability', with constant research into the habitual use of particular products and into the degree to which particular products forms are in fact used for an intended end… Thus the existence of multistability…need not to hamper designers in explicitly trying to anticipate the mediating role of products in their use context*" (Verbeek, 2005, p.217).

In the process of technology transfer, there is a variety of cultural responses to technologies carried by foreign sources to indigenous groups:

(1) *Traditional ("mono") cultures:* they are overwhelmed by the incoming group.
(2) *Selective cultures*: they make compromise adaptations and select technologies to be taken into the indigenous culture.
(3) *Resisting cultures*: they can resist most elements of the incoming group´s technologies.
(4) *Adoptive cultures*: they adopt what is new from the incoming group and modify themselves according to that group's cultural shape.

In fact, technology shapes the lifeworld of individuals to the point that it can create a new culture which Ihde terms *pluriculture*, in order to distinguish it from multiculture. Pluriculturality is a curvature of the contemporary lifeworld arising out of the use of image technology catching up to cultures and, as a post-modern form, is characterized by a proliferation of ways of seeing (the *Compound Eye*).

Now, beyond the notion of pluriculture, the remaining question of the phenomenological perspective – and to some extent, of the analytical perspective – upon the context is that of *interculture*. More precisely, if (1) the core issue of a contextual philosophy of technics is the reversible relation between design, production and use

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[5] This critique targets more or less directly the analytical approaches of the context grounded in a *functional-intentional* account, as distinct from a *structural-physical* account of technical artefacts, and which would result in a *predictive* or at least an *adaptive* modelling of the users' behaviour (see Kroes and Meijers, 2006).

of technical artefacts, and if (2) this relation implies that there can be a dialogue between communities provided with heterogeneous cultural matrices, from the most "technically-shaped" cultural matrices to the most "socially-shaped" cultural matrices, then (3) one must examine the possibility of comparison, discussion and translation between these heterogeneous cultural matrices.

Pragmatic Perspective

The pragmatic perspective on technology originates with John Dewey, but the philosophy of Nelson Goodman also brought some illuminating insights into the frames of reference (Goodman, 1978). The pragmatic perspective is perhaps best illustrated by the work of Thomas Kuhn in the philosophy of science, which addresses more directly the problem of translation of matrices (Kuhn, 1996). It is worth examining whether the concept of *paradigm* (or cultural matrix) elaborated by Kuhn can be a relevant concept for a pragmatic philosophy of technics.

The commensurability of frames of reference or cultural matrices is an acute problem in technology, as compared to science, in that it requires designers and producers to integrate context elements picked out of wider a community and a culture than their own[6]. The problem lies in the option of *radical contextualism*, as opposed to moderate contextualism, stating that the contexts, and especially the *cultural backgrounds* shaping the technical and the social matrices, cannot give rise to comparison, discussion or translation.

Kuhn proposed the concept of *paradigm* (or frame of reference) to designate the "disciplinary matrix" framing and supporting the normal evolutions of science (*normal science*). Kuhn defines a paradigm as: (a) *what* is to be observed and scrutinized (b) the kind of *questions* that are supposed to be asked and probed for answers in relation to this subject (c) *how* these questions are to be structured (d) *how* the results of scientific investigations should be interpreted. In this respect, the ordinary work of a scientist in the normal science is an activity of "puzzle-solving" which nevertheless remains effected within the scope and the frame fixed more or less implicitly by a paradigm. As a comparison, the anomalies popping up in a domain of science entails a *paradigm shift* which is an indicator of a scientific revolution (*revolutionary science*).

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[6] As Bocong Li (2008) suggests, "the structure of engineering communities is quite different from that of scientific communities. *Engineering communities are heterogeneous*. The latter comprise only one kind of members, namely scientists, while the former consists mostly of four kinds of members: engineers, investors, managers and workers. In addition to the above-mentioned members, *engineering communities include other stakeholders*".

One can distinguish two phases in Kuhn's philosophy that can be termed *Kuhn (1)* as opposed to *Kuhn (2)*. Kuhn (1) defended the option of the incommensurability of paradigms and therefore the *impossibility of translation* (alike "living in another world"). The incommensurability of paradigms concerned the theoretical contents, the world ontologies as well as the physical meanings. Kuhn (2) shifted to the option of the commensurability of paradigms entailing a *possibility of translation* (like "learning a new language"). This evolution of Kuhn from incommensurability to commensurability is important if one wants to apply the notion of paradigm from science to engineering. This evolution is especially important if we take a technical matrix to be in fact a *socio-technical matrix* which combines and aggregates heterogeneous forms of knowledge, beliefs, capacities, habits, values and norms: on the one hand, those of the community of engineers, designers and producers and, on the other hand, those of the community of users, consumers and citizens.

It appears that the relation of science and technique is quite complex in Kuhn's account of the dynamics of science. On the one hand, technique is both recognised and externalised: it is everywhere (device, experiment, invention), it is integrated into the work of science and it can even solve the problem of the incommensurability of theories. But, on the other hand, technique is not essential and remains external to the dynamics of science, like the discovery context as opposed to the justification context in logical empiricism (Hottois, 2004). It seems essential to characterize the dynamics of technics in identifying the proper criteria of an engineering matrix as opposed to a scientific matrix. One can mention some attempts in the philosophy of technics aimed at transferring the notion of matrix from science to engineering (Hendricks *et al.*, 2000)[7]. The differences between the structure of a matrix in the field of science and the structure of a matrix in the field of engineering are the following (next page):

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[7] For Hendricks *et al.*, for instance, "puzzle-solving in engineering and applied science resembles puzzle-solving in pure science, though with qualification… Puzzle-solving in engineering science is of two types. Like in pure science in establishing understanding of specific problems, providing parameters, etc. Here the aim is practical usefulness but often not related directly to methods for solving specific practical problems. Secondly, it involves first the development of methods for solving some problem and second includes assessment of the particular developed methods …usability, optimization, stability, etc… The dynamics and development of an engineering matrix is substantially externalistic and may stem from either: (1) new theoretical discoveries either adopted from pure science or the engineering science itself (2) practical challenges while constructing new artefacts (3) possibilities linked to new tools", Hendricks *et al.* (2000)

	Science	**Engineering**
Delimitation of objects	Idealized, isolated objects Causal mechanism	Real entities and artefacts
Epistemic and ontological	Essential	Adopted from pure science
Theory structure	Hierarchical structure of nomological systems. Mainly mono-paradigm	Theory adapted to problems. Poly-paradigm. Eclectical use of theory
Methods	Derived from theory	Methods more fundamental than theory
Values	Explicit justification Truth is important	Implicit justification *Efficiency and practical usefulness*. Pragmatic

However, in this account of the engineering process, society is both recognised and externalised: the matrices remain quite internal to the technical community and are not focused enough on the *variety of social contexts* and *matrices*. Therefore, the questions are the following: How far is the "social matrix" "internalized" into the "technical matrix"? On the basis of which criteria and rules (see "efficiency and practical usefulness")? How can two matrices be compared, discussed and translated? To what extent? For example, in some European countries like France, a public debate is legally compulsory for big scale technological projects (e.g.: electric plant, highway construction). It is now a usual part of the normal technology and engineering process, although it was a kind of cultural revolution in the practice of engineers. Consequently, one can state that it is one thing to compare an engineering matrix with a scientific matrix; it is another thing to compare an engineering matrix with another engineering matrix; it is still another thing to compare an engineering matrix with a *social matrix*.

It might be said that the possibility of inter-cultural translation of cultural matrices for the purpose of discussion or negotiation can be the task of an *inter-cultural engineering*. This specific branch or development of the engineering education and profession would be dedicated to the integration of contextual elements in the design and production of technical artefacts. But this intercultural translation at certain level requires a form of *acculturation* which does not result solely in a method. It also requires an experience of life and a rather subtle and diverse comprehension and "acceptance" of human thought, conduct and taste. In this respect, the intercultural stance cannot be merely an *engineering method* enabling one to optimise a process: it is also a hazardous apprenticeship as well as an existential experience of the relativity, and consequently, of the communicability of cultures.

One can identify two different problems of *inter-cultural translation (translatability)* for discussion to operate between heterogeneous cultural communities or members of these communities: (1) a cultural translatability between different communities of engineers and other experts who do not share the same matrix, but who form a culturally "coherent" community of researchers, designers and producers. (2) a cultural translatability between, on the one hand, different communities of researchers, designers and producers and, on the other hand, different communities of users, consumers and citizens not sharing the same matrix. In general, the intercultural translation implies a form of acculturation as a means of overcoming the problem of incommensurability of cultural matrices (for instance, between Western and Eastern cultures). But, in fact, there are several *levels of acculturation* as shown by the example of somebody (for instance, a Westerner) experiencing a different culture (for instance, an Eastern culture):

Level 1 (weak / superficial): "I enjoyed my business trip to India".
Level 2 (middle / balanced): "I discussed a lot with a guru in India".
Level 3 (strong / radical): "I have spent thirty years in India, learnt Hindi and become a yogi".

The inter-cultural stance can oscillate between several levels of inter-culture and does not equal merely learning a new language (Kuhn): it is also experiencing another life form (Wittgenstein) or another lifeworld (Husserl), creating sometimes a genuine *cultural shock*. It implies in other words a transformation or at least a comprehension or an intuition of the *Backgroun*d (Searle) or the *Habitus* (Bourdieu) which regulates the daily thought, conduct and taste of individuals and communities.

Intentionality, Background and Significance

The notion of *intention* is often referred to in the analytical as well as in the phenomenological perspective for the analysis of the relationship between the structure and the function of a technical artefact[8]. I would like to suggest that the notion of *Intentionality* and the correlative notion of *Background* are also of major importance, especially concerning the significance of technical artefacts.

The significance, as distinguished from the function and the structure, derives from the *Intentionality* (belief, desire, pleasure, etc. and not only the *intention* in the usual sense) of human beings. However, for Searle, the intentionality is rooted in a pre-intentional *Background* which refers to the implicit or unconscious psycho-physical structure of an individual's mind. In the classical phenomenology of Husserl, the concept of *intentionality* designates the relation to the world which is grounded in and characterized by the consciousness of the individual. As for the post-phenomenology of Ihde, it suggests that intentionality can be transformed through a technical mediation consistent with several possible intentionality variations (embodiment, hermeneutic, alterity and background relations). Now, for Searle, it is not necessary for the intentionality to be a conscious state of mind, and all the less for the pre-intentionality (Background) which is stated as a condition for intentionality[9].

The notion of *Background* in Searle's account, which is quite close to that of *Habitus* in Bourdieu's (Gebauer, 2000), is particularly interesting for a reflection on the conditions or pre-conditions for discussion and translation to be effective:

> "*The background is 'pre-intentional' in the sense that though not a form or forms of Intentionality, it is nonetheless a pre-condition or a set of pre-conditions of intentionality… The Background is a set of nonrepresentational mental capacities that enable all representations to take place… In order that I can have the intentional states that I do I must have certain kinds of know-how: I must know how things are and I must know how to do things… The pre-intentional stance I take towards oranges (how things are) allows for a completely different range of possibilities (how to do things) from that which I take toward rocks or cars… The world is relevant to my Background only because of my interaction with the world*" (Searle, 1983).

The notions of Intentionality and Background as applied to a philosophy of technics suggest that the analysis of the relationship between the structure and the function of an artefact can preclude the problem of the significance. Yet, a technical artefact can be analysed from several perspectives, namely the *physical* (structure), the *telic* (function) and the *hermeneutical* (significance). The integration of the significances

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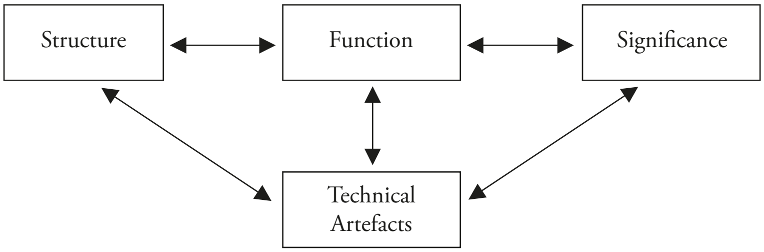
[8] See for instance Peter Kroes (2006a): "Any account of the coherence of the structural and functional description of technical artefacts must involve reference to their intentional feature".

[9] The comparative study of the analytical and the phenomenological perspectives on intentionality was achieved by Jocelyn Benoist (2005) in *Les limites de l'intentionalité. Recherches phénoménologiques et analytiques*.

of technical artefacts requires one to pay more attention to the cultural matrices of interpretation (the "hermeneutical" matrices). In this respect, the hypothesis of the *dual nature of technical artefacts* (structure and function) could be enlarged or enriched by the hypothesis of the *triple nature of technical artefacts* (structure, function and *significance*)[10]:

Figure 4.2: The triple nature of technical artefacts



For instance, the sentimental attachment of a person to a thing (Verbeek, 2005, 223) is a criterion of significance, and not only a criterion of function, which has to be integrated in the contextual assessment and related to the structural-functional analysis.

The important point as far as cultural matrices are concerned is that a discussion requiring a translation between culturally heterogeneous partners can turn out to be effective in enabling an agreement. However, at the individual level, in Searles's account, it might be that a "background shift" ("pre-intentional" stance) is necessary to modify the "foreground stance" ("intentional" behaviour)[11]. At this stage, one can identify two options: (1) *Consequential Option*: the background shift of an individual or a community is a *consequence* of a discussion and a translation between, for instance, the experts and the stakeholders; (2) *Conditional Option*: the background shift of an individual or a community is a *condition* for a discussion and a translation between, for instance, the experts and the stakeholders. It is not easy to demonstrate that (2) is always necessary, but it is quite easy to demonstrate that (1) is not always sufficient. Indeed, there are many cases in which the use of language for discussion or translation between two heterogeneous communities provided with conflicting cultural matrices is not sufficient to provoke a background shift for some or all of the

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[10] The research programme on *The dual nature of technical artefacts* is led by the *Centre for Ethics and Technology* in Delft. Peter Kroes would certainly agree that this research programme could now be enlarged and maybe renamed as *The triple nature of technical artefacts*...

[11] This is the counterpart of the community's level, in Kuhn's language, implying that a "paradigm shift" is necessary to modify the "normal science".

members and then to perform an agreement. However, one can hardly state that the Conditional Option (2) is always valid while the Consequential Option (1) never is: it is a contingent matter whether the use of language (for instance, the use of arguments) can produce a Background shift in an individual's mind.

Let us consider an example in order to explore the limits of comparison, discussion and translation between an expert "technical" background and an ordinary "social" background: *the construction of a highway in a natural zone*. Let us imagine that Mr. Jones is a chief engineer in charge of achieving the preparatory design study for a highway construction including several possible options. Most of the options can be discussed with some local stakeholders, namely, the association "Flower Power", led by Mr. Smith, gathering thousands of opponents to the project. However, though for the engineers the construction of a highway in a natural zone is the single possible option, this construction is simply unacceptable for the opponents. This situation is typically a case for blockage in which two cultural matrices (let us call them the "developmental" matrix on the one side and the "environmental" on the other side) collides without any possible compromise. What will be the possibilities of comparison, discussion and translation between the two matrices, the "technical-developmental" and the "social-environmental"? How far can the community of engineers (Community 1) integrate some context elements issued by a community of users (Community 2) in order to modify their technical project?

If, for instance, the engineers agree not to construct a highway within a natural zone, whereas it is their job and their wish to do so, this implies that they can change a key element of their intentionality and their background. What will be the factors of change in their mind, if we distinguish a rational change (at the conscious level) from a pre-rational change (at the intentional and pre-intentional level)? (1) *Rational Change*: (a) "Flower Power is a very powerful association, with a lot of resources and supports". (b) "The conflict will last a very long time and cost a lot of money, and we just can't afford it". (c) "If we impose our option in using means of constraint, the work on the field will be nearly impossible" (d) "This local failure should not impact my career". (2) *Pre-rational Change*: (e) "The protection of the butterflies and the marmots is after all as meaningful as the construction of highways" (f) "This is a just cause not to be despised by the engineers" (g) "I really admire those people, I would like to be one of them" (h) "I don't care any more about my career".

In this case, it seems that the question is not to *modify* a technical project in order to integrate some contextual claims. It is rather to *renounce* (or not) the technical project on the ground that the major contextual claim is to have it withdrawn. Therefore, one of the two communities has to renounce a basic "intentional" attitude (belief, desire, expectation, valuation, etc.) taking place within a "pre-intentional" background without compromising with the other. This is an example of the limits of discussion and translation between two heterogeneous communities showing that discussion and translation is not merely a *cognitive* problem (knowledge, comprehension) but also a *volitionary* problem (will, acceptance), and furthermore, an intentional and pre-intentional problem (belief, desire, background capacities and judgments). It appears that the possibility of a synthesis between structural and functional features depends upon a change in the intentional stance (*Intentionality*) of the individuals. The former itself depends upon a change in the pre-intentional stance (*Background*) as a condition for a change in the intentional stance. These intentional and pre-intentional changes have something to do with the issue of *significance* of technical objects or projects, in addition to that of function and structure.

Conclusion

The approaches of the context in the philosophy of technology and engineering display several conceptual options: intention, structure, function, norm for the *analytical perspective*; intentionality, co-shaping, multistability, and pluriculture for the (post-) *phenomenological perspective*. As for the *pragmatic perspective*, it is more concerned with the issue of comparison, discussion and translation of matrices, through the concepts of paradigm, inter-culture, acculturation. The important point is that, in spite of their divergences, they are all *relational* approaches in their own way (activity-context relation, humans-world relation, matrix-community relation).

One can summarize the kind of dilemmas that an engineer or any other professional, including philosophers, would face in trying to internalize some context elements within a technical project:

(1) *Representation / Interpretation*: Is not the representation of the context already an interpretation of it? On which basis (formal tools, cultural background, thought and life habits, etc.) can this interpretation be made?

(2) *Selection / Relevance*: Is the selection of relevant elements of the context a neutral operation which can be modelled only by the engineers? Can the relevance of the context elements to be selected depend solely upon the engineers' analysis, or can it be co-framed with the users through deliberative and participatory devices?

(3) *Translation / Adaptation*: How far can the engineers translate the factors of the context being selected into some physical properties of an artefact? Is there not a limit to the adaptation of the design process to the dynamics of the context?

The main point is that the effort toward coherence between the structure and the function of a technical artefact must internalise some contextual elements of *significance*. The request upon significance in a contextual philosophy of technics implies that the dualist account of technical artefacts in terms of structure and function is enlarged in order to integrate some hermeneutic and existential insights. If not, it might be that the efforts toward comparison, discussion and translation of cultural matrices between members of heterogeneous communities remain hopeless. At least, for people who hate conflicts…

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Section 2

Engineering Education in Context

Introduction

John Heywood

The common thread that binds the chapters of section 2 is that of "change" in its several dimensions. This is not surprising for the tussle between the constant need to adapt and the desire for a steady state and security is continuous. All the time we adapt to a flow of continuing small changes and out there are change agents who endeavour to change us to their ideas. Recent educational research has shown that while it is easy for them to bring about small change their endeavours to bring about large change often meet with little success or the changes brought about do not last. Research suggests that the reason why large change so very often fails is that the change agent uses procedures for small change (1st Level) that are inappropriate to bring about big change (2nd Level). A former chairman of Rank-Xerox asked: "can we teach ourselves to change?" An answer to this question is required if the writers of these chapters are correct. On the one hand, they establish an argument for major change (Louis L. Bucciarelli, Denis McGrath, Eugene Coyle in "Engineering Education in the US and the EU" and William Grimson, Michael Dyrenfurth, Mike Murphy in "Liberal Studies in Engineering and Technology") and, on the other hand, they list many impediments to change (Steen Hyldgaard Christensen & Erik Ernø-Kjølhede in "Implementing Liberal Education in Engineering Studies in Denmark" and Jon A. Leydens & Juan C. Lucena in "Knowledge Valuation in Humanitarian Engineering Education"). They consider both macro-change (obtaining to a system) and micro-change that obtains to an institution or a section of an institution. The failure of changes over a long period of time to achieve a desired goal, in this case increasing student diversity in courses, is considered by Jane Grimson and Caroline Rougheen in "Diversity in Engineering".

The comprehensive aim expressed by W. Grimson *et al.* is that the challenges to be faced by engineering education in the 21st century will require a different kind of education. On completion of their education engineers will find that they can no longer hope to focus on the development of new technologies. "They must act as mediators between science and the world they live in." The humanitarian engineering programme (HE) and projects described by Jon Leydens and Juan Lucena in "Knowledge Valuation in Humanitarian Engineering Education", and by Carl Mitcham and David Muñoz in "The Humanitarian Context", illustrate this mediation and the impediments that innovators face when they want to implement such courses. These chapters show that, if engineers are to help the developing nations, they have to learn how the communities they wish to help perceive their own needs. This applies equally to our own societies and the problems they face. Such understanding can only be acquired from a more general education in the humanities and social sciences. This view is taken by W. Grimson *et al.* in Chapter 8 where it is supported by arguments offered by those working in the humanities and social sciences in the area of technology. Support is also found in the argument offered by leading engineers and industrialists who draw attention to the fact that "on both sides of the Atlantic, engineers and technology professionals are under-represented at the highest levels of governmental and policy decision-making." It is as if engineers are seen as technicians who serve the system and are there to be controlled, so if they do not change that will continue to be the case.

The change required is of the second order and will, therefore, be exceedingly difficult to accomplish unless it is imposed by Governments, and even then it is not accomplished without considerable difficulty as the case study by Christensen & Ernø-Kjølhede shows. Implicit in the writings of Bucciarelli *et al.* and W. Grimson *et al.* and their colleagues is the notion that compulsory attendance at liberal studies courses, as is the case in many American courses, has not worked. Evidently they have not bridged the "two cultures." One reason that applies on both sides of the Atlantic is that engineering teachers often have little time for liberal studies so they acquire low status in student minds. Similarly, many students see little relevance to them as judged by their stereotype of an engineer. So on the one hand, there is the need to make the idea plausible to the engineering education fraternity (Christensen & Ernø-Kjølhede, and Leydens & Lucena) and, on the other hand, there is a problem of curriculum design (W. Grimson *et al.*).

Plausibility and identity are closely related concepts. Ideas that challenge our identity may not seem to be plausible, yet at the root of all "change" is the search by individuals and institutions for "identity." As it develops at work self-reliance grows and career salience deepens. Challenges to identity have to overcome the security and self-reliance gained from working in a group of like-minded individuals. How we come to be socialised into that group is of extreme importance and, in this case, the socialisation into teaching is different to the socialisation into engineering in industry and the identities that develop with them are likely to differ. Even the curriculum can affect our identity as is illustrated by Leydens & Lucena in Chapter 7 where it is reported that some students thought the organisation of the curriculum into disciplines was an impediment to their learning, and the investigators suggested that this might prevent them from realising their identity. But who are these students and how are they distributed in engineering courses? Are they, for example, students with different learning styles to the majority of engineering students? Is there an issue of gender?

If there are a large number of them, does this mean that departments should offer an alternative programme?

Associated with our identities are the attitudes, beliefs and values we hold. Change involves shifts in attitudes and beliefs and the larger the change, the more it is likely to be resisted. We bring our identities to the institutions in which we work and the professional associations with which we associate. Through these organisations we search for status and seek protection. The chapters show that by far the most important academic identity that has to be attacked, if change is to be brought about, is that of the engineering scientist. Leydens & Lucena report that in terms of the values ascribed to knowledge the highest valuations were ascribed to the disciplines of engineering science that are taught by Engineering Problem Solving (quantitative) methods. While this dominance of engineering science is also seen to be a problem in the chapters of Bucciarelli and W. Grimson, the slant that is placed on it by Leydens & Lucena is of considerable interest even though it is seen in terms of graduate participation in community service projects. It is argued that three years of solving single solution problems in undergraduate courses induces in them a problem-solving set that is inimical to open-ended problem-solving (set mechanisation). Problems that have to be solved in communities are often complex, open-ended and require information from areas of knowledge other than engineering. The fact that some commentators consider that liberal studies is "one means of equipping students with the "tools" of critical thinking" (W. Grimson) should surely be of concern to those who teach the engineering science disciplines. Surely part of their role is to enable students to acquire skills in synthesis, evaluation and judgement. This is as much a problem of curriculum design as it is for other areas.

The high value placed on engineering science is itself an issue. Ratings of the type of research that it engenders give a department its prestige. In consequence contributions to engineering design, other studies, and teaching do not receive the attention they deserve from administrators. The point is made that because "high tech" is valued over "low tech", this has consequences for higher education. This is because "low tech" and skill in design are the dimensions of engineering that are most likely to help people in developing communities (Leydens & Lucena), a point further illustrated by Mitcham & Muñoz.

Shades of this stereotype of the academic engineer can be seen in the vignettes of academic engineer attitudes to the approach to liberal study adopted by the Danish government as described by Christensen & Ernø-Kjølhede. Following a UNESCO declaration in 1999 that science curricula should include the study of science ethics and the history and philosophy of science, the Danish government in 2000 set down ten aims for philosophy of science courses that were to be implemented in all the institutions teaching engineering. Little in the way of guidance was given. The implementation was left to the universities and there was a great deal of variance in the responses of these institutions. The four universities offer practice-oriented programmes in parallel with academic programmes whereas the three non-university institutions offer only practice-oriented programmes. Because the practice-oriented programmes have taken much longer to implement, a qualitative inquiry among engineering staff in one of the institutions was undertaken to study the problems of implementation at the institutional level.

A striking feature of the chapter by Christensen & Ernø-Kjølhede is the seven sketches that describe the attitudes and beliefs of academic engineers in practice-oriented courses to the incorporation of the philosophy of science/liberal education into engineering courses. For example the "no need" type might argue "that the engineer we educate is supposed to work in a company. He should be able to put things together and make them work. He is not supposed to question philosophically what he is doing and why he is doing it." These profiles show the difficulty of establishing plausibility in centre-periphery or command models of curriculum development where policy makers lay down what should happen, as for example with school curricula. Lack of guidance in this case could be perceived to be a positive advantage for it does provide scope for ownership of developments that might take place. There are models of curriculum change for schools that could assist development in the circumstances of light imposition in higher education. The basis of plausibility is need and the need of central edicts for curriculum leadership and expertise, that expertise to include an understanding of how change might be brought about. The danger is that the light touch might lead to "tinkering" with the problem (see example of another type of legislated reform described by J. Grimson & C. Rougheen).

Christensen & Ernø-Kjølhede conclude that: "philosophy of science / liberal education is not yet a well established concept in the minds of engineering faculty members at our Institute." Having listed the ambiguities inherent in the imposition they find that the Danish executive order has many similarities with ABET 2000. They conclude that courses in the philosophy of science have to be related to "the engineering mode of working and thinking and the context in which engineering work takes place." So they attempt to define the philosophy of science in terms of the skills and competencies that meet both official requirements and the wishes of engineering faculty members as deduced from their data analysis. The domains in which the abilities are located are Research methodology, philosophy of science, international, interdisciplinary and inter-professional collaboration and ethical reasoning. They argue that competency (ability) based approach as opposed to a content approach gives greater flexibility in curriculum design. They would find support for this approach from the pioneers of competency (ability) based liberal arts programmes at Alverno College in Milwaukee. Their curriculum has eight domain ability groups, i.e. communication, analytic capability, problem-solving, making value judgements and decisions, social interaction, responsibility for the environment, awareness and understanding of the world in which the individual lives, aesthetic responsiveness to the arts. In curricula of this type, equal weighting is given to the domains and each subject contributes to their development. There are, therefore, no status differentials at work.

The primary concern of W. Grimson *et al.* is with leadership by engineers and the contribution that the liberal arts can make to the development of the qualities of leadership. It is argued, like Christensen and Ernø-Kjølhede, that there are "aspects of liberal education that should be applied for purposes which are external to it. Through such application the engineering student develops critical reasoning, discourse and contextual skills." For the purist this smacks of general, not liberal, education and perhaps that is an approach to the broadening of studies that ought to be taken. All of us require a general education irrespective of whether we work in the humanities, social sciences or technology. Liberal education is a philosophical disposition arrived at through reflection on "what have I become?", not on "what have I achieved?", it is about the person whereas the liberal studies advocated in these chapters are about the engineer.

Wordplay is important and arguments about general education may be more telling than liberal education. Moreover they might be gathered together under the title of leadership and management studies. They argue the case for the inclusion of philosophy and the history of science and technology as part of the engineers" general education (not the only part) because they give a "broad vision of what it means to be a professional." The dimensions of the history of engineering education, as set out in the chapters by Christensen & Ernø-Kjølhede and W. Grimson *et al.,* should help a student to understand how the factors that have created his identity and that of the profession have come about. Moreover, from the perspective on "change" that it gives, it should help both teachers and students understand what facilitates "change" and what does not. The principles, not the context, are transferable to any situation.

The two reasons for the inclusion of the study of philosophy given by W. Grimson *et al.* are:

> *"First, much of western philosophy is about coming to terms with, in the simplest language, who we are, how we see the world, and how it all fits together. Wittgenstein used the metaphor of philosophy being about unravelling knots which when resolved become science or established knowledge. Considering that the greatest minds over many centuries have devoted their lives to philosophical matter, it would be strange if general insight had not been created. Second, whether by choice or due to the innate nature of philosophy, the insight gained and the 'tools of the trade' that evolved are extremely, if not completely general."*

While embracing several of the aims of the course suggested, Christensen & Ernø-Kjølhede describe a completely different approach to the teaching of philosophy. Evidently many approaches are possible under the same banner. However their conclusions draw attention to the Association of American Colleges and Universities 2005 report on "*Liberal Education America's Promise"* which heralds a change in perspective from an education for an elite "to one that is a necessity for all (and this includes engineers and engineering technologists)." That report includes seven principles with which they concur. They include "such worthy ideals as teaching the arts of inquiry and innovation, engaging in the "big" questions, fostering civic perspectives, connecting knowledge with choices and action, recognizing intercultural and diverse aspects of society, and all conducted within an ethical framework."

If the authors are right in their assumptions about the need for a revamped approach to liberal studies in the engineering curriculum, the issue then is: how do they and the relevant authorities persuade their colleagues to change direction? There is a formidable literature on bringing about change in the curriculum but it is not mentioned here. Although the chapter by J. Grimson & C. Rougheen falls outside the main run of the liberal studies theme that pervades the other chapters, it is nevertheless about second level change. It is about increasing the number of females in academic engineering posts especially at the top level and it recounts the measures that have been taken so far. Four points are of interest. First they argue that diversity is essential for creativity and innovation – which are at the heart of engineering. It is not too far to stretch a point to argue that the same is true of the engineering curriculum. The EPS model described by Leydens & Lucena will simply not release creativity whereas the projects described by Mitcham & Muñoz do. The danger of taught lecture courses in philosophy is that they will not either. To convince colleagues that their programmes are limited, there is a need to replicate the small-scale investigations that have evaluated the outcomes of such courses and show how they limit skill development. But also to explain how research has shown that different approaches to teaching and curriculum design can widen the scope of what is achievable. While it is recognised that the curriculum and its design are complex (W. Grimson *et al.*) there is little other recognition of the impact that the modes of teaching and assessment have on learning. For this reason there is a need for university teacher training and the development of a cadre of curriculum and instructional leaders. It is odd that such activities are a matter of considerable debate at pre-university educational stages but are to a very large extent absent within the university setting. Second, that legislating for things to happen is to "tinker" with the system. There is no guarantee that the intentions will be obtained. Third, a number of approaches need to be taken to find a solution. There is no one solution to these problems but the participants need to pursue common goals. Finally, second level change begins with the recognition that the culture (attitudes & values) has to change. For this reason understanding the cultural history is essential. These chapters make it clear that engineering education is at a crossroads: which direction will it take?

Chapter 5

Engineering Education in the US and the EU

Louis L. Bucciarelli, Eugene Coyle & Denis McGrath

Abstract: Systems for the education of engineers in the US and the EU differ in significant ways. In this chapter we describe and reflect upon differences in accreditation policies and procedures, curriculum structure and content, admissions criteria and student mobility. Within the US there is a surprising uniformity among both private and public university programmes in engineering education, due in large part to the acceptance of ABET's (Accreditation Board for Engineering and Technology) authority in setting standards for curriculum content. Within the EU there is greater programme variety, although some degree of harmonization is in progress resulting from the adoption of the Bologna Declaration. We describe and analyze current efforts in Europe aimed at establishing a pan-EU authority for accreditation – the EUR-ACE Framework. One topic in curriculum structure draws our attention – the perceived value of liberal studies in engineering and the potential for significant reform of the engineering curriculum in this regard. Criteria for admission to university study in engineering differ among the different members of the EU. In the US, criteria are more or less the same whether the student applies to MIT or the University of Michigan. Understanding these differences is essential if transatlantic cooperation in higher (and vocational) education is to be achieved as is the intent of a new EU-US programme – The Atlantis Programme (2006-2013).

Key words: Programme Accreditation, ABET, Bologna Declaration, EUR-ACE, Atlantis

Engineering Education in the EU

A brief history

The first moves towards the formal education of engineers began with the establishment in France of the *École des Ponts et Chaussées* in 1747. Students were essentially state employees, their professors "savants" and engineers of the "corps". Much of their learning was based on actual engineering projects. Their summers were spent in "stages". As outlined by Dooge, at the time of the French Revolution, the standards of this school were markedly raised and to the present day it is one of the leading grandes Écoles in France (Dooge, 2006). The *École des Mines*, established in 1783, another grande école, emphasized the sciences; practical training was again via stages in the field. In 1794, Monge was instrumental in setting up the *École de Travaux Publics* which the next year was replaced by the *École Polytechnique*, a school dedicated to providing a high intellectual and scientific formation to its students through a curriculum of prescribed courses showing a strong mathematical bias. Entrance was highly competitive via a common examination – on the order of 100 students were admitted. This remains the case today.

The *École Centrale des Arts et Manufactures* (1829), offered an education more inclined toward industrial practice – stages again a requirement – and the content of its courses were a bit less abstract. We shall see how these French institutions provided a model for early engineering education in the US. All of them were established to be independent of the nation's university system. Their main concern, according to Wickenden, was "...only with preparing a limited "corps d'élite" of bureau chiefs and directors of industry while the training of subalterns was largely neglected" (Wickenden, 1929).

The more ordinary citizen was not totally neglected: The *Conservatoire des Arts et Métiers*, established like the École Polytechnique by an act of the Convention in 1794, had other aims than the grandes écoles. Its purpose was to spread technical knowledge among the less well educated – ordinary workers and the like. Its collection of technological objects and museum presentations of science provided materials for the explanation of their usefullness to those in industry, arts and crafts (Sebestik, 1986).

In Britain in 1812, a special Royal Engineering School was set up at Chatham as a result of the experience in the Peninsular War that revealed the importance to the outcome of the war, of fortifications. As early as 1796, some lectures on the principles of engineering were given in the University of Cambridge. But for most of the 18th, and well into the 19th century, the education and training of those responsible for the building of bridges and railroads, the improvement of the engines and machinery of the industrial revolution, were schooled by a system of apprenticeship and through "pupilage". The aspiring engineer studied as an intern with a mentor, an already established and practicing engineer. Their internship lasted for three or four years and might cost on the order of 1000 pounds-that's what Brunel charged (Buchanan, 1986).

In 1841 the first professor of Civil Engineering, Irish-born Charles Vignoles was appointed in the University of London (Dooge, 2006). It was only in the latter half of the 19th century that engineering was seen as based on the sciences and programmes developed out of the pursuit of science in institutions of higher learning. Those who worked toward this end found it a challenging task: "The obstacle against which they had to contend was not so much the pupilage system as an attitude of distrust toward scientific methods. The pioneer professors ...were sometimes referred to in mild contempt as 'hypothetical engineers'" (Wickenden, 1929). It was the practical that was of interest. Sir Benjamin Baker, a president of the Institute of Civil Engineers, in 1895 warned "...technical education is of little value unless accompanied by practical experience, sound judgement, and bold initiative, which rather than book knowledge, characterized the famous members of this institution in the past".

In Ireland, the first Professor of the Practice of Engineering, John MacNeill, was appointed in Trinity College, Dublin in 1842 (Dooge, 2006). Engineering education in Italy commenced when, in 1786, a note from the royal imperial assembly of government decreed that "those that want to practice the profession of Engineer or Architect must study in the University of Pavia" (Erba, 2005).

In the UK, by the end of the nineteenth century the Institution of Civil Engineers was setting its own examinations for the qualified membership grade of the Institution. The other institutions soon followed suit. It was, therefore, possible for a person to obtain professional membership without a University degree. Indeed University degree programmes had to be recognised for exemption from the institutions' examinations so the institutions' examinations were the bench mark for standards even though few persons sat the examination. This was primarily because there was an alternative route in the publicly financed state technical college sector. In 1921 the Ministry of Education established a system of national certificates and diplomas to "enable capable and ambitious young workers to break through into the higher ranks of industry". They would enable students in technical colleges to undertake work of a high standard, they would provide technical colleges with a flexible system of examining, and provide industry with a well trained body of technicians and professional men. The scheme was administered by the Ministry together with the relevant professional institution so the institutions were involved in examining in this system.

This route supplied more engineers than the universities in between the two world wars and in the post-war period into the late nineteen sixties. In 1957, only a third of those admitted to professional membership of the engineering institutions possessed university degrees; the remainder had alternative equivalent qualifications (Payne, 1960).

The National Certificates were replaced by a three tiered system of examinations. These provided qualifications for "Engineering Technician", "Incorporated Engineer", and "Chartered Engineer". They are administered by the City and Guilds of London Institute on behalf of the Engineering Council UK (ECUK). This Council regulates the profession in the UK through 36 engineering institutions. They are licensed to place suitably qualified applicants on the ECUK register of engineers which is protected by Royal Charter. The alternative route to professional qualification remains an important to this day.

The University of Karlsruhe was formed as a Polytechnische Schule (polytechnical school) in October 1825, having as an example the École Polytechnique in Paris. As such, it was the first Technical University or Technische Hochschule (TH) in Germany. However, the Technical University of Freiberg originated in a mining academy in 1765 (University of Karlsruhe, 2008).

Curriculum Structure and Requirements

The duration and structure of engineering programmes in continental Europe are based on a relatively long programme of studies of four to five years in duration and firmly grounded in mathematics and the sciences. In France, for example, students wishing to pursue a degree in engineering must complete two years (or three) in "classes préparatoires" before gaining entry into a three year degree ("licence") programme at one of the Grandes Écoles. A further requirement in Germany, Austria and Switzerland was the integration into the curriculum of a period of approximately 12 months in practice in industry, together with project work in the research units of universities. A "stage" in industry or R&D laboratory is also a requirement of many engineering schools in France.

We take as an example, that of the École Centrale de Nantes (École Centrale de Nantes, 2008) – which leads to the award of a "Diplôme d' ingénieur certifié CTI", a programme of three years duration. Admission can be by several different routes but the great majority (over 80%) take the "concours central supélec", an examination given nation-wide, originally established for those seeking entry to the École Supérieur d' Électricité". Two hundred and sixty five (265) places at Nantes are reserved for students who, in competition with their peers, take this examination.

As is the case for all Grandes Écoles, students spend the two years intervening between when the student has completed his or her studies (and examinations) for the BAC, what in the US would be called a high school diploma, in "classes préparatoires" – an intense period of study at a 'lycée'" in mathematics and physics (roughly 75% of the time), philosophy, foreign languages, and, via electives, study in engineering science, chemistry, and computer science.

The students follow a common programme the first two years of the three year programme at Nantes. In the first three semesters the students study mathematics and the fundamental sciences, the engineering sciences (e.g. mechanics of continuous and discrete media, thermofluids, signals and systems, instrumentation, vibrations), industrial management, and continue their language learning. In the fourth semester, students have some elective freedom and can begin to specialize. In their third year they choose both an "option disciplinaire" (systems engineering, IT, industrial product and system development, materials, simulation in mechanics, civil and environmental engineering, hydrodynamics and ocean engineering, energy) and an "option professionnelle" (Finance, Entrepreneurship, Industrial design, Marketing and innovation, Project management, Quality, R and D, Sustainable cities and services,. Students are also required to do a summer "stage" in industry and a "Travail de Fin d' Études". The latter requires a research and development stint in an industrial laboratory, a research laboratory, or in an international laboratory.

Students may choose to continue at Nantes and obtain a master's degree in, for example, applied mechanics, automation and production systems, science and technology of the urban environment. There are other degree programmes leading to other degrees, including double degree programmes in management and engineering, architecture and engineering. The École Centrale de Nantes has structured its programmes so as to accommodate foreign students, in line with the Bologna recommendations.

In the UK, which included Ireland until 1921, the programmes were originally generally of three years duration. The structure in the UK has evolved into a four-year Master degree programme or a three-year Bachelor degree leading to a one-year Master programme, as the educational standard for the professional engineer.

We take as an example, the course in Mechanical Engineering at the University of Manchester where a student may work toward a 3 year BEng degree or a 4 year MEng degree. There are options for students of management, and for others aiming to study abroad.

To be admitted to the University, an applicant must have studied at least three A-level subjects, including Mathematics and a science (Physics preferred but Chemistry, Biology or Engineering Science also acceptable), and received grades of A, B, and B upon examination. Students choose their A-level subjects upon passing the General Certificate of Secondary Education (GCSE) exams in a number of subjects usually by the age of 16. Two years of A-level study, for many at a "sixth form college", culminate with examination usually by the age of 18. There is a special Bachelor's programme "Engineering with a Foundation Year" (4 or 5 years) which includes a year of preparation for students who have backgrounds different from the norm, e.g., older students, applicants lacking in the prerequisite A-levels. Total undergraduate population at the university is between 25 and 30 thousand – the biggest single-site university in the UK. Tuition and fees for a citizen of the UK or the EU is on the order of £3,000 sterling. A non-European (foreign) student pays about three times that amount.

The curriculum includes a common first year of study for students in the School of Mechanical, Aerospace, and Civil Engineering. Students together study mechanics, thermo-fluids, materials, mechatronics, communications, design and mathematics. The school highlights its innovative teaching method called Enquiry Based Learning (EBL) – "In this environment you will work in small groups, supported by a member of staff, to analyse and solve a wide range of problems and challenges. You will need to think creatively, carry out personal research and work as a team." (MACE, 2008).

In the second year, students not only continue on in the engineering sciences but spend time in engineering design, in professional studies and in management. The course literature stresses an "innovative application-driven environment". In the third year, the student can specialize in their choice of courses – machine tools, management, manufacturing, materials, processes, mathematics, micro-mechanics, modelling & simulation, plant monitoring, power plant, environment, and others. They also must engage in an individual project under the guidance of a member of the academic staff.

In Ireland, a four-year Bachelor degree has been in place for nearly 50 years. Taught Master degree programmes have been offered for over a decade (from the mid-nineteen nineties) at several universities, including Dublin City University, Dublin Institute of Technology, Trinity College Dublin and the University of Limerick. In 2004 the first Master degree programme, based on a 3+2 (Bologna) structure commenced. Further Master degree programmes commenced in 2006 and it is expected that this structure will become the norm within the next five years.

The total formation of the professional or Chartered Engineer in the UK and Ireland is deemed to require, in addition to completion of an accredited engineering degree programme, a number (normally a minimum of four) of years working in industry, developing a range of professional engineering competencies which are then tested through a professional review process.

The Bologna Declaration

In June 1999 the Bologna Declaration (Bologna, 1999) was published. To date it has been signed by 45 national governments. Its overall objective is the establishment of a European area of higher education in which student mobility would be facilitated and enabled. A further objective was to increase the international competitiveness of the European system of higher education in attracting overseas students. The section of the Declaration relevant to accreditation is that which states that higher education in Europe should be structured in two main cycles where access to the second cycle shall require successful completion of first cycle studies, lasting a minimum of three years. The degree awarded after the first cycle "shall also be relevant to the European labour market as an appropriate level of qualification. The second cycle should lead to the master and/or doctorate degree as in many European countries."

Shortly after the publication of the Bologna Declaration, the main European consortia involved with engineering education began to discuss the implications of the two-cycle degree structure. The Declaration is being widely interpreted and applied so that a significantly large majority of universities and colleges are applying the new structure to their engineering programmes. However, there has been little dialogue between national governments on the different ways of interpreting and implementing the policies contained within the Bologna Declaration in their home education systems. This has given rise to difficulties in some European countries where changes to engineering education structures lie within the remit of the relevant ministry of education. In certain cases, questions about new structures and funding of these new structures remain open.

The position of the European engineering community is best described in the CESAER/SEFI Communication "Engineering Education and Research and the Bologna Process – On the Road to Bergen 2005" (Bologna, 1999).

> 2. *Bachelor/Master Studies in Science and Engineering*
> 2.1. *The 3+2 model has become a standard reference in engineering. This should not exclude other possible paths towards the second-level degree as an integrated 5 years curriculum or a 4+2 scheme or a 4+1 model.*
> 2.2. *Engineering needs at least two types of first-level degrees, each with clearly defined aims and objectives. First cycle degrees should be a gateway to a wide choice of second cycle programmes. The receiving institutions have the freedom to define criteria and procedures for the selection of students for the second level degree courses.*

Typically, the new structure accommodates two different career paths. First, three-year programme leading to a Bachelor degree in *engineering science*, the primary purpose of which is preparation for a two-year programme in engineering (science) leading to the degree of Master of Engineering, in any European university. The Bachelor degree is generally deemed a "mobility hub" rather than a qualification for immediate use in the work place. It should be noted that in some countries there are internal disagreements between universities, accreditation agencies and industry on whether or not such Bachelor degree graduates are employable in engineering roles. Second, three-year programme leading to a Bachelor degree in *engineering technology* leading to immediate employment as an engineering technologist. Normally, universities offering 2-year Master degrees in engineering will require such Bachelor degree in engineering technology graduates to successfully complete a programme of additional studies before admitting them to the Master degree programme[1].

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[1] In Germany, Universities of Applied Science offer two-year Master degree programmes tailored to enable such Bachelor degree graduates to be admitted directly to a Master degree without a requirement for any additional studies.

Accreditation institutional development

Quality assurance of engineering education in most European countries is carried out on a faculty or university-wide basis, sometimes on the basis of state legislation. In the UK it is carried out under licence from the Engineering Council, by professional bodies such as the Institution of Engineering and Technology, and in Ireland by Engineers Ireland (EI) under "The Institution of Civil Engineers of Ireland". The Charter Amendment Act of 1969 empowered Engineers Ireland to establish the standard required to become a Chartered Engineer in Ireland. Regions, Divisions and Societies within EI include all of the primary engineering disciplines, including electrical and electronic, mechanical and manufacturing, chemical and process, civil, agriculture and food, biomedical, energy and environment, ICT, road and transport and health and safety.

The need to accredit programmes is a relatively recent development in Europe. In France, although the Commission des Titres d'Ingénieurs (CTI) was established in 1934, it was not until 2007 that this organization developed policies and procedures to carry out programme-based accreditation of engineering education. In Germany, the Fachakkreditierungsagentur für Studiengänge der Ingenieurwissenschaften, der Informatik, der Naturwissenschaften und der Mathematik e.V. (ASIIN) was authorized to carry out accreditation of programmes in engineering, science and mathematics by the German Accreditation Council in 2002. The Russian Association for Engineering Education (RAEE) through its Accreditation Centre has accrediting engineering education programmes commencing in 1992. The Portuguese Order of Engineers (Ordem dos Engenheiros) became involved in programme-based accreditation in 2008.

For a number of years, the European engineering community, primarily under the auspices of the Fédération Européenne d'Associations Nationales d'Ingénieurs (FEANI) has been considering the possibility of developing an instrument to enable the mutual recognition of professional engineering degree programmes which would operate in a manner similar to the Washington Accord:

"The Washington Accord, signed in 1989, is an international agreement among bodies responsible for accrediting engineering degree programmes. It recognizes the substantial equivalency of programmes accredited by those bodies and recommends that graduates of programmes accredited by any of the signatory bodies be recognized by the other bodies as having met the academic requirements for entry to the practice of engineering." (Washington Accord, 1989)

The objective is that standards would be set, which accreditation agencies would have to meet, if they were to be included under the scheme. Under the auspices of FEANI, a group of individuals representing European engineering professional bodies was brought together to form the European Standing Observatory for the Education of Professional Engineers (ESOEPE). ESOEPE submitted a proposal to set up the European Accredited Engineer (EUR-ACE) project with the objectives of

- ensuring consistency between existing national engineering accreditation systems,
- establishing a European "quality label" for accredited programmes,
- assisting with the establishment of accreditation in European countries where it does not as yet exist, thus improving the quality of engineering education, facilitating trans-national recognition and ultimately the mobility of graduate engineers.

In September 2004, the European Commission supported the EUR-ACE project with funding of 0.5 million euros. The partners in the project were made up of six European engineering associations/networks and eight national associations active in accreditation of engineering programmes. The six associations/networks were FEANI (contracting partner), SEFI, CESAER, EUROCADRES, ENQHEEI, UNIFI/GREE and CLAIU-EU. The eight national associations active in accreditation were ASIIN (Germany), CTI (France), EC(UK), Engineers Ireland, COPI (Italy), OE (Portugal), UAICR (Romania) and RAEE (Russia).

On 7th October 2005, most of the EUR-ACE partners, together with a number of new engineering associations, decided to establish ENAEE as a "Not-for-Profit International Association" under Belgian law. The founding members adopted statutes on 8th February 2006. ESOEPE dissolved itself on 30th March 2006. Article S5 of the statutes cites the purposes of ENAEE in general as -

"to build confidence in systems of accreditation of engineering degree programmes within Europe and to promote the implementation of accreditation practice for engineering education systems in Europe....in particular....participating in the creation and ultimately the administration of a European accreditation framework for engineering education programmes" (translated from French).

Funding was secured from the EU for the initial establishment of ENAEE. In future, ENAEE will need to be self-funding on the basis of incoming fees where the fees will be paid by accreditation agencies seeking the authorisation to disseminate the EUR-ACE label.

At a General Assembly meeting held in Brussels on 30th March 2006, an Administrative Council was elected. It was also decided that the EUR-ACE acronym should be used to describe the quality mark to be known as the "EUR-ACE Label". The "EUR-ACE Label Committee" has responsibility for establishing policies and procedures whereby accreditation agencies in Europe will be authorised to add the EUR-ACE label to their accreditations.

Accreditation process, criteria, and guidelines

The criteria used by EUR-ACE in the project were:

- Accreditation would be the result of a process certifying the suitability of an engineering programme as an entry route to the profession.
- Would involve periodic assessment against accepted standards.
- Would involve peer review of written and oral information by trained and independent panels, including academics and professionals.
- Accreditation will be only of each engineering programme and not of a department or university.
- Accreditation will be only of the engineering programme and not of the full formation of the registered professional engineer.

The EUR-ACE partners completed the project in October 2005. In implementing the project a series of meetings were held in Brussels and other European cities. The EUR-ACE partners published a set of documents at a workshop hosted by the European Commission on 31st March 2006. The documents included a framework of standards for the accreditation of engineering programmes (with template and commentary); a proposal for the organization and management of the EUR-ACE Accreditation System; a financial plan; an overview of accreditation procedures and criteria; and a report on trial accreditations: *these are available at www.enaee.eu.*

The first of these documents established accreditation criteria for first cycle (Bachelor) and second cycle (Master) degree programmes in line with the Bologna Declaration. An agency that employed these established criteria – and deemed to have done so after the fact – would be authorised to attach the EUR-ACE "label" as a quality mark on all its accreditation decisions. Thus, the graduates of all engineering degree programmes with the EUR-ACE label would be, at some future date, recognised by all other accreditation agencies authorised to issue the EUR-ACE label, in a similar modus operandi to the Washington Accord.

Engineering programme outcomes were grouped under the following six headings:

- Knowledge and Understanding
- Engineering Analysis
- Engineering Design
- Investigations
- Engineering Practice
- Transferable Skills

All six headings are used for both first and second cycle programmes though there are significant differences in the requirements at the two levels, particularly in relation to the first three headings. Students entering an accredited second cycle programme will normally have graduated from first cycle programmes but universities should provide opportunities for students with a similar engineering qualification, though not accredited, to be admitted to the second cycle programme.

Guidelines are also provided on how an engineering programme for accreditation should be described. These include,

- Programme educational objectives consistent with the mission of the higher education institution and the needs of all interested parties (such as students, industry, engineering associations, etc.) and programme outcomes consistent with the programme education objectives and the programme outcomes for accreditation;
- A curriculum and related processes which ensure achievement of the programme outcomes;
- Academic and support staff, facilities, financial resources and cooperation agreements with industry, research institutions and other Higher Education Institutions adequate to accomplish the programme outcomes;
- Appropriate forms of assessment which attest the achievement of the programme outcomes;
- A management system able to ensure the systematic achievement of the programme outcomes and the continual improvement of the programme.

Further guidelines have been published on actions to follow the outcome of the accreditation process, the decision and the agenda to be followed on the visit to the college.

Engineering Education in the US

While the urge to change engineering education has always been a prominent feature in the development of college and university programmes in the US over the past century, today's need for renovation seems more acute than at comparable times in the past. New technologies prompt the formation of new departments or cloud the boundaries between the old; "globalization" moves faculty and administration to re-evaluate the sufficiency of traditional narrow disciplinary course requirements; teamwork and communication seem to require something more. And the problems engineers are expected to confront and help resolve – global warming, sustainable development, energy sufficiency – appear to be of a new kind, reaching beyond the confines of the firm, national boundaries and the customary constraints and specifications of an instrumental nature. The political and the social intrude in ways the engineer is unaccustomed to- or so it seems.

The recognition that improvements need to be made, that the traditional content and teaching methods no longer fit the bill, brings to the fore tensions that have always been part of the growth of programmes in the US. Chief among these has been the tension between "theory" and "practice", between the relative importance given to science, the relative importance given to practice in the curricula. Not unrelated is the question concerning who sets criteria for accreditation of programmes and professional status of graduates. And who are the programmes to serve – the student, the needs of industry? How these tensions and questions are addressed depends in part upon tradition and history. The aims and ideas, philosophies and purposes – and perceived avenues for improvement – of today's programmes are rooted in the past.

A brief history

History shows that the genesis of engineering education in the US was the result, not of government policies, but of the efforts of individuals, both scientists and educators well established and of independent means. In 1823, Stephan Van Rensselaer a public figure of some note, together with Amos Eaton, a lawyer, civil engineer versed in the earth sciences, set the groundwork for what was first called "the Rensselaer School" in Troy New York:

"...for the purpose of instructing persons who may choose to apply themselves in the application of science to the common purposes of life...to qualify teachers for instructing the sons and daughters of farmers and mechanics, by lectures or otherwise, in the application of experimental chemistry, philosophy and natural history to agriculture, domestic economy, the arts and manufactures " (Wickenden, 1929).

This became, after a decade or so, a professional school of civil engineering (the phrase first appeared in the school's catalogue of 1828). It was B. Franklin Greene, Eaton's successor as director who, beginning in 1846, reorganized the school to be a comprehensive polytechnic providing a technical education that went beyond narrow utilitarian concerns. According to Wickenden, "Greene found his models in the highly developed technical schools of Paris, chiefly the École Centrale des Arts et Manufactures". The curriculum of 1850 was of three years duration and included courses in English, foreign languages, and philosophy over that span of time; another group of the sciences – mathematics, physics and chemistry – were studied in the first two years. The third year was devoted to practical courses including descriptive geometry, mechanics, industrial physics, metallurgy, practical geology, mining, geodesy, machines and construction (structures, bridges, hydraulic works, railways). Wickenden notes as a distinguishing feature "...the parallel sequences of humanistic studies, mathematics, physical sciences and technical subjects which have marked American engineering curricula to this day." An additional preparatory year was deemed necessary and added at the front end to make up for deficiencies in the capabilities of students admitted. This in time became a regular part of a four year programme – the form to this day.

While Greene was not the only person to travel to Paris to find a model for technical education – Col. Sylvanus Thayer, made director of the Military Academy at West Point in 1817, had traveled to Europe to survey military schools and found a model in the École Polytechnique – it was the Rensselaer Polytechnic Institute under Greene's direction that set the example for other schools, e.g., Union College, Dartmouth, Brown, and the University of Michigan which began instruction in engineering in 1852 under the tutelage of a civil engineering graduate of Rensselaer (1855).

Harvard and Yale started schools of applied science in 1847. But according to Wickenden, Harvard College was "openly hostile to technical studies" and this "... appears to have been a major factor contributing to the establishment of the Massachusetts Institute of Technology on an independent foundation in 1860". Yale made better progress, establishing a three-year programme in civil engineering in 1856 and another "on paper" in mechanical engineering that same year. Hostility from the college also made life difficult for faculty holding chairs in mathematics and civil engineering and another in metallurgy but a $100,000 gift from J.E. Sheffield led to the Scientific School bearing his name and mechanical engineering became a reality.

Up to this point, the establishing of these programmes was the result of hard fought, local and individual effort. But in 1862 the government intervened in a positive way, passing the Morrill Land Grant Act

"...without excluding other scientific and classical studies and including military tactic, to teach such branches of learning as are related to agriculture and the mechanic arts, in such manner as the legislatures of the States may respectively prescribe, in order to promote the

> *liberal and practical education of the industrial classes in the several pursuits and professions in life."*

Each state received a grant of federal land (121 km^2) to be used, or the proceeds from its sale to be used, to establish an educational institution having this stated purpose. Within a ten year period, the number of engineering schools went from six to seventy. Other than the requirement that the schools teach military tactics – the justification for today's Reserve Officer Training Programmes (ROTC) – the government kept its distance.

The last quarter of the 19th century saw a move away from shop-work and practice and the emergence of science based instruction – albeit not without resistance from faculty who distrusted theory and who themselves were active in collateral practice. This was fostered in large part by needs in electrical and chemical engineering. Those who taught in these fields were not trained as engineers but in the sciences.

The sciences were to gain further amplification and importance in engineering schools with the arrival of foreign engineers after the first world war but especially in the wake of World War II. Vannever Bush, President Franklin D. Roosevelt's Director of the US Office of Scientific Research and Development, is credited with articulating the fundamental and essential place of science in the development of new products and technologies for the welfare of all mankind. The last half of the 20th century saw funding for research on campus, often in dedicated laboratories, grow by leaps and bounds. One consequence was a significant de-emphasis of the relevance of industrial practice in engineering education.

> *"... it wasn't until the 1950s,... [that] the federal government decided to fund fundamental research (as opposed to "applied" research) and unleashed an avalanche of money for university programmes, [and] American engineering schools almost universally adopted engineering science as the core of engineering education....*
> *The new emphasis on federally funded research (more than 70 percent of university research was funded by the government) severed the tight linkage between engineering faculty and business corporations. The change was so complete that by the late 1960s practicing engineers were complaining that the pendulum had swung too far toward theoretical concerns, that engineering graduates lacked problem-solving capabilities, and that engineering faculty and practicing engineers spoke entirely different languages."* (Seely, 2005).

Features for comparison

Several characteristics of engineering education in the US emerge from this brief history as worthy for comparison. One concerns the perceived relevance of the humanities and social sciences to the education of the engineer. The structure of the curriculum and the nature of requirements is another. Accreditation of programmes is still another topic for comparison. Finally, we look at the students; at admission requirements and procedures and how the neophyte engineer attains professional status.

The relevance of the humanities and the social sciences

One notable difference in engineering curricula of the US and many countries of the EU (France, and for a limited period the UK, appear to be exceptions) is that, in the US, students are required to accumulate a significant number of credits in the Humanities and Social Sciences (HSS). While the history shows a recognition, on the part of those responsible for establishing the first programmes, that to be a considered professional, some measure of the humanities must be an integral part of the curriculum, it was in 1939, with the H.P. Hammond Report, *Aims and Scope of the Engineering Curriculum*, that the Humanities and Social Sciences received explicit and significant status as a "stem" to be offered in parallel with the student's technical track. The report recommended that the humanities and social sciences be given "...a minimum of approximately 20% of the student's educational time. This allotment should be at least the equivalent to one three hour course extending throughout the curriculum, and on the average somewhat more." (Quoted in ASEE Report, 1956).

This recommendation became the norm, though the 20% was indeed treated "approximately". The general rule took the form of one HSS course per semester for each of the eight semesters a student was expected to complete for the Bachelor's degree. The importance of "liberal education" as part of the engineer's "professional identity" was re-enforced in the oft cited Grinter *Report on the Evaluation of Engineering Education*, done for the ASEE and published in 1955.

"Looking at the subject of instructional goals even more broadly, one concludes that the engineer should be a well-educated man. He must be not only a competent professional engineer, but also an informed and participating citizen, and a person whose living expresses high cultural values and moral standards. Thus, the competent engineer needs understanding and appreciation in the humanities and in the social sciences as much as in his own field of engineering. He needs to be able to deal with the economic, human, and social factors of his professional problems. His facility with, and understanding of, ideas in the fields of humanities and social sciences not only provide an essential contribution to

his professional engineering work, but also contribute to his success as a citizen and to the enrichment and meaning of his life as an individual."

In particular, the relevance of courses in the HSS to engineering management was emphasized:

"It is clearly recognized that many engineers progress into managerial and top executive positions in industry and government. For such individuals the foundation should be laid in college for an understanding of human relationships, the principles of economics and government, and other fields upon which the engineering manager can build. The foundation may be built more solidly in humanistic and social courses than in highly applied studies in management." (Grinter, 1955).

In the 50's, the sequence of courses offered in the humanities and social sciences by different engineering schools varied one school to another but within each programme the student had but limited freedom of choice – compared to today. For example, at MIT, all freshmen engineering students were required to complete a two semester sequence *Foundations of Western Civilization* the first semester of which focused on 5th century Athens, then moved to the Middle Ages. The rise of science and its effects on philosophy and political theory in the 16th and 17th centuries was the focus of the second semester. Similar courses were required at other engineering schools e.g., *History of Western Civilization* at Stanford, *The Background of Western Civilization I, II, III, and IV* at Case Institute of Technology, (an upper-class, four semester sequence). Some required courses at the schools had a decidedly utilitarian purpose, e.g., English composition, Speech, Engineering Economy, but for the most part, the courses – particularly those offered as electives – kept to the "liberal studies" theme.

The Grinter report was quickly followed by another titled *General Education in Engineering* (ASEE Report, 1956) in which the authors explored, through visits to approximately 60 engineering schools and interviews of humanities and social science as well as engineering faculty, how the schools had fared in incorporating study in the humanities and social sciences into the curriculum. Their focus was "..on the crucial problem of how to develop and maintain an effective programme of humanities and social sciences in the very limited time usually available in an undergraduate engineering curriculum".

The committee found that some embraced the notion of including the Humanities and Social Science because they might contribute to the professional competence of the engineer "...on narrow utilitarian grounds..." through "...the improvement of technical efficiency". These engineering faculty claimed that in order to write well, to speak effectively, to win friends and influence people, to understand business problems and operations, engineering students "...should take courses in composition, technical writing, speech, applied psychology, and business administration." Some along this line argued for the study "…of literature and philosophy as subjects which will enable the engineer to manage people more effectively as a result of an improved ability to analyze their motives and points of view."

The committee rejected this rationalization remarking that:

> *"The committee believes that the humanities and social sciences are, in a deeply serious sense, practical and useful. It believes that engineering educators have performed an invaluable service to liberal education by their stubborn insistence that contemporary relevance is the standard by which to judge any humanistic-social programme. What we object to is an essentially frivolous definition of practicality that limits its attention to the development of a few surface skills, while failing to recognize that literature and philosophy and social organization are, like science itself, basic aspects of human activity in which depth of understanding provides the only sound foundation for the student's future growth. The emphasis upon immediately useful techniques narrows the scope of the humanities and social sciences and seriously diminishes their educational value." (p.4,* ASEE Report, 1956)

The committee went on to denounce ("less defensible") the "finishing school concept" which holds that the humanities and social sciences provide a "...cultural veneer designed to make the engineer acceptable in polite society." From this perspective "literature and the arts are primarily conversation pieces, or aids to smoother family and social relations since they give the engineer something to talk about besides transistors, strain computations, and fluid flow." They sum up "... A statement of objectives which fails to respect the centuries of solid scholarly accomplishment represented by the humanities and social sciences can scarcely provide the requisite intellectual framework for a sound programme of study (in HSS)". The authors of the *General Education* report presumed that the 20% HSS content would be contained in a sequence or set of courses taken over the students' four year undergraduate studies but standing apart from their engineering course requirements. This indeed is the structure that endures to this day.

Curriculum structure and requirements

Admission to an engineering school in the US, whether state university or private institution is an opportunity available to all. Of course there are hurdles to leap; e.g., passing the Scholastic Aptitude Test (SATs), a regime of tests taken in the final year of high school at the age of 17 or 18, remain for most colleges and universities a necessity. Letters of recommendation authored by teachers and others in a position to judge the student's accomplishments both inside and outside the classroom are also required. Acceptance depends upon a good measure of subjective judgement as well as the numerical results of the SAT; diversity in the student population is valued. Entrance to an MIT or Stanford or the University of Michigan is highly competitive but if students are truly motivated they can find a place to pursue an engineering degree – and if they excel and succeed at their undergraduate studies, graduate study at a premier institution is a real possibility.

Costs of an engineering education vary significantly when one compares a public and a private institution. For example at MIT, nine months' tuition for 2007–2008 is $34,750; a Student Activity Fee of $236 increases the total to $34,986. Living on campus in a dorm costs approximately $10,400. But it is noted that approximately 90% of undergraduates receive some form of financial aid. For comparison, at the University of Massachusetts at Amherst, tuition and fees for a resident of the Commonwealth of Massachusetts is approximately $5000; for students from outside the state, it is approximately double that amount.

The undergraduate engineering education curriculum in the US as a whole has hardly changed since the 50's as measured by the fraction of time devoted to the different kinds of courses constitutive of an undergraduate programme. For example, at MIT, student credit hours in the humanities and social sciences amount to approximately 20% of the total required to obtain the Bachelor of Science degree in a designated field such as mechanical engineering. Required courses in mathematics (Calculus, Differential Equations) and science (Chemistry, Physics, and now Biology) account for another 20 – 25%. Engineering science courses, including laboratories, consumes 25% of the student's life on campus; engineering design, roughly 10%, advanced courses in whatever subfield the student may elect, roughly 10%, leaving the balance, approximately 10%, as free electives.

If one takes a bird's eye view, this structure appears not all that different from what it was in the 50's. One has to look up close at the content and methods within a category to see the extent of significant change. Design is no longer limited to machine design and mechanical drawing, for example. The humanities requirement is no longer so rigid; the *Western Civilization* courses are gone the way of all things limited to white, western and male. But studies in the humanities remains a requirement, substantial in scope and depth.

The fore-mentioned required courses in the calculus and in the sciences also distinguish engineering programmes in the US from those in the EU. This reflects the more advanced standing and capabilities of entering students in the EU. In France, for example, two years in a "classe préparatoire" where mathematics and physics are studied intensely is prerequisite to taking a competitive exam in seeking admission to one of the "grandes écoles" in engineering.

Accreditation – ABET

The official history of the Accreditation Board for Engineering and Technology (ABET), since 2005 renamed ABET, Inc., dates its birth to 1932, the year the Engineers' Council for Professional Development (ECPD) was established. This organization of seven engineering societies – The American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, the Society for the Promotion of Engineering Education, the American Institute of Chemical Engineers, and the National Council of State Boards of Engineering Examiners – focused on four areas: guidance, training, education and professional recognition. (ABET History, 2008).

According to Edwin Layton, licensing was also very much on the minds of the engineering societies. In the depression years there was an oversupply of engineers and ways were sought to limit membership in the "profession". The ECPD became a forum for debate, seeking "...some means of drawing a sharp line between professional engineers and other technical workers". But little was done in this regard; the conservatism of the different founding societies and their different definitions of membership grades prevented agreement to even a modest system for "certification" (Layton, 1971).

One less contentious way to maintain professional status was to ensure that engineering degree programmes were of high quality; the year after its founding, ECPD began evaluating such programmes. By 1940, "...through the inspection programme of its committee on engineering schools..." ECPD had accredited 461 engineering curricula at 129 colleges and universities in the US. Another 104 curricula received provisional accreditation (Engineer's Council, 1941).

It wasn't until 1980 that ECPD was renamed the Accreditation Board for Engineering and Technology (ABET) "...to more accurately describe its emphasis on accreditation." (Lattuca *et al.*, 2008). And in 2005, the label changed to simply "ABET, Inc." – a step that "...allows the organization to continue its activities under the name that represents leadership and quality in accreditation for the public while reflecting its broadening into additional areas of technical education" according to the official history. Currently, the number of accredited programmes has grown to 2,700 at 550 colleges and universities.

A significant change in ABET's programme evaluation criteria was made in 1997. After several years of discussion and debate the criteria moved from "bean counting", i.e., ensuring that a degree programme required specific science and engineering courses relevant to the particular discipline, to an outcomes-based assessment with the added demand for continuous programme improvement. The new criteria, Engineering Criteria 2000 (EC2000) were meant to foster innovation as well as assure a programme's worth.

"The revolution of EC2000 was its focus on what is learned rather than what is taught. At its core was the call for a continuous improvement process informed by the specific mission and goals of individual institutions and programmes. Lacking the inflexibility of earlier accreditation criteria, EC2000 meant that ABET could enable programme innovation rather than stifling it, as well as encourage new assessment processes and subsequent programme improvement." (ABET. History, 2008)

ABET lists eight "General Criteria for Baccalaureate Level Programmes": Students; Programme Educational Objectives; Programme Outcomes and Assessment; Professional Component; Faculty; Facilities; Institutional Support and Financial Resources; and Programme Criteria. The "programme educational objectives are broad statements that describe the career and professional accomplishments that the programme is preparing graduates to achieve." Programme outcomes "...describe what students are expected to know and be able to do by the time of graduation". These are specified as follows:

(a) *an ability to apply knowledge of mathematics, science, and engineering*

(b) *an ability to design and conduct experiments, as well as to analyze and interpret data*

(c) *an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*

(d) *an ability to function on multi-disciplinary teams*

(e) *an ability to identify, formulate, and solve engineering problems*

(f) *an understanding of professional and ethical responsibility*

(g) *an ability to communicate effectively*

(h) *the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context*

(i) *a recognition of the need for, and an ability to engage in life-long learning*

(j) *a knowledge of contemporary issues*

(k) *an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.*

In addition, an engineering programme must demonstrate that its students attain any additional outcomes articulated by the programme to foster achievement of its education objectives.

The "Professional Component" criteria lists subject areas that must be included in a programme in general terms – college-level mathematics, basic sciences, engineering design and a "general education component" that complements the engineering courses. The criteria include the number of years that must be devoted to each category but do not spell out specific courses.

This shift from requiring specific courses to managing a process has not come without its costs; we see the appointment of evaluation leaders and specialists to collect data and lead faculty through the assessment process at each college and university. Faculty complain about the number of forms to be filled out, the time spent to collect data, and hours in meetings to try to live up to the "spirit of EC2000". Is it worth it? "Today, the spirit of EC2000 can be found in the evaluation criteria of all ABET disciplines, and studies like Penn State's Engineering Change prove those criteria are having an impact on accredited programmes." (ABET History, 2008).

The positive impact of the change, both on student learning outcomes and on organizational and educational policies and practices, appears to be a greater emphasis on professional skills and active leaning and high levels of faculty support for continuous improvement. Yet while, "...half to two-thirds of the faculty report that they have increased their use of active learning methods, such as group work, design projects, case studies, and application exercises, in a course they teach regularly", (Engineering Change, 2006) there was little evidence that any major renovation of these courses regularly taught, or any major programmatic renovation, had been stimulated by EC2000. There is evidence nonetheless that the changes are positive in respect of creating a new paradigm for delivery of engineering education and facilitating the empowerment of graduates by providing them with the academic and societal skills necessary to contribute as professionals in today's ever changing and challenging world. We are asking questions and getting to know each another's ways, not only at national level but between Europe and the US and across the greater global divides, an essential requirement to tackling the major problems, not least energy or more generally resources, facing us today.

Summary

This brief comparison points to several ways in which programmes in engineering education differ across the Atlantic. (It suggests, too, that differences among programmes in the EU are as great as between those of the US and the EU – as those attempting to restructure in accord with the Bologna agreement are discovering). Generally speaking, programmes within the EU appear more regimented in the requirements for admission relative to the US, the hurdles one must leap, more standardized, "objective" and preparatory courses limited in the main to mathematics and science. This reflects the more rigorous, as well as regimented, preparation prevailing in Europe where the education standard for entry to the profession is largely through completing a five year diploma/degree programme at Master degree level.

In the US, students have a wide variety of engineering schools to which they may apply for admission – public or private, small college or large university, near home or far afield. Within a member state of the EU, programmes have more of a standard character, but variation from country to country is as wide as in the US, perhaps more so and this in terms of programme content as well as size, etc. A project-based learning programme at Aalborg differs significantly from a classical engineering degree programme at Cambridge. A product design programme at Delft contrasts with science based curriculum at the École Polytechnique. The Bologna accord is intended to create a European area of higher education within which Bachelor Degree graduates may transfer to Master degree programmes in any university in any European country thereby significantly increasing student mobility throughout the area.

The relationship of the institution, whether college or university, to the state has a different nature: while schools in the US rely upon federal funding for research (and the guarantee of student loans) relationships with agencies, including laboratories, of the government do not have the same intensity as they do in the EU. In the EU, state subsidy of the student's educational expenses is often direct and traditional. In the US, even public (state) schools require their students to cover a significant portion of the costs of their education.

In marking all of these differences, and we have not done much more, differing historical contexts reveal the roots and reasons for why programmes in engineering education are as they are. Tradition will also continue to guide and constrain their form in the future.

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Chapter 6

Implementing Liberal Education in Engineering Studies in Denmark

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Abstract: Some authors have argued that future engineers will have to face up to a long term convergence between technical and liberal education. This development is seen in Denmark where liberal education in the form of philosophy of science has recently become a compulsory part of the curriculum of degree programs. However, the process of implementation in engineering degree programs, in particular in practice-oriented engineering degree programs, has been characterized by a good deal of doubt and hesitation resulting in a remarkable delay when compared to degree programs like those in the humanities and social sciences. In this chapter we discuss the mechanisms which might have caused the delay on the basis of the findings of an empirical case study carried out at our Institute. We first investigate attitudes among engineering faculty toward the aim and scope of philosophy of science in engineering education. Second, we discuss overall principles regarding the delivery of philosophy of science courses in engineering and suggest guiding principles regarding skills and competencies to be acquired by students. Finally we suggest a pedagogy that may enhance learning.

Key words: Global Challenges, Philosophy of Science, Platforms and Rationale, The Arguments of Engineers, Skills and Competencies, General Complexity of Curriculum Reform

Introduction

Some authors, e.g. Beder (1997, 1999), Williams (2002), Christensen *et al*. (2006), and Hyldgaard Christensen *et al*. (2007), have argued that future engineers will have to face up to a long term convergence between technical and liberal education to meet the needs of the future labor market where purely technical competencies are increasingly becoming insufficient. Other authors have argued that convergence between technical and liberal education is necessary to provide future leadership for engineers (National Academy of Engineering, 2004; Heywood, 2007; Grimson *et al*., 2008). All derive their arguments from key developments in the global knowledge economy.

Devon and Liu (2002) have presented a short and instructive list of trends of the global knowledge economy which translate into challenges for engineering education (see also National Academy of Engineering, 2004):

1. People become increasingly interconnected and geographically mobile. National economies become more and more interdependent
2. Information is a new currency
3. Decentralisation of power, reduction of hierarchy, and increasing complexity
4. Globalization of economy, workplace and culture, including international standards (ISO)
5. Strengthened influence of multinational corporations which increasingly operate as transnational players
6. Functionalizing of relationships – the extent to which we know and relate to people only as an extension of our work
7. Diversification of relationships; multicultural and multinational teams become the norm
8. Continuous change in technology and organizational structures

Not only engineering education but society in general has to deal with these global megatrends to predict and plan for skills gaps in the work force. However, a much debated consequence of these “new realities” is that the role and purpose of higher education is increasingly becoming linked with an instrumental “employability” agenda to meet the needs of the economy and ensure future competitiveness of companies. Some critics see this as a “downgrading” of higher education to merely training graduates for jobs rather than (also) educating them for life by improving their minds, stimulating their intellectual orientation and broadening their horizon (Harvey, 2000).

According to Steiner (1998, p. 2) one of the engineering educator’s dilemmas in a globalised world is the problem of teaching engineering certainty under uncertainty and contingency conditions. This means that when engineering students gradually become acculturated into the engineering culture and the paradigm of their field of technology they must simultaneously learn “to depart from..[their].. professional paradigm, to exceed its bounds, to look beyond its borders both for problems and solutions”. This critical self-reflection is made difficult by the fact that a rapid and exponential growth of knowledge in all engineering fields leads to a high degree of specialization in engineering curricula which is likely to be a narrowing factor (McCowan & Knapper, 2002). Steiner’s observation suggests that degree programs that are largely focused on technical content in a limited technological field and on inculcation of a specific professional culture and epistemic paradigm are insufficient as engineering work takes place in increasingly diverse social and technical contexts;

engineering problems thus often cut across not only different technological fields but also fields within the social and humanistic sciences, for example. From a global macro level to a local micro level, consideration of social issues will therefore impact on both engineering education and practice in the future. At the macro level major social issues include depletion of natural resources by population increase, political and economic conflicts between nations and peoples, concerns regarding intellectual property, cultural diversity, moral/religious repercussions and national security. At the micro level engineers will increasingly work in project teams across disciplines, professions and (national) cultures, necessitating the development of a broader range of professional/personal/interpersonal skills and competencies (US National Academy of Engineering (2004)).

In Europe these new requirements have been acknowledged and outlined under the heading of "transferable skills" within the EUR-ACE framework. The EUR-ACE framework was launched in 2006 in order to establish an accreditation system of engineering education on a continental scale (see EUR-ACE, Doc. A1-en Final, November 17, 2005 and Doc. C1-en Final, November 17, 2005). "Transferable skills" is one out of six categories of criteria regarding knowledge and skills which have to be satisfied to obtain accreditation of an engineering degree program. The six categories of criteria apply at different levels of complexity to both first cycle and second cycle programs. In the United States the above developments are mirrored in and reinforced by the ABET 2000 criteria (Accreditation Board of Engineering and Technology). These criteria are an ambitious attempt to improve the level of accredited engineering programs in the US. It is, however, important to notice that both the ABET 2000 criteria and the EUR-ACE criteria are concerned with skills and attitudes and not with curriculum content. McCowan and Knapper (2002) have translated the ABET 2000 criteria in the following way which is similar to the "transferable skills" requirements of the EUR-ACE criteria:

- Improve communication skills
- Increase design content in curriculum
- Develop lifelong learning skills
- Increase societal understanding and sense of social responsibility
- Increase understanding of management and business issues
- Increase understanding of environment and sustainability
- Increase awareness of health and safety issues
- Improve team skills
- Broaden knowledge of other disciplines

In the US the teaching of a number of the above skills and competencies is traditionally referred to as "liberal education". Both in Europe and in the US the responsibility for teaching such skills to engineering students is generally left to academics trained in the humanities and the social sciences (Steneck *et al.*, 2002). In the light of the above observations of global megatrends, the aim of this article thus is to discuss at an institutional level some of the complexities and didactic/pedagogical problems in implementing liberal education into engineering curricula in Denmark. In Denmark liberal education under the heading of philosophy of science has become high on the agenda since 2000. In 2000, the Danish government recommended the inclusion of philosophy of science courses in degree programs at the bachelor's level. Since then the process of implementation has been characterized by a slow pace in engineering education where it has taken longer to implement than elsewhere such as in the humanities and the social sciences. We have been wondering what kind of mechanisms have caused this time lag?

The Platform and Rationale for Implementing Philosophy of Science into Engineering Studies in Denmark

Before embarking on our case study let us look into what in the first place initiated the discussion on introducing philosophy of science in engineering studies in Denmark. In 1999, a UNESCO World Conference entitled "Science in the Twenty-First Century: A New Commitment" was held in Budapest. In section 4 of the preamble of the ensuing "Declaration on Science and the Use of Scientific knowledge" the Declaration states: "Science curricula should include science ethics, as well as training in the history and philosophy of science and its cultural impact". The UNESCO Declaration also includes engineering science: "We seek active collaboration across all the fields of scientific endeavor that is the natural sciences such as the physical, earth and biological sciences, the biomedical and engineering sciences, and the human sciences".

In 2000 as an echo and immediate outcome of the UNESCO Declaration to which Denmark had subscribed (Fink *et al.*, 2003, p.7), preparatory measures were taken by the Danish Government to implement philosophy of science courses into higher education. Accordingly, the Danish Ministry of education in 2000 sent out a letter to the universities outlining 10 basic and very overall principles regarding the aim and extent of philosophy of science in bachelor programs. The aim of introducing philosophy of science was defined as follows: "Students should be offered an opportunity to qualify their professional specialty by seeing it in a broader and more general perspective" (Ministry of Education, 2000). The letter also outlined that philosophy of science courses were expected to be implemented in all university degree programs by 2004. However, the concrete implementation was left to the universities themselves allowing for differences as to the pace, content and way in which philosophy of science was to be implemented in degree programs. The Danish Institute of Evaluation (EVA) in connection with an accreditation process in 2006 formulated the following criterion concerning professional engineering degree programs: “Research methodology and philosophy of science must be part of the degree program in order to enable students to follow and apply R&D results in their field of specialization” (The Danish Institute of Evaluation, 2006). To be accredited, institutions of engineering education were obliged to document that the above EVA criterion among 39 other criteria were met. Like the above ministerial 10 basic principles from 2000 this criterion is also relatively loosely defined, and how to meet the criterion is open for interpretation. The loose definitions are also found in other official documents, such as in ministerial orders concerning degree programs, which has accordingly resulted in a good deal of variance between institutions and between degree programs. Very specific guidelines have thus not been issued by the Danish education authorities. To put the Danish initiative into perspective it should be mentioned that in the US the platform for discussions on philosophy/liberal education in engineering studies is the ABET criteria and, as a further example, the American Society for Engineering Education. In Denmark, the situation is different in the sense that the platform for such discussions is governmental executive orders which serve to regulate a broader range of studies both at universities and other institutions of higher education. Illuminating as to how liberal education is facilitated in the US is a White Paper from the Liberal Education Division of the American Society for Engineering Education, in which Steneck, Olds and Neeley (2002) present an extensive set of valuable general guidelines and broad standards for the engineering education community to use in implementing ABET’s criteria 2000. Such valuable guidelines have not been discussed or issued in Denmark. However useful the US White Paper may be in defining the aim, scope and ways to assess the outcome of liberal education it nevertheless raises a number of pertinent questions as to the concrete implementation of liberal education in engineering degree programs inasmuch as a number of concrete contextual constraints can be expected to play a crucial role.

As such broad standards and guidelines are lacking in Denmark in practice this has also meant that discussions at the level of the 7 Danish Universities and other institutions of higher education offering engineering studies (93 bachelor degree programs in 10 different cities) have been uncoordinated and very different as to the content and priority they are given. Contacts to colleagues in all 7 Danish engineering education institutions have thus revealed a great deal of variance as to when and how philosophy of science was/is to be implemented in the various degree programs. This picture is also blurred even more by the Danish institutional set-up in engineering education. Danish engineering education has two tracks at the bachelor’s level: 1) a professional, more practice-oriented track including an internship in a company, and 2) an academic, more theoretically oriented track without an internship. Each track leads to a bachelor's degree in engineering and gives the possibility to study for an academic master's degree. The four universities offer both practice-oriented and more academic degree programs (in 7 different cities) whereas the three non-university engineering education institutions offer only practice-oriented degree programs (in 3 cities) – making for differences within the same institution. Thus no clear-cut institutional differences may be found as to the implementation process. Neither can we point to significant differences between the practice-oriented and the more academically oriented degree programs. In both types of program there has typically been a good deal of difficulties and disagreement concerning the form, content and duration of the philosophy of science element to be incorporated in the degree program. However, as to the time aspect of the implementation process the more academic programs have generally been faster in meeting the deadline whereas in the professional, practice-oriented programs there has typically been a delay of two or three years in the implementation (supposed to have taken place by 2004). In general, however, it may be said that in most programs, be they practice-oriented or more academic, the process of implementation is still ongoing in terms of course design, place and duration. And a few programs had in fact not even begun the implementation process by autumn 2008.

At our Institute it was decided that each degree program was given individual freedom to decide upon its own implementation process. In the business and language degree programs at our Institute the ministerial recommendation was followed by almost immediate action and was fully implemented by 2004. In the engineering degree programs, however, philosophy of science courses were still in the process of being implemented in spring 2007 where our data was collected. Currently (autumn 2008) the implementation process is still ongoing.

In the following we thus set out to discuss on the basis of the findings of an empirical case study some of the difficulties and didactic problems at an institutional level in defining and implementing philosophy of science in engineering studies in Denmark. The methodology we used is semi-structured focus group interviews carried out in 2007 with 3 faculty members in each focus group representing the three BSc engineering degree programs at our institute. We first investigate attitudes among engineering faculty toward the aim and scope of philosophy of science in engineering education. Second, we discuss overall principles regarding the delivery of philosophy of science courses in engineering and suggest guiding principles regarding skills and competencies to be acquired by students. Finally, we suggest a pedagogy that may enhance learning.

The Focus Group Interviews

The data which was recorded from 3 focus group interviews each of a duration of 2 hours have been fully transcribed and subsequently analyzed as a whole. In our analysis we concentrate on what is said rather than on who said what from which degree program. In this way we guarantee the anonymity of the respondents. The interviews focused on 7 themes regarding respondents' attitudes toward:

1. aim, scope and value of philosophy of science in engineering studies at the bachelor's level
2. the place of philosophy of science in the engineering curriculum and the trade-offs to be dealt with in the curriculum design
3. obsolescence of technological knowledge and the trade-offs between broad and specialized skills and competencies in engineering studies
4. international, interdisciplinary and inter-professional collaboration and the significance of engineering culture
5. roles of engineers in society
6. teaching social responsibility in the engineering curriculum
7. stakeholders in engineering education

Based on the responses related to the 7 themes we were able to identify what the respondents believed would be core characteristics of future engineering work and accordingly focal concerns of practice-oriented engineering degree programs. All respondents thus believed that interdisciplinary skills, broadmindedness and ability to think independently would be essential features of future engineers. The knowledge, skills and competencies needed would be:

- Solid, basic knowledge of the natural sciences
- In-depth knowledge of the engineer's own field of technology
- The ability to solve problems creatively
- Good language skills and other skills needed in international relations
- Good skills in written and oral communication (lacking presently according to respondents)
- The ability to work in teams and networking capabilities
- Business knowledge and market orientation
- Entrepreneurial skills and competencies

(for comparison see Yrjänheikki & Takala (2001)).

Of the above 7 themes guiding the interviews, themes 1-3 are mainly concerned with didactic/pedagogical issues whereas themes 4-7 refer to a Socratic element of professional self-reflection and hence the prospects of re-contextualizing engineering studies.

Based on our analysis of respondents' attitudes regarding the 7 above themes, we below reconstruct responses in the form of ideal types of arguments which illuminate complexities in implementing philosophy of science in engineering degree programs. These ideal types of arguments allow a partial understanding of the time lag as to the implementation of philosophy of science in engineering degree programs at our institute. In the ideal typical arguments there is a clear resonance of the above profile of future engineers. We have termed the ideal type arguments regarding the rationale and scope of philosophy of science as follows:

1. The "no need" argument.
2. The "instrumentalize it" argument.
3. The "split it up" argument.
4. The "lack of staff qualifications" argument.
5. The "keep it simple" argument.
6. The "loyal employee" argument.
7. The "trade-off" argument.

In the following we present these ideal typical arguments followed by a number of typical quotations to illustrate our interpretation:

Ideal type arguments regarding the rationale and scope of philosophy of science in engineering degree programs

The "no need" argument

The argument: Practice-oriented engineering degree programs at the bachelor's level at our institute have been very successful in meeting the needs of companies which is an ongoing concern in all engineering studies. It is thus relatively easy for engineering graduates from our institute to find work due to the fact that they have acquired the skills and competencies which make them readily useful in companies. The success owes to the fact that both students and engineering teachers work in a close cooperation with companies. Students have assignments with companies regarding their project work including their final project. The goal of their education is to educate broad minded and independently thinking engineering graduates who are able to cooperate with others in order to creatively solve engineering problems in companies. To divert attention from this goal by introducing philosophical questioning of what engineers are doing and why they are doing it would be a mistake that might jeopardize what has been achieved so far. _

Examples: *“The type of engineer that we educate is supposed to work in a company. He should be able to put things together and make them work. He is not supposed to question philosophically what he is doing and why he is doing it”.*

“We educate people who are able to take an independent stand be it at a technical, economic, device or company level. It is sound engineering wisdom to know how these things relate to each other. However, I don’t think that such knowledge builds on or relates to philosophy of science. It rather relates to the professional core of engineering”.

“Our students have a very good reputation indeed in the local companies. Quite often we receive mail from companies that wish to hire our students or ask if we have students who will complete their study within a short time in order to offer them employment. This quality stamp on our education therefore allows us to conclude that we currently teach our students the qualifications which are requested by companies”.

The “instrumentalize it” argument

The argument: As the core of engineering is practical problem solving; all activities in engineering studies should ideally aim at enhancing the student’s competence in this area. Philosophy of science would be a positive novelty in engineering studies if interpreted and instrumentalized as research methodology. In this way it will be meaningful for the students in making them better aware of how to formulate a problem, how to use different methodologies and research techniques in the data gathering process and how to analyze and validate the data. In making them better at solving problems by teaching them how to work in a structured way, they will become better engineers.

Examples: *“Philosophy of science for me thus designates a structured way of working. Hence what Socrates and Plato said in the past would largely be irrelevant”.*

“Taking diploma engineering studies which are not wildly academic as a point of reference, I think that some of these abstract concepts, especially the methodological part of philosophy of science, simply may help the students to become better at solving problems”.

“In my opinion the purpose [of the governmental decision to implement philosophy of science in degree programs] is to make the students more conscious about their own perception of the world in order to better understand how such perceptions influence their analyses and … results, that is to say the quality of their analysis and results. I think that there is a need here to be more conscious”.

“In my opinion it is beyond dispute that it will be extremely difficult to aim at Bildung in many engineering studies. Engineers do not think along these lines. It has something to do with the engineering mode of thinking. Engineers do not seek knowledge just for the sake of knowledge in order to be able to discuss it in the lunch room…….Our students are put into a context in which they are supposed to produce useful results. Hence their approach is not overly reflective”.

The "split it up" argument

The argument: Implementing philosophy of science in the form of research methodology as a separate course module into a practice-oriented 3 ½ year engineering degree program would be risky business. There is a risk of making such courses both too time-consuming thus stealing valuable time from more important issues in a tightly packed curriculum and of wasting time by entering into philosophical and methodological subtleties which nobody understands and which is of no use in practical day-to-day engineering problem solving. Ideally, philosophy of science should only be taught when needed and requested in connection with the students' project work. In this way it would be both relevant and meaningful for students and teachers. Another way to do it would be to consciously label what we are doing already regarding philosophy of science in the curricula of engineering degree programs.

Examples: *"In my view it is not wise to make philosophy of science an independent module. Ideally it should be taught when needed in specific engineering disciplines or problem areas. In doing so, it would not have the negative side effect of increasing the pressure to remove vital engineering topics".*

"When summarized into a few tangible elements, you might say that we already teach the subject without clearly labeling this activity as philosophy of science. Thus the subject is taught but not as an identifiable course module".

The "lack of staff qualifications" argument

The argument: As practical engineering problem solving does not hinge on philosophy and the ability to engage in meta-disciplinary reflections as important parts of the engineer's toolbox, most engineers are not trained to be sensitive to the more intellectual and philosophical aspects of engineering. Accordingly, most engineering teachers cannot be expected to be familiar with the concept and scope of philosophy of science. Therefore they have to be taught the subject. In order to gain legitimacy, implementation of philosophy of science courses must be supported by engineering faculty members. Otherwise it won't work.

Examples: *"In principle I believe that one has to start with the engineering teachers. If they don't understand what it [philosophy of science] is, it simply won't work".*

"I believe that the most important kind of Bildung takes place during the engineering study. However, it might appear that this kind of Bildung is wrong in the sense that it is building on a culture and a set of norms, which are imposed upon the students without the students being conscious of it…. This imposition, so to speak, takes place at an unconscious level ".

The "keep it simple" argument

The argument: As philosophy of science in general and philosophy in particular are perceived to be abstract, difficult and peripheral by engineering students, the likelihood of success will depend on three pedagogical preconditions: 1. The teacher should be capable of using a straightforward and simple vocabulary in order to convincingly bridge the gap between engineering and philosophy for the engineering students, 2. Suitable examples from engineering practice and project work should be provided in order to demonstrate the practical applicability of meta-disciplinary reflections, and 3. The subject should be taught at a very basic level. Otherwise the students will lose their motivation and simply skip it.

Examples: *“It also depends on which pedagogical approach is chosen…the students have to be able to see the practical applicability... If the students are unable to comprehend that universe, they simply skip it…We have tried that many times before”.*

“You are getting at a higher level of abstraction… that is to say you are supposed to get an insight into how other people think which for me is a fine intention…however I believe that it will be extremely difficult for the students to cope with”.

“We all agree that engineers should be able to cooperate with people from other professional and national cultures. In that context the concept of Bildung might be relevant. I think Bildung is o.k. if you can teach it at an extremely basic level”.

The “loyal employee” argument

The argument: Questions of personal responsibility are of minor importance for the engineer as patronage is essential in two ways in engineering. First, the patron establishes the intention, and decides on particular grounds what engineers have to do. Second, the patron provides the means to accomplish that purpose. It is the patron who energizes professional work towards a specific goal, not what the engineer might know or can do. As engineers are dedicated to their work and loyal to their patron, ethical concerns for engineers are largely related to the choice of patron. When the patron is chosen, ethical problems are usually located at a higher level within the organization. For this reason philosophical engagement with engineering ethics and the responsibilities of the engineer as a citizen are largely irrelevant in practice-oriented engineering degree programs.

Examples*:* *“The responsibilities of the engineer as a citizen, that’s a difficult one!.....You ask whether they [the students] are supposed to take part in the public debate on technology. You have simply gone totally astray”*.*“I fail to see that this is our job”.*

“They simply live and breathe for the companies, in which they are hired and in which they work. I personally feel likewise”.

“If you work in a company you equally well serve as a citizen. There is a connection between those things. Speaking of ethical concerns such as: In which companies do you want to work, what do you want to do and how do you want to do it, what is the overall strategy of the company? Does it fit with your personal strategy and ambition? These concerns also mean that you act as a citizen”.

“In principle we don’t discuss the responsibilities related to citizenship with our students. However, we do discuss ethical concerns, which in itself represents a societal perspective. Of course we do not possess the tools needed in order to be able to discuss ethics at an abstract and philosophical level but we discuss such concerns at a level a step higher up than ordinary common sense”.

The "Trade-off" argument

The argument: In a tightly packed, practice-oriented engineering degree program, trade-offs have to be made when proposals of implementing new topics are put on the agenda. Trade-offs should be made in favor of strengthening the skills and competencies which serve to enhance the immediate employability of engineering graduates. To the extent that philosophy of science courses enhance the immediate employability of engineering graduates, it should be implemented and other important topics left out. To do so would be sound engineering judgement in a situation where a number of constraints has to be taken into consideration in order to design a future oriented engineering curriculum.

Examples: *"Which new topics should be incorporated and which ones should be removed? At the moment the curriculum is tightly packed…with courses which we have selected very carefully and which have proved their practical value in a company context. If additional courses are to be incorporated into the engineering curriculum they must relate to the engineering mode of working. They should not be constrained to merely philosophical reflections".*
"If we have come to the conclusion, that we don't believe in the value of a specific course module, we simply skip it for the benefit of something more useful"

The seven ideal typical arguments show that attitudes amongst engineering faculty members towards the incorporation of philosophy of science in the curricula are ambiguous. The "no need" argument on the one hand shows that there is a good deal of skepticism toward philosophy of science. Other arguments, however, show that underneath the skepticism there is also a welcoming attitude and that engineering faculty is trying to come to terms with the new subject. Taken together the seven arguments therefore show that philosophy of science/liberal education is not yet a well-established concept in the minds of engineering faculty members at our Institute.

In order to understand at an overall institutional level why the process of implementing philosophy of science into degree programs has been slower in the making and more complicated in engineering studies than in the business and language programs at our institute, a number of concrete ambiguities have to be mentioned which have resulted in a relatively low involvement among constituencies at our institute:

1. The governmental requirement of making philosophy of science a compulsory part of all degree programs at the bachelor's level did not originate in a proposal from the engineering community.
2. The official regulation of the philosophy of science component in engineering degree programs has been unclear, thus leaving ample space for doubt and hesitation.
3. No specific guidelines have been issued as to content, place and duration.
4. No collaboration between constituencies has taken place, resulting in a lack of concrete decisions as to the implementation process.

5. The rhetoric and expectations of engineering constituencies have differed significantly from those of the humanities an the social sciences.

We would argue that the ambiguities mentioned in number 1, 4 and 5 clearly indicate that discussions of philosophy of science have brought to the surface a difference between the value systems of different professional cultures at our institute which has proven difficult to bridge to the detriment of implementation. Contacts to colleagues in other educational institutions offering engineering degree programs in Denmark reveal that the above picture is more or less the same.

To move beyond what we have established so far we discuss in the following section overall principles regarding the delivery of philosophy of science courses and suggest guiding principles regarding skills and competencies to be acquired.

Discussion of Guidelines Regarding the Aim and Scope of Philosophy of Science

Executive order no. 527 of 21 June 2002 from the Danish Ministry of Education stipulates that

"Practice-oriented engineering studies at the bachelor's level are complete professional engineering degrees which qualify the students to undertake occupational functions both in a national and an international context in which they are able to

1. *put technical research results, scientific and technical knowledge into practical use in development projects and in solving technical problems*
2. *critically acquire new knowledge within relevant field of engineering*
3. *solve engineering tasks independently*
4. *plan, realize and control technical plants, and in doing so, to include societal, economic, environmental and work environmental consequences in the solution of technical problems*
5. *fulfill a role in management and cooperative relations with people with other educational and cultural backgrounds.*

> *Furthermore the education should qualify the students for further studies".*
> *(Our translation).*

Even though executive order 527 has not been instrumental in discussions of philosophy of science, it nevertheless has resemblances to the ABET 2000 criteria. It thus provides opportunities for defining and strengthening the role of liberal education in practice-oriented engineering degree programs. Thus the term philosophy of science may be slightly misleading in the sense that traditional, de-contextualised courses of philosophy of science undoubtedly would be useless in order to achieve the skills and competencies put forward in the executive order. If not related properly and consistently to the engineering context, i.e. the engineering mode of working and thinking and the context in which engineering work takes place, philosophy of science would most likely be a waste of time in an already tightly packed engineering curriculum. In the following we thus try to define the aim and scope of philosophy of science in engineering curricula in terms of skills and competencies that meet both official Danish requirements, i.e. research methodology and philosophy of science and some of the wishes of engineering faculty members as presented in our data analyses. Attempting to be realistic in defining the scope of philosophy of science at a bachelor's level, we have left out a number of important issues regarding the historical and intellectual dimension of engineering. Accordingly we would recommend that the following limited number of learning objectives of philosophy of science in terms of skills and competencies should be met (for further elaboration see Steneck *et al*., 2002).

A. **Research methodology**
   - Ability to make a well planned research design for the data collection of an empirical investigation within technical science or social science
   - Ability to analyze quantitative and qualitative data
   - Ability to present data and draw conclusions accurately and fairly, based on the use of critical reasoning

B. **Philosophy of science**
   - Ability to identify the philosophical foundation of the research paradigm used when making a research design
   - Ability to describe and discuss the strengths and weaknesses of a scientific worldview
   - Ability to describe and discuss how engineers produce and use knowledge with particular emphasis on the strengths and weaknesses of scientific methods and engineering design processes

C. **International, interdisciplinary and inter-professional collaboration**
   - Ability to identify and discuss how differences in cultural backgrounds have bearings on problem definitions of both engineers and non-engineers
   - Ability to identify and discuss the value systems and working habits of other national, regional and ethnic cultures
   - Ability to identify and discuss the value system and working habit of the engineering culture

- Ability to identify and discuss the value systems and working habits of other professional cultures
- Ability to negotiate and find common ground between different ways of defining problems, value systems and working habits

D. Ethical reasoning

- Ability to identify stakeholders in an engineering problem/solution
- Ability to identify and analyze moral problems and dilemmas at the micro, meso and macro level

As to assessment, clear criteria for the range of skills and abilities, as well as the knowledge to be acquired in the relevant part of the curriculum should be provided, and clear feed back against these criteria should be given (for further elaboration see Harvey (2000)). Defining the aim and scope of philosophy of science in terms of skills and competencies instead of content allows for a more flexible curriculum design. Undoubtedly some of these skills and competencies are already taught without being clearly labeled. A compulsory requirement in Denmark for accreditation of engineering degree programs is that philosophy of science in engineering curricula must be identifiable as a separate course unit. It therefore cannot be entirely "split up" although this to some extent is both feasible and desirable. Thus a division between a basic course common to all engineering degree programs and separate course units related to the specific design spine of the individual degree program is feasible and allows us to define the boundary between the two in a flexible way. We would argue that a prerequisite for success in teaching philosophy of science for engineering is the provision of, 1) opportunities for training the skills of comprehensive research design related to either technical science or social science (without conducting the actual research), 2) opportunities of creating projects in which the students work in multidisciplinary and multicultural teams, 3) opportunities to document the results in papers/reports, 4) opportunities of collaboration between faculty members from engineering, the humanities and social sciences.

As to curriculum design and pedagogy, McCowan and Knapper (2002) and Bordogna *et al.* (1993) suggest that the current emphasis on reductivism in engineering studies should be replaced by a more holistic approach. The current approach in which the curriculum is designed to present the students the set of topics engineers "need to know" creates the impression that engineering education is a collection of isolated courses which have to be learned before the students are "allowed" to frame an engineering problem. Instead of this "bottom up" approach, they argue that integrated learning would be an ideal approach and pedagogy. By integration is meant integration both as to curriculum and the use of a variety of pedagogical methods. McCowan and Knapper argue that learning in most fields and at all levels is most effective when the student is put in the role of an active participant in the learning process, and not in the role as a passive recipient of merely theoretical knowledge. In the passive role student learning has a much greater tendency to be both superficial and quickly forgotten. Moreover, the crucial point is that active involvement in learning helps the student to develop the skills of self-learning while at the same time contributing to a deeper, longer lasting knowledge of the theoretical material. To link philosophy of science to students' project work in general and to the students' final project in particular would most likely be both meaningful and motivating for the students. In this way lecturing can be reduced to short introductions of theoretical/philosophical frameworks when needed.

Conclusion

Our study has highlighted a number of barriers amongst engineering faculty in connection with the implementation of philosophy of science/liberal education in engineering curricula (cf. the above ideal type arguments regarding the rationale and scope of philosophy of science in engineering degree programs). These barriers have resulted in a lack of concrete actions of implementation amongst the very same faculty reinforced by a lack of official governmental or institutional specific guidelines as to content, place, duration and assessment of philosophy of science courses in engineering programs. However, in spite of the above barriers and in spite of the respondents' hesitation and doubts as to the role and value of philosophy of science in engineering, the general impression from our interviews is that the overall attitude among the interviewees is in fact welcoming (see also Christensen and Ernø-Kjølhede (2009)). Respondents thus generally expressed a belief that at the end of the day and given the "right" course design, philosophy of science would as a newcomer to the curriculum be more likely to strengthen the skills of engineering graduates rather than the opposite. In a broader perspective, liberal education curricular reforms such as the Danish initiative with the inclusion of philosophy of science also serves the useful purpose to establish a meta-disciplinary platform among faculty enabling them to currently reflect upon and improve the quality of engineering degree programs. However curricular reforms are difficult to implement as they are very complex on at least five counts (International Bureau of Education, 2006): 1. They are inextricably linked to perceptions of current thinking and actions on educational concerns and reforms around the world, 2. The vision behind curriculum reform is concurrently the expression of a political and a technological agenda which is open to criticism, 3. Curriculum reform is both a process and a product, which involves a wide range of institutions, stakeholders and actors, 4. The process of constructing a curriculum is unique to each national and institutional setting. It is the complex outcome of negotiations between stakeholders to meet the perceived needs and requirements of companies, students and society, 5. Quite often the strategic goals of stakeholders collide. Accordingly there are no international or national models that are readily applicable as our study also confirms. General guidelines for curricular reform may thus be helpful; however, successful implementation is dependent on its local context. As can be seen from our study, implementation has to go through a process of gradually gaining legitimacy among institutional constituencies. The duration and complexity of that process may vary considerably according to local context and degree program.

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Chapter 7

Knowledge Valuation in Humanitarian Engineering Education

Jon A. Leydens & Juan C. Lucena

Abstract: Although engineering is a latecomer to humanitarian work compared to other professions, historical examples of humanitarian engineering exist, and interest in such work has grown significantly since the 1990s. Before launching a humanitarian engineering ethics (HEE) graduate project, we needed to understand the barriers and opportunities involved in starting such an initiative. To investigate these barriers and opportunities, we conducted semi-structured interviews and participant observations in multiple contexts using comparative analysis to identify emergent categories in the interview data. Three dimensions within knowledge valuation were found to be the most significant barriers to implementing HEE – knowledge organization, content, and hierarchy. Knowledge valuation includes a resistance to non-quantitative solutions that emanates from the way in which knowledge is organized, characterized, and valued. Specifically, the organization of knowledge in engineering education can prevent meaningful inter- or multidisciplinary collaboration. The focus of engineering education on the Engineering Problem Solving (EPS) method can hinder understanding of human needs as a critical component in engineering work. Finally, diverse knowledge hierarchies affect HEE implementation, especially in terms of devaluations of small grants, design, service learning, teaching, and low-tech solutions. Interviewees suggested opportunities for addressing these barriers, and we make recommendations based on these findings.

Key words: Humanitarian Engineering, Engineering Ethics, Knowledge

> *[W]hen the [founder of our program] took a group of students on a service trip, it was such a moving experience for both the students and himself that once they came back, the students [said], 'Well, we're going to do more of that, right?'…[But the faculty in charge] realized that you can't take engineers that are taught the same old way and expect them to work out in the field and in developing communities with an entirely different perspective. So, he realized that the academic background that students would need was slightly different.*
>
> *– Carole, Program Administrator*
> *in an Engineering and Community Development Program*

Introduction

What sorts of issues might have led Carole's colleagues to question the effectiveness of the engineering curriculum in preparing students for humanitarian or community-service projects? How does knowledge organization within the engineering curriculum affect students in similar contexts? This chapter explores responses to these questions with the goal of informing students and faculty about the connections and conflicts between engineering knowledge and humanitarian or community development activities. As background for these questions, an overview is described below of the historical links between humanitarianism and engineering and of the Humanitarian Engineering Ethics (HEE) initiative.

A Brief History of Humanitarianism and Engineering

From its 19th century origins as an organized profession, US engineering has had a marginal connection to non-military, humanitarian efforts. Most humanitarian work took place among medical professionals in the battle fields. The International Red Cross/Red Crescent, founded in 1864, originated as a humanitarian response to battlefield conditions. Since its inception, *humanitarian* has been used as a term related to "an ethical vision for the use of science and technology (initially in the form of medicine) to benefit human beings who may have previously been harmed by technology (at first in the form of military weapons)" (Mitcham *et al.*, 2005). During World War I, Herbert Hoover became one of the first engineers to deal with large-scale humanitarian problems as he headed the Commission for the Relief of Belgium in 1914 and directed the relief efforts of the Great Mississippi Flood of 1927 (Nash, 1998). His leadership in these efforts led the American Society of Mechanical Engineers (ASME) to establish the Hoover Medal in 1929 "to recognize great, unselfish, non-technical services by engineers to humanity" (American Society of Mechanical Engineers, 2006).

However, the US engineering profession did not engage in humanitarian work in its own terms until the mid-20th century, when engineering became more instrumental to international development policies and projects. Many of these projects were humanitarian in character but driven mainly by US national interests. Without a concerted effort by the engineering profession, engineers' initial involvement took place within the wider context of international politics and policy developments such as the creation of the United Nations (UN) in 1945 and its affiliated units responsible for humanitarian efforts, the formation of the Marshall Plan (1947), and the adoption of the Universal Declaration of Human Rights (1948). Other developments include President Truman's famous "Point Four" of his second inaugural address (1949), identified as the key policy statement that invented development and acted as the direct precursor of the creation of the World Bank in 1956 and the US Agency for International Development (USAID) in 1961 (Rist, 2004).

Despite these developments, engineering education, particularly after the launching of Sputnik (1957), did not respond to the challenges of development and humanitarianism, taking a more scientific path by making engineering sciences the core of the curriculum (Seely, 1999). In spite of the isolated interventions of engineers like Fred Cuny (1944-1995) in humanitarian crises, and the largely unrecognized participation of engineers in development projects throughout the 1960s and 70s, engineering education and the engineering profession remained primarily focused on science-based instruction for jobs in the military-industrial complex (Lucena, 2005).

A shift in engineering education and practice began to take place in the late 1980s and 1990s. After the end of the Cold War, national concerns over economic competitiveness and globalization led engineers in industry and academia to question the ability of engineering graduates to cope with these new challenges (Lucena, 2003). Ironically, these concerns, which contributed to the development of the Accreditation Board for Engineering and Technology (ABET) 2000 accreditation criteria, opened an opportunity for educators and practitioners committed to international community development to justify their efforts in terms of meeting new accreditation criteria. Within this context, engineers have created national and international networks that bring humanitarian relief through the application of engineering knowledge and skills to communities in need. National networks include student organizations such as Engineers for a Sustainable World (ESW) and Engineers Without Borders (EWB). These networks are complemented by local organizations such as Engineers in Technical and Humanitarian Opportunities of Service (Iowa State University), Technology Assist by Students (Stanford University), and Engineering World Health (Duke University).

Related efforts have resulted in recent curricular changes at many institutions with strong engineering programs, such as Purdue University, University of Colorado, Michigan Technological University, and the Colorado School of Mines (CSM) (Shallcross, 2005; Selingo, 2006; Engineering Projects in Community Service, 2007; Engineering for Developing Communities, 2007; Master's Degree in International Peace Corps, 2007). Similar curricular changes are occurring at Massachusetts Institute of Technology, California Institute of Technology, Cornell University, and elsewhere (Mulraine, 2006). International and domestic growth of these educational initiatives is reflected in the growing national stature of Purdue's Engineering Projects in Community Service (EPICS) Program, the appearance of the International Journal for Service Learning in Engineering, and the launching of the initial Service Learning in Engineering Conference in 2006, co-hosted by the National Academy of Engineering (NAE).

At CSM, the HEE initiative is predicated on, among others, the idea that many unexplored questions, particularly ethical ones, arise from the intersection between engineering and humanitarianism. However, engineering ethics education has to date mainly focused on individual and social responsibilities, especially on the concept of professional responsibility toward society in the forms of public safety and welfare, risk and the principle of informed consent, conflict of interest, and whistle blowing, among others (Herkert, 2000a; 2000b). In focusing on individual and social responsibilities, engineering ethics education has overlooked an important dimension of engineering practice: the role of engineers in domestic and international humanitarian activities. One notable exception builds a conceptual bridge between engineering ethics and service learning (Pritchard, 1999).

Humanitarian Engineering Ethics at CSM

Prior to launching the HEE initiative, we sought to investigate the barriers and opportunities involved in establishing an HEE graduate minor. Impetus for the minor emanated in part from the desire to augment opportunities for students to consider humanitarian engineering work and critically reflect on its ethical implications. Although still under construction, the working approach for the HEE minor involves an introductory seminar team taught by faculty in engineering and the liberal arts, modules and case studies developed within new and existing engineering courses, and humanitarian ethics courses in the liberal arts. In creating this initiative, we also sought to explore potential intersections between HEE and our undergraduate program in humanitarian engineering (HE). Defined as "design under constraints to directly improve the wellbeing of underserved populations," the HE Program has sparked student interest. As of 2008, almost 200 students have been involved in 40 HE projects on four continents in 13 countries (Humanitarian Engineering, 2008).

Methods

"Before implementing HEE, we needed richer understandings of the opportunities and barriers inherent in general reforms of graduate engineering education and inherent in launching HEE, and our literature review accentuated the importance of understanding both institutional culture and systemic barriers to ethics education and curriculum development" (Meyers, 2004; Newberry, 2004).

Data to inform such understandings emerged from 20 semi-structured interviews and several participant observations. Of the 20 interviewees, 16 were engineers, and most of these were engineering faculty involved in diverse types of community-service programs. We interviewed six engineering students – two graduate and four undergraduate. Participants hailed from institutions ranging from small engineering schools to large, research-focused universities. After briefly describing our HE program and HEE initiative, we asked participants to comment on the barriers and opportunities that might foster or prevent HEE implementation. Interviewees signed approved informed consent forms guaranteeing confidentiality and anonymity (via pseudonyms) in publications. All interviews were audio taped and most were transcribed. We used constant comparative analysis to identify emergent categories in the interview data (Strauss and Corbin, 1998).

Participant observations occurred at bi-monthly meetings for HE and HEE initiatives. We also conducted participant observations of students and faculty discussing humanitarian and service learning at two conferences, the Engineers Without Borders International Conference (2006) hosted by Rice University in Houston, Texas and the 2006 Service Learning in Engineering Conference hosted by the NAE and Purdue University.

Trustworthiness is generally established by using various data collection and/or data analysis methods (Creswell, 1998; Leydens *et al.*, 2004). Trustworthiness refers to how researchers determine whether they have accurately described the settings and events, participants' perspectives, or content of documents (Guba, 1981; Skrtic, 1985). To establish trustworthiness, we used four methods, separate coding of interviews, purposeful sampling, triangulation, and thick description; the last three of those are adapted from Creswell (1998).

Barriers and Opportunities in Humanitarian Engineering Education

Barriers

Interview data indicate that differing knowledge valuations are the most significant barrier to the implementation of HEE. Knowledge valuations can include resistance to non-quantitative solutions that emanate from the way in which knowledge is organized, characterized, and/or prioritized. For instance, resistance to the interdisciplinary solutions required in HE may stem from the high value assigned to certain kinds of knowledge (e.g., engineering science) and relatively low value assigned to others (e.g., design, ethics, service learning).

After analyzing the interview data, the following categories of focus emerged: 1) organization of knowledge; 2) content of knowledge; and 3) hierarchy of knowledge.

I. Knowledge Organization: Do Disciplines Get in The Way?

The organization of knowledge in U.S. engineering education into the categories of basic sciences, engineering sciences, applied engineering, design, and humanities and social sciences goes back to the Cold War (Seely, 1999). The engineering sciences were formally institutionalized as research categories at NSF and as curricular categories in most US engineering schools in the 1960s (American Society for Engineering Education, 1968). ABET accreditation criteria decisively came to reflect this emphasis on science (Lucena, 2003). With the end of the Cold War and the emergence of global economic competitiveness, new curricular categories have gained the attention of engineering educators. Yet for the most part, the engineering sciences remain unquestioned and the engineering disciplines unchanged. Although a humanitarian project could meet all 11 (a-k) outcomes under ABET criterion 3, the engineering sciences are protected by ABET program-specific criteria. ABET criterion 3 specifies what graduates of engineering programs should know and be able to do, including technical and professional outcomes.

Multiple faculty interviewees told us that HEE's inter- and multidisciplinary collaboration would collide with the "stove pipe" mentality, prevalent in the engineering sciences wherein disciplinary specialists remain in separate niches; interviewees indicated this mentality, a phenomenon not limited to engineering, would persist despite the growing acceptance for the notion that many complex problems are best solved by drawing from multidisciplinary expertise. As one faculty participant put it, "the barrier is the way we educate at the present time." Our interviewees noted that because faculty are often wary of stepping outside their disciplinary comfort zones, they need to be informed of the nature, scope, and objectives of HEE as well as be convinced that the benefits of a more holistic, interdisciplinary approach to teaching and learning outweigh the time and complexity involved.

Some interviewees suggested that the organization of disciplinary knowledge presents a barrier for faculty who were educated in the engineering sciences. Even with the necessity for interdisciplinary collaboration between engineering and humanities/social sciences implicitly foregrounded by ABET's current accreditation criteria (Accreditation Board for Engineering and Technology, 2006) most faculty have a difficult time knowing how to integrate social and cultural dimensions into technical work, particularly in the ways required by community-service and service-learning projects. Referring to the double challenge of integration brought by ABET and community-service projects, Carole, a program coordinator, said that faculty struggle with implementation and assessment, especially with non-technical competencies: "How [our faculty] are supposed to look at the social and economic and political aspects of what they are doing [in community-service projects], I don't think faculty necessarily know how to do.… [And some faculty think that] it does not make sense to teach [students] the sociological aspects of designing a new wind turbine".

The organization of knowledge around disciplines also conditions how students working in community-service projects view each other. Bob, a faculty member involved in a large-scale community-service program told us that multidisciplinary service-learning teams stereotype each other along disciplinary lines in their divisions of labor. For instance, computer science students would become webmasters, liberal arts students would be excluded from all technical discussions, and so on.

For some of the students we interviewed, the organization of knowledge around disciplines proved to be a barrier to their own learning. In brief, students voiced the desire for an infusion of relevant technical aspects in non-technical courses and relevant non-technical aspects in technical courses. It is possible that for those students who wish to integrate the technical with the non-technical, and solve problems holistically, that the organization of knowledge in the engineering curriculum prevents the integration and challenges the realization of their identity (Downey and Lucena, 1997).

II. Knowledge Content: Does Engineering Problem Solving Hinder Understanding of Human Needs?

The core content of engineering sciences is taught through the engineering problem-solving (EPS) method. Beginning usually in the Introduction to Engineering course and continuing throughout the engineering science courses, students commonly learn EPS in a particular sequence, often via representative textbook problems:

1. *Given*. Given certain information, students find and extract the relevant technical information necessary to solve a problem.
2. *Abstract idealizations*. Students learn to create idealized visual abstractions, such as free-body diagrams, of the problems at hand.
3. *Assumptions*. Students make assumptions (e.g., fluid is non-compressible) to solve problems more rapidly and effectively.
4. *Science*. Students learn to identify and apply scientific principles, often via equations that generally come from the engineering sciences.
5. *Math*. Once the equations are in place, students deploy mathematical strategies to solve these equations.
6. *Credit*. Finally, students produce a single solution, for which they do or do not receive credit (Hagen, 2001).

Some students, but not all, also learn to reflect back on the answer and ask whether it makes sense in the physical world. However, in most cases students are not taught how to consider non-technical issues in this process or are taught that such issues are irrelevant. Hence, EPS draws a sharp boundary between what is to be considered as engineering (what stays in the problem) and what is not (what stays out) (Lucena, 2003). Although a powerful and important analytical tool, EPS conditions students to dismiss social, cultural, and other non-technical issues and to remain passive problem-solvers who come to expect pre-defined problems to be given to them.

Study participants identified EPS in engineering sciences as a barrier. When asked how students respond to community-service design projects after three years of an engineering sciences curriculum, one interviewee, for example, told us that when students encounter open-ended problems and complex community partner needs, they are often overwhelmed and "*freeze*." By contrast, participants at universities with significant pre-senior design experiences stated that seniors were more accustomed to problem-based learning characterized by open-ended problem-solving.

Students commented that courses with EPS as their core method served as a potential barrier to their understanding of problem-solving. That barrier was addressed in part by alternative problem-solving approaches learned in liberal arts courses within the HE minor. Jill, a graduating senior, noted that her engineering courses taught her to find the most efficient, cost-effective solutions, but in that mindset one "may completely overlook something that is culturally important to where it is being implemented."

Another graduating senior, Susan, concurred that EPS methods serve as a potential barrier to understanding broader conceptions of problem-conceptualization and problem-solving. "Engineering problem solving will be great when you are trying to solve a chemistry problem or a strengths problem.... But …[for] a real-world problem in the humanitarian context, that problem solving process … definitely has to be re-evaluated, …. to take into account all those human factors," she said. Susan even encountered resistance to incorporating non-technical factors in her senior design course, wherein her team worked on a humanitarian project designing a building that would run electrical components off of 100-watt hours of solar energy. The project, however, occurred in a vacuum as "there was no community in need specified, so our group was asked to spin the globe and pick a spot to design for."

Her HE minor courses led her to think "that a general fix … and a top-down procedure like that was really inefficient, unsustainable, and, in my mind, kind of insulting – to think that I, as a senior in college, raised in a middle-income family in the United States, had any right to tell these people what the best solution for them was." To design such a building, Susan said she first needed to understand answers to questions such as, "Has the community requested this? Has there been some outcry for need? What necessitated this senior design [project]?" In the absence of such information, "it felt like we were designing something for no reason," she said. "I didn't know what the community's traditional housing was like, I didn't know if they had methods that would be better than mine." Most disappointing for Susan was the dehumanized design process: her dashed hope that her humanitarian senior design project "would be the first chance where these two passions [engineering and people] were going to combine."

Student comments suggest EPS as a potential barrier to implementing HEE, as engineering coursework generally and EPS specifically could limit their aspiration to bridge passions for engineering and helping people.

III. Knowledge Hierarchy: Are Design, Low-Tech Solutions, and Non-Engineering Ideas Marginalized?

Most engineering science faculty conduct research while most design faculty facilitate team design projects. Comments from interviewees suggest that differences in what these two kinds of faculty value affect the following three specific knowledge value differentiations.

Engineering science valued over engineering design. One faculty interviewee, now tenured, related that a former dean of engineering at his university did not think involvement with design helped a faculty member's case for tenure; in fact, when he received attention for student design projects, the dean sent the then-untenured faculty design advisor a letter both thanking him and telling him not to be involved again. After that, the young faculty member's department head, who by contrast was supportive of his efforts, was listed as the advisor of all design competitions to shield the untenured faculty member.

The hierarchy of knowledge influences even the ways in which people value grants and funding sources. Carole, a program coordinator, said that grants for education reform, such as those that fund most service-learning initiatives, are not perceived as having the same status as research grants, regardless of their financial size.

High-tech design valued over low-tech design. Within design, many engineering faculty value high-tech, sophisticated solutions over low-tech, simple solutions, even when the latter might be more appropriate to community service or HE projects. Bob told us that in community service projects "you let [community] needs drive the sophistication of the project" yet faculty "look at how elegant something is… [even] when a group in need may be in need of an efficient solution, not necessarily the most high tech."

In a similar vein, during a recent review of HE projects on our campus, a senior design group presented a simple LED circuit as a low-energy solution to the need for portable nightlights in a small Ecuadorian village. Reacting to the design, Antonio, an engineering science faculty member said, "That is not high tech enough. I am concerned that we are not teaching our students to be high-tech, and then they will not be competitive in the job market." Ironically, we are seeing increasing interest from employers of all kinds for engineering graduates with humanitarian engineering coursework, perhaps due to HEE's alignment with ABET criterion 3.

Engineering valued over non-engineering. Some interviewees noted that many engineers consider ethics easy, soft, or just common sense, so it is disregarded or trivialized. Ethics is not alone in its marginalization. In engineering education, some study participants indicated, community service and service learning are also frequently seen as lacking in academic rigor. The difference in the levels of available research funds also reinforces a hierarchy of knowledge in which engineering science is more highly valued. Such disparities can discourage engineering faculty from collaborating with humanities/social science faculty.

Byron, an engineering faculty participant, noted that he was able to launch several HE projects at his university primarily because he had first built a strong reputation doing traditional engineering science research. "It would be hard to start from ground zero if we weren't doing it under the cover of something else," he noted.

Opportunities

For each of the dimensions of imbalanced knowledge valuation above, respondents described potential means to address such barriers.

I. Knowledge Organization: Dealing with Disciplinary Boundaries

Several interviewees suggested specific opportunities to overcome the rigidity of disciplinary thinking. For instance, recruiting faculty who are big-picture, holistic thinkers, especially senior faculty who have tenure and some campus clout. Because of their established reputations, such faculty can actually build new initiatives inside existing disciplinary programs.

Despite the stereotyping of students along disciplinary lines, moreover, some evidence counters that phenomenon. Students at Tufts University, for example, included on their humanitarian project team students from six disciplines after recognizing that their water project in Tibet involved issues related to engineering, art, economics, international relations, physics, and public health (Engineers Without Borders, 2006).

Another graduating senior, Laura, lamented that most of her undergraduate coursework merely focused on “learning the material, and how to do engineering, instead of the wider [societal] implications.” Laura said that most courses stressed content knowledge until Senior Design. However, Senior Design included a societal implications component that was “only a small section of the course” done “at the end [of the project],” so the opportunity comes in the chance to “weave [societal implications] into the course more,” Laura noted.

Overall, whether through established programs or within technical and nontechnical courses, faculty and students encouraged making explicit connections to bridge disciplinary chasms and especially to link HEE and engineering.

II. Knowledge Content: Transcending the Limits of EPS

If prior to travel to developing communities, faculty and students learn how to listen and value perspectives of people with other histories and cultures, they are better prepared to question the relevance of the content of knowledge, particularly EPS. For instance, Carole described faculty and students returning from a community development project with a desire to do more such work. However, she said the faculty in charge “realized that you can’t take engineers that are taught the same old way and expect them to work out in the field and in developing communities with an entirely different perspective.”

As we have seen, EPS makes little to no accommodation for incorporating other perspectives in the problem-solving process. Thus, opportunities arise, Carole said, for inquiry into cross-cultural communication and understanding as well as community agency and ownership of the projects.

Another opportunity to alter the content of knowledge came from authoritative challenges for community development such as those stated in the UN's Millennium Development Goals (UN, 2007). For instance, Carole explained that their program emerged at the right time because of "the Millennium Development Goals of 2000 and the understanding that engineers are going to have to have a significant role in improving people's lives world wide." Even if these challenges are viewed as a set of given problems to be solved, and hence do not challenge the passivity reinforced by EPS, the challenges at least change the focus of traditional engineering problems.

However, these challenges by themselves did not represent a new challenge to engineering education. After all, many reports like these have been published before. Two new elements make these challenges unique right now. First, some engineering students who have been involved in hands-on collaborative learning strongly desire to work on addressing such challenges. At the same time, these desires are now more frequently supported by institutionalized collaborative- and service-learning programs and centers.

Charles indicated that his undergraduate design experiences helped him understand the importance of going beyond the confines of EPS and integrating technical and non-technical knowledge bases. He said his challenge in his second-year design project involved more non-technical than technical constraints. Likewise, for his senior design project, the process of building a bicycle-driven water pump for people in Ghana primarily involved the challenge of making an affordable, repairable, sustainable pump – mostly a non-technical challenge.

Student comments regarding opportunities to transcend EPS often referenced design courses, one of the most viable curricular spaces for accentuating a multidisciplinary, integrated problem-solving approach.

III. Knowledge Hierarchies: Transcending Rigidity

The hierarchy of knowledge in the engineering curriculum also opens unexpected opportunities for community-service or service-learning-based courses. Since many of the faculty interviewees were interested in seeing HE projects succeed, they provided case studies as a plausible inquiry-based pedagogy to foster reconceptualizations of the hierarchies of knowledge outlined above. Case studies from the World Bank and USAID, for example, can help us learn from mistakes and successes regarding issues such as the efficacy and complexity of single-sector vs. multi-sector approaches; planning and installing a clean drinking water system, for instance, involves more than engineering science. Health, community development, language, cultural, social, and political issues also play key roles, and dealing with these issues also opens new yet realistic constraints and complexities. Two faculty interviewees stressed that hopelessness in developing communities is fostered or perpetuated when outsiders solve problems for people instead of creating an atmosphere in which people have the resources, training, and ownership to solve their own problems. Thus, HEE gives us the opportunity to teach engineering students and some faculty about the efficacy of less hierarchical approaches to problem solving.

Charles stated that his experience in the HE minor expanded his awareness of the limitations of rigid knowledge hierarchies, which made him take a more "holistic" approach to solving problems. When considering a problem now, he does not just ask "how are we going to fix it?" but "what are the different things we could do?" and if the solutions function socially.

Collectively, these recommendations and comments from students and faculty augment our awareness of the challenges and opportunities involved in moving beyond sometimes rigid knowledge hierarchies.

Recommendations

Participants described both barriers and opportunities to HEE implementation in terms of knowledge valuations, specifically regarding the organization, content, and hierarchies of knowledge.

These findings suggest multiple areas for further consideration. First, engineering educators need to reconsider the effects of existing knowledge valuations. Given that the majority of curricula focus on engineering science and marginalize design and/or non-technical issues, some might suggest inverting the imbalance. We disagree with such an approach. Rather, the findings in this study suggest locating students in positions of power, ones in which they are capable of solving a vast array of problems by drawing from diverse yet appropriate knowledge bases; those knowledge bases include engineering science, engineering design, social sciences, humanities and communications, and others. In this conceptualization, knowledge bases are complex toolkits from which to pick and choose based on the nature of the problem.

Such a revised system would mean each academic unit, including engineering departments, would need to show its unique contribution to the goals of helping to foster better engineers, citizens, and human beings. This proposal also requires that faculty be more strategic about interdisciplinary collaborations, deciding which partnerships will yield better solutions to particular types of problems. Since humanitarian and community development problems are complex, faculty collaborations must include partnerships across the academic spectrum, which challenge disciplinary identities. Further, students who see successful instances of interdisciplinary problem solving among faculty may be more likely to pursue such collaborations in the future. Our hope is that students begin to question the content of their engineering knowledge and its relationship to who they are and who they can be and that faculty facilitate such inquiry and reflection. Each student must decide what it means to be ethical in engineering education, considering that one has the responsibility of understanding the limitations and opportunities inherent in the bodies of knowledge that one is studying and deploying strategies to be and become an agent for positive social change.

A more conscious "toolkit" approach to problem-solving also has strong pedagogical and professional implications. In the end, students so educated will more likely realize that the solution of HE (and other) problems should not be about the amount of engineering science content, or about the degree of high-tech and sophisticated design, or about the use of EPS. Rather, the success of a solution, which could include the humble realization that no action might be the best action, is about human welfare and well being. This study suggests that some HE student projects are already making this realization.

We have acted on the knowledge gleaned from this study in multiple ways. For instance, we have revised the introductory HEE seminar to focus on issues surrounding sustainable community development. Also, we have brought in practicing humanitarian engineers as guest speakers to articulate the value of an engineer able to see EPS as just one of many vital tools in an ever-expanding toolkit. Further, we have shared our study findings with faculty colleagues and fashioned ways in which "barriers" can be made into opportunities to enhance the status of humanitarian- and community-service engineering knowledge and practices within traditional engineering programs. As our findings suggest, if committed faculty frame HE courses, until now undervalued within the curriculum, in terms of ABET criteria and clearly address the calls for designing systems within realistic constraints, functioning on multi-disciplinary teams, etc., then these HE courses could become critical for program accreditation. Of course, these courses need to go beyond ABET desired outcomes to teach students to see the strengths and limitations of their expertise, including EPS, to engage communities through empowering participatory practices, from design conception to system implementation.

Also, we have facilitated discussions on having different disciplines represented in HE teams, as an opportunity instead of a source of stereotypical labeling. For example, some researchers have proposed a method of problem-solving to explicitly include human perspectives, a method which allows engineering students to understand, analyze, and value perspectives of others who think differently than engineers (Downey *et al.,* 2006). This method can be integrated early in HE design courses to help engineering students understand the strengths and limitations of each participating perspective, including their own, to negotiate amid alternative problem-solving methods, including those of non-experts, and to assess the implications of proposed solutions to all those involved.

We now know the importance of exploring whether the way knowledge is valued, organized, created, and disseminated most constrains a graduate program in humanitarian engineering ethics and possibly engineering ethics education in general.

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Chapter 8

Liberal Studies in Engineering & Technology

William Grimson, Michael Dyrenfurth & Mike Murphy

Abstract: A general case can be made for making Liberal Studies available to those students undertaking engineering programmes. But a more specific case can be made that engineers need to be well equipped if they are to be leaders in their community and capable of entering into meaningful dialogue (discourse) with their fellow citizens. Engineers contributing to or initiating a debate with those who do not understand technology, or who express an anti-technology stance, need to understand the "language" of all participants; and it is not reasonable for the engineer to expect that others adapt to the language and mind-set of the engineer. In Europe and the United States criteria have been established specifying the broad outcomes required of accredited engineering programmes and within these criteria it is clear that the wider interests of society become the concern of the engineer. These criteria, being outcomes-focussed, are not prescriptive as to the means within engineering curricula by which this is to be accomplished, but they point to the need for, if not Liberal Education, at least a move in that direction. This chapter reviews the rationale supporting the addition of a Liberal Education dimension to Engineering programmes and briefly considers Liberal Studies subjects that might be included in an Engineering or Engineering Technology Curriculum and their relevance and suitability. The chapter also emphasises the role of Accreditation Boards in the process by which curricula are reviewed and developed.

Key words: Liberal Education, Liberal Studies, Arts, Engineering Curriculum, Engineering Technology, Philosophy, Leadership

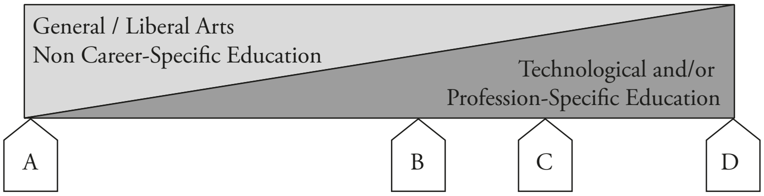
Introduction

Understanding the needs of society and meeting those needs in a technologically sound and sustainable manner, whilst keeping within the constraints set by citizen stakeholders, is a fundamental goal for engineers. To set and reach this goal requires leadership. Since engineering has been and continues to be at the forefront in shaping our modern world, such leadership should come from within the engineering profession in cooperation with society. This in turn requires mutual understanding and effective communications between those involved in the design and implementation of technology and those who use and are affected by the use of those technologies. "Broadly educated engineers will be better able to explain technology to fellow citizens involved in democratic decision-making" (Jackson, 2002).

On both sides of the Atlantic, however, engineers and technology professionals are under-represented at the highest levels of governmental and policy decision making. This creates a challenge to the engineering profession in establishing a true dialogue between decision makers and engineers. In turn, this also creates a challenge to those charged with the responsibility for the education of engineers to ensure that their graduates are capable of participating in the dialogue. With this as context, this chapter explores the role of Liberal Studies within the engineering curriculum as one means of equipping engineers with the "tools" of critical thinking, leadership, and "language" by which they can engage in effective discourse with society and its decision makers, and hopefully increase their participation in that latter role.

Pragmatically, the extent to which engineering and engineering technology baccalaureate programmes incorporate, and even integrate, liberal studies depends on each university's view of what professional programmes at that university should encompass. Perhaps such views can be characterized along a continuum of varying proportions of liberal arts versus technical focus as shown in Figure 8.1.

Figure 8.1: The Education Continuum



In some universities, engineering programme content is almost exclusively technical (i.e. science, technology) in nature. This is depicted by position D on the above continuum. In direct contrast is, of course, the traditional liberal arts college where no treatment of profession-specific content is provided and the focus is on classics, critical thinking, philosophy, etc. This is depicted by position A in the continuum. Perhaps the typical US professional baccalaureate degree programme (depicted by position B) represents a plausible compromise, where generally between 20-45% of the curriculum (Russell & Stouffer, 2005) is devoted to the liberal arts and general education. The position on the spectrum for many European universities is somewhere between B and D, say at C. However, on a practical note, even in such environments (B and C) the issue comes down to who controls the decision about what is considered to be a liberal arts/general education course. Is it the liberal arts teaching staff or is it the professional programme's teaching staff who decides?

According to Jackson, "recognition of the importance of liberal studies to engineering education dates to the Morrill Act of 1862, which established the land-grant colleges, and there has been an abiding recognition that engineers must appreciate and understand the human condition, in order to apply the principles of mathematics and science in the service of humanity" (Jackson, 2002). This line of reasoning can also be traced back to the late forties (App, 1946) and the heart of the argument calling for increased presence of the liberal arts in engineering and engineering technology programmes of the future is more recently articulated in Badley (2003). He states:

> *Indeed, the crisis in culture is our uncritical adoption of a mechanistic – scientific – technological – world view (see Biesta & Burbules, 2003, p.13).. This crisis in culture is also a crisis in rationality since scientific rationality is thought to be confined to hard facts and means while human values and ends appear to be excluded from rational (i.e., scientific) deliberation (Biesta & Burbules, 2003, p.13). … The solution is an integration of the beliefs we have about the world and the values and purposes that should direct our conduct* (p.487-488).

Curriculum design for engineering educational programmes is itself a typical engineering exercise in that many constraints need to be taken into account. Judgements are made that are not necessarily based on a set of educational principles. However the underlying objectives in including a Liberal Education dimension are clear and are set out in a technical report in the UK by Heywood (1994) and from a similar but not identical perspective in a set of recommendations for MIT by Dertouzos *et al.* (1989). University traditions and professional accreditation criteria may find themselves in conflict given the crowded nature of baccalaureate curricula. Frequently, optimum curriculum solutions are not readily apparent. Custom and practice play a role within the university, and an understandably conservative approach is often adopted.

It must be acknowledged that engineering curriculum design is a non-trivial task, and retrospection suggests that one particular dimension of this task has been underweighted. This is the societal dimension in which engineering is practiced and technology operates. At its bleakest this dimension may be absent completely, or it may be addressed in a solitary ethics course. Even then, more often than not this concentrates on cases studies where some catastrophe occurred and seldom deals with the more general aspect of the welfare of the public. For example, there are complex issues surrounding the tensions between collective and individual responsibilities, and the legal and protection aspects surrounding whistle-blowing. MacIntyre (1990) was far from convinced by the provision of applied ethics courses within universities and colleges partly because of their focus on separate modes of professional life: a more general approach is required.

The issue of a societal dimension not featuring more significantly in the engineering curriculum is increasingly at odds with the thinking and writing of senior members of the profession. The reasons for this disconnect are clear enough – much time is required to achieve competency in mathematics, the sciences, engineering fundamentals, discipline-specific skills, and technology. This leaves little time to address other subjects in an already crowded undergraduate curriculum. Therefore even finding space in the curriculum for the development of effective communications skills – writing, communications and team work – has not been an easy one. It is not surprising then that the challenge to find time for inclusion of topics considered by some engineering academics as extrinsic to any particular discipline of engineering, namely philosophy, the history of science and technology, etc., seems so difficult to surmount. One partial remedy is to take an Integrated Studies approach where certain themes can be picked up across a set of subjects reinforced by a consistent use of terminology and concepts.

But, can a future-oriented profession, whose rationale is to serve the needs of society, afford to ignore the evidence that points to the necessity of addressing shortfalls in what it means to be a professional?

Before addressing this question, let us first turn our attention to the study of liberal arts for their own benefit, as distinct from our specific question as to whether they are of benefit to the student engineer. The next section addresses this question. It should be noted, however, that the arguments presented are derived from documentation originating on either one side of the Atlantic or the other. It may well be that a given perspective has more legitimacy on one side than the other but clearly the contention is that such points, regardless of origin, are worthy of consideration on both sides of the ocean. It is also perhaps worth noting that John Henry Newman (1959) in his *Idea of a University* had more impact directly and indirectly on the development of universities in the USA than in the UK and Ireland, where a focus on specialization eventually prevailed. But there is a hankering for a return to at least some of the ideals of Newman and re-engineering the curriculum accordingly. Trinity College Dublin, one of the classical universities that Newman based his model on, has introduced measures to counter the excesses of specialization by broadening the curriculum (TCD, 1999).

The Purposes of Liberal Arts

What are the purposes of the liberal arts in our universities? What do liberal arts educators claim as the purposes of their own curricula? How do they set forth their own goals and aspirations? Youngdahl (1942), Reiner (1975), Bradley (1985), Hersh (1997), Nussbaum (1998), Badley (2003), Boren (2004), Brint *et al*. (2005), Berube (2006), and Lind (2006) have all spoken to this point. And whilst its focus was not solely on university education the *Padeia Proposal* as a system of liberal education originating from Mortimer Adler (1988) should be mentioned as well as the work of the Boyer Commission in Reinventing Undergraduate Education (1998). Also, the objectives of Andrew Carnegie and the philanthropically driven concrete outcomes both sides of the Atlantic should not be forgotten.

Badley is concerned that our culture is "bombarded with competing *ideologies"* (2003, p.480) one of which is the primacy of the career preparation function of the university. Already in 2003 Badley (p.483) asked "what is education for?" In answering his own question he suggests that: "the current answer appears to be that the purpose of education, even higher education, is simply to help society become more economically productive and competitive (p.483)." He buttresses his argument with Rhodes' (2001) claim "that professionalism has now shifted the function of the university from that of providing students with an opportunity for education to that of acquiring employability" (Badley, 2003, p.486). Indeed the philosopher Wolff has argued that such a shift is detrimental to the fundamental role of the university and that consequently the education of the professions should not even reside within the modern university (Wolff, 1971).

Badley worries that "our current cultural consensus is too dominated by a form of *competitive globalization"* (2003, p.478), and claims that two ideologies *science-technology* and *business-economics* dominate "our post modern world culture" (p.487). Badley continues with, "governments now see the university as an economic investment rather than as a cultural and educational asset" (p.488). Despite compelling arguments such as those raised by the USA Council on Competitiveness (2005), pragmatists "resist the attempt of the new economy to consume our valued educational institutions. They do so on the grounds that institutions such as universities have always had and should continue to have broad cultural, humanistic, and social objectives which should not be overwhelmed or crushed by globalization, commercialization and marketization" (p.489). Given this, and working from the pragmatic perspective of contemporary culture, Badley claims that effective education must serve integrative purposes that "bind culture and education together" (p.477).

Badley (2003) cites Rorty's (1999, p.118) perspectives on higher education, that it is "a matter of inciting doubt and stimulating imagination, thereby challenging the prevailing consensus. If pre-college education produces literate citizens and college education produces self-creating individuals, then questions about whether students are being taught the truth can safely be neglected."

In 2005 the Association of American Colleges and Universities launched its LEAP (Liberal Education and America's Promise) initiative to speak to "the aims and outcomes of a twenty-first-century college education" (National Leadership Council, 2007, p.1). In many respects LEAP echoes the work of the Enterprise Learning initiative referred to earlier (Heywood, 1994). The LEAP initiative identified the following essential learning outcomes (p.3) summarised as follows:

The Essential Learning Outcomes
Beginning in school, and continuing at successively higher levels across their college studies, students should prepare for twenty-first-century challenges by gaining:
• Knowledge of human cultures and the physical and natural world through study in the sciences and mathematics, social sciences, humanities, histories, languages, and the arts
Focussed by engagement with "big questions", both contemporary and enduring
• Intellectual and practical skills, including inquiry and analysis, critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork and problem solving
Practiced extensively, across the curriculum, in the context of progressively more challenging problems, projects, and standards for performance
• Personal and social responsibility, including civic knowledge and engagement – local and global, intercultural knowledge and competence, ethical reasoning and action, foundations and skills for lifelong learning
Anchored through active involvement with diverse communities and real-world challenges
• Integrative learning, including synthesis and advanced accomplishment across general and specialized studies
Demonstrated through the application of knowledge, skills, and responsibilities to new settings and complex problems

In working towards these outcomes, the LEAP initiative claims that "liberal education has always been this nation's signature education tradition" and that the tradition's core values are: "expanding horizons, building understanding of the wider world, honing analytical and communication skills, and fostering responsibilities beyond self" (2007, p.3). Because of this, the LEAP leadership not only advocates that these aims be fostered in general education but also within the courses in students" majors "whether the field is conventionally considered one of the arts and sciences disciplines or whether it is one of the professional and technical fields" (2007, p.4). The inevitable conclusion is that, regardless of the discipline, the inclusion of liberal studies should be an essential feature of any undergraduate programme.

Leadership and the Engineer

There are many definitions of "engineering" in circulation and they have in common some or all of the following features: the use of mathematics and the natural sciences; the exercise of judgement; the optimum use of the resources of nature; meeting the needs of society or mankind. It is the two words "society" and "needs" that are at the core of the arguments within this chapter.

The President of the Royal Academy of Engineering, Lord Browne (2008), at a presentation in Oxford University noted that "too few engineers get involved in public life" and he went on to quote his colleague Lord Darzi that "engineering is about the technological solutions to human problems," from which he concluded that "engineers must appreciate the nature of human problems as well as understand the technical aspects of their solutions." In his Presidential Address (as President of Engineers Ireland) *Who will be tomorrow's leader? The engineering profession's 21st century challenge*, Jack Golden (2008) noted that Plato believed that the foundation of leadership was expert knowledge, accompanied by such factors as courage, self-discipline and a philosophical mind. Meijknecht and van Drongelen (2004), who are not themselves engineers, explored how engineers are "produced" in Delft University, came to the realization that for engineers "the days of comfortable autonomy are over and done with. Engineers can no longer hide in the realms of science and technology and focus solely on the development of new technologies. As mediators between science and the world they live in, engineers have the task of finding ways to sustain and develop life in a balanced and adequate way by controlling and explaining the complicated processes in nature and human existence." Rosalind Williams has conjectured that the profession of engineering has lost its identity and argues that in the long run professional engineers will have to face up to a long term convergence between technological and liberal education. The prediction is that if engineers do not accept a hybrid educational activity they will be consigned to purely technical work activities. And consequently the professional engineer would not be ideally suited to provide the type and level of leadership required in our more complex society (Williams, 2003).

There is also a need to counter or at least understand the anti-technology stance often associated with the postmodern movement and that is discussed in Samuel

Florman's (1976) book *The Existential Pleasures of Engineering*. As an aside, that book was first published in 1976 and was re-printed in 1994, and its main topic and themes are as relevant today as they were over a quarter of a century ago – pointing to at least a partial failure of the profession to heed its message. Engineering as political judgement has been considered by many authors, and Little, Barney and Hink (2008) in a general review of professional ethics make the point that "the call to engineers to engage in their practice politically echoes the obligation to attend to the public welfare that is explicitly stated in most of the ethical codes that govern the contemporary profession." Taft Broome (2006) arguing for a "unity principle" applicable to engineering notes that generalist expertise, being different to specialist expertise, "consists in the ability to obtain meanings of a broad variety of learned works from their storied terms, and in the skill to bring them to bear upon the problems of participating effectively in public decision making venues, and finding and fulfilling one's destiny in globalizing cultures." This phrase *participating effectively in public decision making venues* echoes a point made by Florman and succinctly states the challenge that the profession should be obliged to address.

One of the engineering profession's largest professional organisations, the IEEE (Institute of Electrical and Electronics Engineers), has among its member societies the Society on Social Implications of Technology. Within its scope this society includes such issues as environmental, health and safety implications of technology; engineering ethics and professional responsibility; history of electrotechnology; technical expertise and public policy; peace technology; and social issues related to energy, information technology and telecommunications. On the European side of the Atlantic, the Royal Academy of Engineering (RAE) in the United Kingdom initiated in 2006 a series of seminars on the philosophy of engineering and this initiative is continuing. The topics that the RAE has chosen to explore have been wide in scope and have included the nature of engineering knowledge, ethics, and metaphysics. All these initiatives have as a basic underlying objective the idea that engineers need to be in a position to provide leadership to society.

Consequently, senior figures in engineering and professional and honorary academic bodies should be aware of the challenges in providing leadership, entering into dialogue with the public and generally understanding the needs of humans both in terms of society and as individuals. This in turn leads to a central question: why is it that engineering educators appear not to deliver an education that sufficiently considers societal and humanist challenges in their baccalaureate engineering programmes?

The situation has not been helped by the engineering science movement which has led to a gradual de-contextualising of engineering programmes. Johnston, Lee and McGregor (2006) express their "concern that the discourse of engineering education has been dominated by the discourse of engineering science, to the virtual exclusion of other discourses which contribute importantly to the practice of engineering." Already in 1994, Herbert Simon wrote that "schools of engineering have become schools of mathematics and physics" in which, it must be admitted, dialogue and negotiation with the public is not a central objective. Even earlier, and making a more general point, George Bugliarello (1991), former Chancellor of Brooklyn Polytechnic University noted that C.P. Snow's two cultures are in fact on diverging trajectories (Snow, 1998). In part this might be due to difficulties with the language of discourse. Wittgenstein (1998) pointed out in his posthumously published *Philosophical Investigations* that although we may believe we are speaking a common language with our fellow colleagues, it is very often the case that what we understand from our own perspectives is quite different for each. An economist or historian may understand things quite differently than do colleagues in civil engineering or environmental science. In Wittgenstein's terms, we are involved in different "language games" and we must learn the rules of the different games if we are to communicate meaningfully.

Finally, a more general set of points are covered in a number of chapters in the section titled *The Roles and Status of the New Engineer in a Global Knowledge Society* in the book *Philosophy in Engineering* edited by Christensen, Meganck and Delahousse (2007). In particular the status of the engineer in Europe, as discussed by Gasparetto, Avila and Arias, considers the disconnection between engineers and humanism.

This section has made two central arguments, summarised here. The first is that the challenges that the engineer of the 21st century faces require a different engineering education, a broader engineering education, and that the broadening aspects should be drawn from among traditional liberal arts subjects. While it can be argued that a key purpose of a liberal education is to be an end in itself, this chapter has argued that aspects of such a liberal education should be applied for purposes which are external to it. Through such application the engineering student develops critical reasoning, discourse and contextual skills. But this section has not explored the possible effects on the liberal arts students sitting in the same class with the engineering students: a topic that might usefully be explored as part of addressing the "two cultures" issue.

The second argument is that, upon completing their education, engineers can no longer focus solely on the development of new technologies. They must act as mediators between science and the world they live in. To successfully achieve this, they must seek to play leadership roles within society. Some of these leadership skills cannot be developed without liberal studies within the context of their engineering education. Again in paraphrasing Plato that the foundation of leadership was expert knowledge, accompanied by a philosophical mind, it might be argued that this could be interpreted as a call for philosophers to provide leadership. However, in the world of the 21st century, the relevant "expert knowledge" is scientific and technological and supports the argument that the engineers should become leaders with some philosophical insight.

To enable engineering leadership a deeper understanding of societal needs and their context must be achieved and coupled with a form of communications that ensures a common view of the issues involved. Where better to start than through education?

Framing a Curriculum Solution

In contrast to this chapter's earlier perspectives which emanated from inside the liberal arts community, consider the statements from the world of engineering and engineering technology. Here, many of this profession's leaders and reports have called for curriculum change despite significant national or continental differences in preparatory programmes at the baccalaureate level. Among them are the Boeing Corporation's description of the desired attributes of an engineer, the American Society of Engineering Education (ASEE), and the National Academy (2006). After reviewing 25 years of change within the National Science Foundation (NSF) and other drivers of reform in the USA, Padros (1998) outlined an action agenda for systemic engineering reform. Included in his new paradigm were integration, increased attention to social concerns and the creation of a more holistic baccalaureate education. Another valuable compilation of reports addressing engineering education and change was contributed by Ernst (1998) and published as Appendix I to the National Conference proceedings on the same theme. A broader perspective on change in university mission was published by Scott (2006).

Undoubtedly, one of the more powerful voices for engineering education reform has been that of William Wulf, the former president of the US National Academy of Engineering. In various speeches (Annual Meeting of the American Association for the Advancement of Science [1998]; Realizing the new paradigm for engineering education [1998], for example) he highlighted the urgency for reform of engineering education. He noted that while engineering considers the baccalaureate degree a professional degree "most professions (e.g., business, law, medicine) do not… Doing so is a misrepresentation" (p.28). He goes on to comment that one of the consequences is that "liberal education in the humanities is being squeezed out of the engineer's undergraduate experience, as are courses in social and management sciences" (p.28).

Even leading industrialists call for a well rounded engineering education. For example, Arthur Glenn, a former vice-president of General Electric, stated that "the broader context of engineering education is necessary for our engineering graduates today and tomorrow, and if we don't broaden the education, we will be shortchanging them to be prepared for the workplace they will find" (1998, p.31). More recently, Jones (2005) has joined this call as has Reed (2004).

Ernst & Peden (1998) compiled the proceedings of a national (USA) conference addressing needed changes in university engineering education programmes. They cited the purpose of the conference was to explore: "what an individual institution does to change from its present approach to the new engineering education, one that seeks to develop students as emerging professionals with the motivation, capability, and knowledge base for life-long learning; one that helps students see the whole world and sense the coupling seemingly disparate fields; one that incorporates a diversity of backgrounds and approaches; and one that enhances student capability to build connections between the world of learning and the world beyond" (p. ii).

Some innovative approaches to curricula, for example the Worcester Polytechnic Institute's PLAN incorporated attention to the liberal arts because they noted that "knowledge of human relationships and human need was as important to engineers and scientists as to liberal arts majors" (Durgin & Parrish, 1998, p.63). Similarly, in Drexel University's approach "humanities are integrated into the freshman curriculum. Humanities faculty coordinate the content of the course with all other course instructors" (Bilgutay & Mutharasan, 1998, p.67).

In summary, there are significant voices in the engineering profession who place real value on including liberal studies in the educational phase of forming a professional engineer. Further, collectively they have influenced professional bodies charged with establishing accreditation criteria to include outcomes that would best be obtained by the inclusion of liberal studies in an engineering curriculum.

The Role of Accreditation Criteria in the Curriculum Solution

As described in greater detail in Chapter 5, the current approach with respect to the professional accreditation of engineering programmes is that they be outcomes-focused. Programme criteria do not need to be prescriptive about how learning outcomes are achieved. Once it is clear that the desired competencies have been developed by the student, the precise mechanism by which they were gained is chiefly of concern to the provider of the education.

Accreditation of engineering and engineering technology programmes are conducted by engineering education accrediting bodies such as the Accreditation Board for Engineering and Technology (ABET) in the US, the Engineering Council in the UK ($\mathrm{EC}^{\mathrm{UK}}$) and Engineers Ireland in Ireland. There are also pan-national accrediting initiatives such as the EUR-ACE project in Europe which has developed a progressive, outcomes-based framework for the accreditation of engineering degree programmes within the European Higher Education Area.

Under EUR-ACE, the six Programme Outcomes of accredited engineering degree programmes are: Knowledge and Understanding; Engineering Analysis; Engineering Design; Investigations; Engineering Practice; and Transferable Skills. It is readily apparent that the learning outcomes specified in the EUR-ACE Framework require, in addition to the expected scientific, mathematical and engineering material, non-technical and liberal studies input. An interpretation can therefore strongly be made that is supportive of a broad education that considers the context and societal aspects of engineering. For example, under the Knowledge and Understanding outcome the Framework states that "graduates should demonstrate their knowledge and understanding of ... the wider context of engineering." Similarly, and more directly, under the Transferable Skills outcome, the Framework states that the "skills necessary for the practice of engineering, and which are applicable more widely, should be developed within the programme." Therefore, it is reasonable to conclude that the EUR-ACE Framework does indeed set an accreditation agenda in which engineering programmes should be designed to address the issues discussed in the first section of this chapter.

Turning to the US, ABET's new accreditation criteria (ABET, 2007), in addition to technical and analytical competences, call for an ability to understand professional, ethical and social responsibilities, and a respect for diversity and a knowledge of contemporary professional, societal and global issues. Again, it is reasonable to conclude that the accreditation criteria in the US provide the demand and stimulus for engineering and technology curricula to be designed so that the wider societal dimensions are addressed.

Looking beyond Europe and the US, and due in part to the need to have multinational engineering accords, there is strong convergence worldwide with respect to the criteria used in accrediting engineering programmes. Consistent with an outcomes-focussed approach, these criteria generally do not specify how the outcomes are to be achieved: that is a matter for the education providers to consider and thence to design appropriate curricula.

In concluding this section, the agenda has been set by which the concerns of senior members of the engineering profession to broaden the curriculum can be addressed. The onus is primarily on the education providers to rise to this challenge. But, it should also be noted that to coherently bring about such curriculum changes, those charged with undertaking an accreditation of a programme must be fully empowered to discharge all their duties. Currently, the members of accreditation teams are drawn from within the engineering community, and so the pace of curriculum reform lies, in the first instance, within the hands of the engineering profession itself. The inclusion of lay persons on accreditation teams has been raised in some quarters – a concept that is being considered by other professions too.

The Choice of Liberal Studies

It has been said that in some respects the Russian composer Igor Stravinsky was a magpie – borrowing styles and ideas from diverse sources for whatever musical project he was working on at the time. The practice of engineering has this same characteristic in that it willingly takes ideas, knowledge and techniques from wherever in pursuit of completing its goal. Yet engineering educators appear reluctant within their curricula to borrow and use material from other disciplines in the furtherance of offering their students the ability to conduct a satisfactory dialogue with society as well as providing the basis for the development of leadership. If it is accepted that there is a shortfall in what constitutes the engineering professional, should it not follow that engineering educators are prepared to make curricula or learning changes that would help to improve the situation?

What means are best suited to the task of curriculum reform in this dimension? For those who have tried to deal with the challenge, more commonly encountered in the USA than in the UK and Ireland, a number of solutions have been tried. For example, MIT has a general policy that requires all engineering undergraduates to take credit bearing courses from within the Humanities. As another example, Virginia Tech has University Core Curriculum Areas (UCCA) that include topics such as Creativity, Aesthetic Experience, Ideas, Cultural Traditions, and Values, Society & Human Behaviour and these can be found in the engineering curricula. Another very different approach is one that has been promoted in Denmark where in 2004 the Danish government recommended the inclusion of philosophy of science courses in degree programmes at the bachelor's level. This was in response to a UNESCO (1999) declaration in which it is stated that "science curricula should include science ethics, as well as training in the history and philosophy of science and its cultural impact". And it should be noted that engineering was also included in the declaration.

Taking a broad view of the challenge and the many possible solutions it appears that some form of framework is needed in which various strands can be drawn together. Using the Library of Congress classification, for example, it is possible to divide subjects into three broad categories: (a) those that are generic and are foundational and contribute to a "breadth of mind", e.g., philosophy; (b) those that aim to provide generic competences and skills, e.g., languages; (c) those that seek to provide specific competences in what for some would be their professional area but for others provide useful insight e.g., economics, law. Most universities that make provision for the inclusion of liberal studies in the curriculum are relaxed about the choices made by students. Nevertheless some writers have argued that philosophy, because of its truly foundational character, and the history of science, engineering and technology, because it provides context, are prime candidates for inclusion in a curriculum that sets out to develop within the engineer a broad vision of what it means to be a professional. The inclusion of history needs little in the way of justification but why philosophy? Grimson (2007) has previously attempted to provide an explanation and so only a few points will be made here. First, much of western philosophy is about coming to terms with, in the simplest of language, who we are, how we see the world, and how it all fits together. Wittgenstein used the metaphor of philosophy being about the unravelling of knots which when resolved become science or established knowledge. Considering that the greatest of minds over many centuries have devoted their lives to philosophical matters it would be strange if general insight had not been created. Second, whether by choice or due to the innate nature of philosophy, the insight gained and the "tools of the trade" that evolved are extremely, if not completely, general. And so the five classical branches of philosophy (Epistemology, Metaphysics, Ethics, Logic, and Aesthetics) that have been developed and tested across time and in different domains are as applicable to engineering as to any other human activity. Specifically the relevance of these branches to engineering can be summarised as follows:

Epistemology seeks to understand the distinction between different forms of knowledge (rational, empirical etc); to consider how knowledge is acquired, recorded, organised, maintained and used; and to provide a platform by which the provenance and limits of applicability of knowledge may be evaluated.

Metaphysics considers the question of what is reality, including abstract concepts such as substance, knowing, time and space. Metaphysics also includes ontology, mereology, and teleology considerations.

Ethics examines the determinants of appropriate behaviour, placing value to personal actions, decisions, and relations; impact of legislation and professional code of ethics.

Logic studies concepts of "right reasoning", forms of logic (e.g., temporal logic), role of logic in building conceptual models, the role of logic in how knowledge is deployed.

Aesthetics examines the distinction between "values" in arts, science and engineering; the tension or even dialogue between form and function. Since engineering involves designing and making things that did not previously exist, the aesthetic issue is raised at each departure, and case studies would illustrate the concerns.

The claim, then, is that philosophy coupled with history (of engineering, science and technology) are fundamental subjects that should be included in an engineering curriculum. And, as a co-requisite, technological education should also be added as a mandatory component of second-level education. What of the other subject areas?

These might include Economics, Law, Theory of Organisations, Library & Information Sciences, Ethnography, Education, Psychology, Social Sciences, Public Administration, Languages, Music, Visual Arts, Architecture, etc. Clearly room can never be found in the curriculum to enable a student to study more than a limited number of subjects, so one strategy could be to encourage diversity by which cohorts of students don't all make the same choice, that way the profession generally is enriched across a spread of non-technical subject areas. A more focussed approach would be to have engineers educated in specific liberal studies. Upon reflection this would appear to be an over-engineered approach, and one that runs counter to many of the arguments presented earlier. It could lead to an overly prescriptive curriculum which would in turn risk alienating both the students and the staff conscripted to teach those subjects. Better then to rely on the enthusiasm of staff, local expertise, free choice for students and the diversity argument.

Conclusions: Consequences of the Liberal Arts

Badley maintains that much of what the engineering reformists are calling for by the inclusion of more liberal arts in baccalaureate programmes with "the kind of integration we hope for… is one that seeks to unite culture and higher education in a *cooperative* or *democratic globalization* which values and implements social and educational practices and narratives based on such democratic and pragmatist principles as freedom, growth, justice and tolerance" (2003, p.478). Pascarella *et al.* (2005) even compiled evidence of such impacts.

Notably, many of the voices for change have, on the surface, called for increased presence of the liberal arts in baccalaureate engineering programmes. Looking more critically one might note that many of the calls have been more for the outcomes or consequences most frequently attributed to the liberal arts rather than to increased "seat time" in required liberal studies courses. These outcomes include the aforementioned ABET outcomes, in particular outcomes g, h, i, & j (see Chapter 5).

But, even beyond this it should be noted that the LEAP initiative, as one of the cogent calls for educational change:

> *"places special emphasis on liberal education as the portal to economic opportunity because so much of the public – and so many students – have been told just the opposite. Today, powerful social forces, reinforced by public policies, pull students – especially first-generation and adult students – toward a narrowly instrumental approach to college. This report urges educators to resist and reverse that downward course. It is time to guide students away from limiting choices and toward a contemporary understanding of what matters in college"* (2007, p. 17).

It should also be noted that within the US and parts of Europe, and for complex reasons, liberal arts has changed its perspective and is seeking to remap itself from a purview for an elite to one that is a necessity for all (and this includes engineers and engineering technologists). In addition to the consequences/outcomes of liberal arts as highlighted by LEAP's essential learning outcomes referred to earlier in this chapter, the LEAP initiative encourages programmes, including engineering ones, to address seven principles – called principles of excellence – that in their totality provide further detail to the desired consequences of increasing the presence of the liberal arts in engineering and engineering technology programmes. These include such worthy ideals as teaching the arts of inquiry and innovation, engaging in the "big" questions, fostering civic perspectives, connecting knowledge with choices and action, recognising intercultural and diverse aspects of society, and all conducted within an ethical framework.

In conclusion, regardless of any particular stance taken, the overall picture is that it would be wise to include liberal studies in engineering programmes. To set the bar at a high level, engineers need to be able to act in the role as public intellectuals and not just as technocrats. And in achieving that position the choice of what non-technical subjects to include in the curriculum remains an open question with the possible exceptions of both a philosophical and historical treatment of engineering.

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Chapter 9

The Humanitarian Context

Carl Mitcham & David R. Muñoz

Abstract: Engineering can influence and be influenced by many different contexts. Having originated in the context of industrial development, the engineering profession today is able to consider ways it might also contribute to humanitarian relief work. Following brief reviews of the historical development of engineering as a profession and the emergence of the humanitarian movement, this chapter introduces some engineering responses and comments on some efforts in engineering education to promote humanitarian engineering.

Key words: Humanitarianism, Engineering, International Service Learning, Sustainable Community Development, Humanitarian Engineering

Introduction

More directly than science, engineering is actively influenced by context. Unlike science, which claims to produce knowledge cut free from particular social histories, engineering aims to engage those histories by designing, constructing, and operating structures, machines, and diverse products, processes, and systems. Engineering can only be engineering in context.

The primary context within which engineering arose as a non-military profession in the early 1800s was the Industrial Revolution, especially in England. It has continued ever since to be closely involved with nationalist technological and economic projects in an increasing number of countries. Indeed, many people – from engineers themselves to politicians – have argued that development is synonymous with engineering achievements. This was certainly the vision of U.S. President Harry S. Truman in "point four" of his inaugural address (January 20, 1949). After committing the United States to, first, supporting the United Nations; second, economic recovery; and third, countering (Communist) aggression; Truman announced that

> *"Fourth, we must embark on a bold new program for making the benefits of our scientific advances and industrial progress available for the improvement and growth of underdeveloped areas....*
>
> *The United States is pre-eminent among nations in the development of industrial and scientific techniques. The material resources which we can afford to use for the assistance of other peoples are limited. But our imponderable resources in technical knowledge are constantly growing and are inexhaustible.*
>
> *I believe that we should make available to peace-loving peoples the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life. . . .*
>
> *Our aim should be to help the free peoples of the world, through their own efforts, to produce more food, more clothing, more materials for housing, and more mechanical power to lighten their burdens".*

Although the term "engineering" did not feature in the President's speech, it is clear that engineering constitutes a significant part of what he had in mind. Indeed, well before Truman gave the notion public expression, on the basis in part of just such ideas, colonialist powers had been exporting their engineering prowess to countries in Latin America, Africa, and Asia, while peoples in the colonies themselves had been attempting to jump start engineering education in the contexts of their own development.

Yet late in the same century in which engineering emerged as a civilian profession, there also arose a number of movements critical of different aspects of industrialization, especially in its nationalist or imperialist guises. Humanitarianism, as a criticism of some of the implications of nationalism and imperialism, indirectly invited engineers to self-examination and to consider the possibility of contexts alternative to those in which their professional practices had commonly been pursued.

The focus here will be on humanitarianism as a socio-historical movement that presents an alternative context of particular relevance to engineering. In what follows we seek to explore how the humanitarian context might give rise to new opportunities in the engineering profession at the levels of both practice and education. The exploration will begin with some brief background reflections on the rise of engineering as a profession, followed by a review of the humanitarian movement and, finally, conclude with a description of some steps taken at various universities to develop programs in humanitarian engineering education.

Background

Engineering as it is currently known and professionally practiced is highly sensitive to context. As commonly defined, for example, in the *McGraw-Hill Encyclopedia of Science and Technology* (2008), engineering is the art or science of "directing the great sources of power in nature for the use and the convenience of humans." But people in different contexts can have very different ideas about what counts as use or convenience.

The *McGraw-Hill Encyclopedia* definition is little changed from an 1828 formulation by Thomas Tredgold that was used in the Royal Charter of the Institution of Civil Engineers (ICE): "Engineering is the art of directing the great sources of power in nature for the use and convenience of man" (see Watson, 1988). What "use and convenience" meant to Tredgold and other members of the ICE is spelled out in the seldom quoted short "Description of a Civil Engineer" that identified use and convenience non-problematically as designing, building and maintaining infrastructure needed for industrial production and commercial trade: "The most important object of Civil Engineering is to improve the means of production and of traffic in States, both for external and internal Trade" (Tredgold, 1828, p. 20). In the original historical context, then, use and convenience was simply assumed to be synonymous with the advancement of industrial and commercial interests. Although this view was common at the height of the Industrial Revolution, it became over the course of the following century subject to social and philosophical qualification.

The trajectory from Tredgold to the present is complex, and made more so by the distention of engineering across numerous professional associations and the lack of unifying organizations such as those manifested in law and medicine. Yet such complexity need not affect the point at issue. Here it is sufficient to note that the current "Code of Professional Conduct" of the ICE states in its third rule as a contemporary restatement of use and convenience that "All members shall have full regard for the public interest, particularly in relation to matters of health and safety, and in relation to the well-being of future generations" (Institution of Civil Engineers, 2008). Whereas in the early 1800s it was easily assumed that the practice of engineering knowledge and skill would easily redound to human benefit, nearly two centuries later this assumption calls for explicit articulation and defense – no doubt because of a change in context that includes a humanitarian questioning of unfettered industrial production and use.

Humanitarianism

One of the most consistent, critical accounts of the real world of human health and safety in the broadest sense is to be found in the humanitarian movement, which emerged in parallel with the engineering profession itself. It was only shortly after the crystallization of engineering as a profession in the early 1800s that a challenge to some of its contextual assumptions began to emerge in the late 1800s in what has become known as humanitarianism. Like engineering, humanitarianism exhibits a complex history. Humanitarianism has roots in the cosmopolitanism of classical antiquity (stoicism), Christian missionary theology (from St. Paul to Albert Schweitzer), the moral universalism of Enlightenment rationalism (Immanuel Kant), and political revolutionary movements (such as socialism and communism). For present purposes, however, humanitarianism will be restricted to a particular movement that has itself adopted the term, the history of which can be outlined in five phases. (The following historical sketch draws heavily on Smyser, 2003.)

With regard to the first phase, the humanitarian movement is generally described as having originated in the mid- to late 1800s. It is usually associated with the rise of another profession, that of nursing, as promoted in the work of Mary Seacole and Florence Nightingale in the Crimean War (1854-1856) and Clara Barton in the U.S. Civil War (1861-1865). But the key event was the reaction of Swiss businessman Henri Dunant (1828-1910) to the Battle of Solferino (1859), which ended the Second Italian War of Independence. This battle resulted in approximately 30,000 Austrian, Italian, and French casualties in nine hours of fighting. When Dunant witnessed the industrial carnage of the Solferino battlefield and the tendency of medical personnel from each army to restrict attention to their own injured, he was stimulated to imagine a new kind of medical care that would address need irrespective of national identity. This vision led five years later to creation of the International Committee of the Red Cross / Red Crescent (ICRC), an effort for which Dunant subsequently received the first Nobel Peace Prize (1901). The progressive institutionalization of the ICRC involved creation of the Geneva Accords for the conduct of hostilities and granted battlefield protection to all medical personnel. The ICRC also became a neutral institution attending to the needs of prisoners of war; on condition that it respected national sovereignty and only reported any observed mistreatment of prisoners to the offending state, not to other states or the international community.

During a second phase, the first half of the 20th century saw the development of new forms of humanitarianism that expanded the movement beyond the limits of medical care directed toward military personnel. The ICRC became concerned with the plight of civilian non-combatants and for persons caught in natural disasters. With regard to new models of humanitarianism there was the work of Norwegian scientist and explorer Fridtjof Nansen (1861-1930) and of U.S. mining and civil engineer Herbert Hoover (1874-1962): Nansen in post-World War I work resettling refugees under the auspices of the League of Nations, and Hoover in relief work during and after the war as well as in response to the Great Mississippi Flood of 1927. This period also witnessed the emergence of humanitarian NGOs other than the ICRC: e.g., Baptist World Aid (1905), American Friends Service Committee (1917), Catholic Medical Mission Board (1928), Save the Children (1932), OXFAM (1942), and CARE (Cooperative Action for American Relief Everywhere, 1945). At the same time, with regard to the ICRC, its knowledge of the Holocaust, war crimes, and crimes against humanity during World War II, and its inability to reveal these to the world because of its respect for national sovereignty, raised fundamental questions about some of its operating assumptions. Creation of the United Nations (1945) and international adoption of the Universal Declaration of Human Rights (1948) provided a further basis for questioning the primacy of national sovereignty.

In a third phase, however, something like humanitarian development became a kind of free-world ideological alternative to Communism. This was the explicit proposal of Truman and was embodied as well in the European Recovery Program or Marshall Plan (1947-1951). The creation of international agencies such as the United Nations Educational, Scientific and Cultural Organization (UNESCO, 1945), the UN High Commission for Refugees (UNHCR, 1950), the Organization for Economic Cooperation and Development (OECD, 1961), the U.S. Peace Corps (1961), and a series of UN peacekeeping actions (India-Pakistan, 1949; Suez, 1956; Congo, 1960; *et al.*) combined to give humanitarianism the character of an anti-communist program. (As an aside, it is worth noting that one of the primary contributors to the concept and development of the Peace Corps was a civil engineer, Maurice Albertson.)

Beginning in the late 1960s, however, and indicative of a fourth phase, humanitarianism began to separate itself from its previous close association with anti-communism. One key event was the Nigerian Civil War in the break-away province of Biafra (1969), which became as well the first televised international humanitarian crisis. The experience within the disaster relief community was one of gut wrenching paradox: providing relief that only enabled killing to continue and become more murderous. In such a situation, humanitarian aid workers began to challenge the primacy of respect for sovereignty. Aid workers began to openly criticize governments on both sides of the civil war and governments outside the conflict supporting one side or the other. The resulting crisis of conscience in the humanitarian community catalyzed the founding, by the French physician Bernard Kouchner, of *Médecins sans Frontières* (MSF or Doctors without Borders) in 1971. MSF refused to be limited by state sovereignty. Even without permission, MSF was in many instances willing to take action and has often openly criticized state and non-state actors alike. Over the course of what came to be known as the "decade of the refugee" (1975-1985), as people fled state-initiated disasters in a series of countries from Indochina to Africa and Afghanistan, respect for the sovereignty of states that were in fact killing their peoples became increasingly hard to defend.

Finally, since the end of the Cold War (late 1980s) and the rise of non-state actor terrorism (late 1990s) the crisis of humanitarianism has become only more acute. Indeed, worry that the rejection of the primacy of sovereignty could lead to indefinite warfare was part of a European resistance to military action led by the United States in the Balkans. And the "humanitarian war" against Yugoslavia during the Kosovo campaign (1999) called into question the whole meaning of humanitarianism, as has the so-called "war on terror" that became the touchstone of international relations post-2001.

Two perspicacious articulations of the early 21st century crisis in humanitarianism can be found in works by David Rieff and David Kennedy. As Rieff observes, "[H]umanitarianism is an impossible enterprise. Here is a saving idea that, in the end, cannot save but can only alleviate.... For there are, as Sadako Orgata, the former head of UNHCR, put it, "no humanitarian solutions to humanitarian problems." More than that, the pressures on humanitarian workers ... have become all but intolerable". (Rieff, 2002, p.86). Or, in the words of Kennedy,

> *"We promise more than can be delivered – and come to believe our own promises. We enchant our tools.... At worst, ... our own work [contributes] to the very problems we hoped to solve. Humanitarianism tempts us to hubris, to an idolatry about our intentions and routines, to the conviction that we know more than we do about what justice can be".* (Kennedy, 2004, p.xviii)

At the same time, in spite of these well recognized difficulties and failings, it is important to recognize that there have also been some successes. As other observers have argued, humanitarian action has made important contributions to the lives of the many of the powerless and poor (see, e.g., DiPrizio, 2002; Minear, 2002; Terry, 2002; and Architecture for Humanity, 2006).

Humanitarian Engineering

It is against this double background of engineering as context dependent and the emergence of a new context that what has come to be called humanitarian engineering began to emerge during the war in Biafra as a new form of humanitarianism. The key figure was an engineer named Fred Cuny (1944-1995).

The Cuny story has been told in more than one medium. A Public Broadcasting System *Frontline* program, "The Lost American" (1997), did so for television. Michael Pritchard's "Professional Responsibility: Focusing on the Exemplary" (1998) is an academic paper. Scott Anderson's *The Man Who Tried to Save the World* (1999) did so in book form. In brief summary: after graduating with a degree in civil engineering from Texas A&M University and doing some engineering work on the new Dallas-Ft. Worth international airport, Cuny went in search of a more fulfilling form of engineering. He wound up flying relief supplies into Biafra in 1969. Moved by such an experience, he returned to Dallas to found the INTERTEC Relief and Reconstruction Corporation and became involved in a series of disaster relief operations.

One of Cuny's beliefs was that there was a distinct place for engineering in humanitarian disaster relief work. More people than physicians and nurses were needed. Even in the area of development, there was a need for more than agricultural specialists and agronomists. In some ways he picked up and carried forward (mostly without knowing it) some of the alternative technology ideas from the 1970s such as those associated with E.F. Schumacher's *Small Is Beautiful* (1973). But Cuny's work in the Nicaraguan and Guatemalan earthquakes (of 1971 and 1976, respectively) led him to formulate what became known as the "Cuny approach" to using disasters as a catalyst to improve people's lives (see Cuny, 1983). Further disaster and development work undertaken during the Sudan-Ethiopia famine (1985) and with the Kurds in Iraq (1991); during the Somalia relief operation (of 1992); and to repair the water system during the siege of Sarajevo (1993-1994) extended Cuny's influence. Awarded a MacArthur Foundation Fellowship for 1995 in a program designed to recognize "hard-working experts who often push the boundaries of their fields in ways that others will follow," Cuny was assassinated in Chechnya in 1995 before he could be notified (Arenson, 1995).

Stimulated by the ideals of MSF and Cuny, the early 1990s witnessed the emergence of a humanitarian engineering NGO network. Using some form of the name "Engineers without Borders" (EWB), engineering students began independently to explore possibilities for engineering in the context of humanitarianism in diverse localities: Ingénieurs Sans Frontières (France), Ingénieurs Assistance Internationale (Belgium), Ingeniería Sin Fronteras (Spain), "Ingeniører uden grænser" (Denmark), and "Ingenjörer och Naturvetare utan Gränser – Sverige (Sweden), Ingegnería Senza Frontiere (Italy), and others. In 2003 these groups organized "Engineers Without Borders – International" as a network to promote "humanitarian engineering ... for a better world," now constituted by more than 41 national member organizations. At the same time, engineering and technology came increasingly to be recognized as able to play a crucial role in humanitarian action (see Cahill, 2005).

Toward Humanitarian Engineering Education

Given the more or less spontaneous emergence of this spectrum of humanitarian engineering interests and initiatives, it is to be expected that engineering education would attempt to make its own contributions. In many cases EWB activities, which are primarily project based, have become associated with educational programs, especially service-learning programs. Some illustrative cases in diverse institutional contexts include:

- **Technology Assist by Students (TABS), founded 2000 at Stanford University.**
- **Engineering World Health (EWH), founded 2001 at Vanderbilt University and currently residing at Duke University.**
- **Engineers for a Sustainable World (ESW), founded 2001 at Cornell University, now headquartered in Oakland, CA.**
- **Engineers in Technical and Humanitarian Opportunities of Service (ETHOS), founded 2004 at Iowa State University.**

Even more closely linked with curriculum developments have been

- Engineering Projects in Community Service (EPICS), founded 1995 at Purdue University, to "create partnerships between teams of undergraduate students and local community not-for-profit organizations to solve engineering-based problems in the community," which was recognized in 2005 with the Gordon Prize at the National Academy of Engineering.
- Engineering for Developing Communities (EDC), founded 2001 at the University of Colorado, Boulder, in order to educate "globally responsible graduate engineering students and professionals who can offer sustainable and appropriate solutions to the endemic problems faced by developing communities worldwide."

There are further illustrations from outside the United States. In Japan the Tokyo Institute of Technology offers undergraduate and graduate programs in International Development Engineering to help "students become engineers who have ability, courage, and leadership, and can solve the problems" associated with international development projects.

Given the complexities of such educational efforts and the ways in which tensions within them can reflect those within the world of humanitarian activism itself, it may be useful to consider in slightly more detail, as a brief case study, the emergence of one program in humanitarian engineering at the Colorado School of Mines. In 2003 (with support from the William and Flora Hewlett Foundation) a team of faculty from the Division of Engineering and the Division of Liberal Arts and International Studies undertook to develop an undergraduate minor in Humanitarian Engineering (HE). As is often the case in interdisciplinary work (see, e.g., National Academy of Engineering, 2004), difficulties arose in communicating both between engineering faculty involved and those not, as well as among the involved engineers, social scientists, and humanities scholars. For example, some faculty not involved objected to the very term "humanitarian engineering." To them it implied that other types of engineering were not of human benefit. All engineering, they maintained, was humanitarian engineering (Bauer *et al*., 2005). With regard to communication among different disciplinary traditions, there were tensions between those who wanted to go slow in order to incorporate knowledge and perspectives from the social sciences and the humanities and those who wanted to move forward with doing good work.

After considerable debate, humanitarian engineering was described in the following way:

Humanitarian: to promote present and future wellbeing for the direct benefit of underserved populations.
Engineering: design under physical, political, cultural, ethical, legal, environmental, and economic constraints.
Humanitarian Engineering: design under constraints to directly improve the wellbeing of underserved populations.

In accord with this description, the HE team structured the minor to include at least three courses in Liberal Arts and International Studies (one of which is introduction to ethics) and a technical elective focused on meeting basic human needs or providing a more holistic view of the role of technology in sustainable human development. The program culminates in a two-semester capstone senior design project. One of the most extended and successful among a number of such projects has been with a small village in Honduras to design and construct a water system, which was among the 21 of the UNESCO/Daimler sponsored 2004/2005 Mondialogo Engineering Awards for "sustainable development and poverty reduction worldwide."

Deciding what really counts as a humanitarian engineering project has nevertheless not always been easy. Efforts to clarify our understandings in this regard have led to the formulation of a set of four operationalizing principles:

- There must be a need that originates from the people directly benefiting from the proposed work.
- Whatever need is involved should be related to a basic human need, usually physiological although some have included higher level needs such as education and economic development.

- Good communication is essential, preferably with the people directly benefiting from the work and/or commonly through a non-governmental organization intimately familiar with the local context.
- The need should be one that can benefit from engineering knowledge.

With regard to the first principle, use can be made of an engineering design process as systematized in the quality function deployment technique (see Cohen, 1995). The fundamental approach is to begin by identifying stakeholders and then working with them to establish a set of needs to be prioritized. Subsequent analysis compares competitive solutions and finally, based on such inputs, a set of specifications for the design are developed.

With regard to the second principle, one way to identify basic needs is to consider the prior work of Abraham Maslow. According to Maslow (1954) there exists a hierarchy of human needs, from physiological and safety needs near the bottom of a pyramid through needs for belongingness and esteem, needs to know and aesthetic needs, and culminating at the top with needs for self-actualization (and, as some contend, self transcendence). Admittedly, there have been criticisms of Maslow, especially his conceptualization of higher level needs. One issue focuses on cultural differences, i.e., the fact that more emphasis in some countries, as in the United States, is placed on individual needs, while in other societies greater value is given to the community (Hofstede, 1984).

Yet from an engineering perspective, there clearly exists a hierarchy of physiological needs, defined by the average survival time for a human who is denied access to a number of basic life requirements. A human can live only a few minutes without air, so this represents the most pressing physiological need, closely followed by "heat" or thermal regulation. People living on the extreme latitudes of the planet would be most concerned with thermal regulation during the winter months. However, thermal regulation can also be a problem associated with overheating in tropical desert regions. Need for water and food would follow, respectively. An emergency response or triage worker must keep this hierarchy in mind when responding effectively to disasters (Davis and Lambert, 2002). At the same time, engineers involved in efforts to meet such needs may be manifesting an effort to meet their own higher level needs for esteem and self-actualization.

Working with principles three and four has pushed us to appreciate the degree to which social and political aspects of a project are often more crucial than technical ones. This recognition has led us to seek a deeper understanding of (sustainable community) development (Bridger and Luloff, 1999). If projects are to really benefit others, for instance, it is crucial to seek out local sources of knowledge and to value that knowledge in discussions. This idea, formerly known as participatory action research, elaborates on the work of Paolo Freire (1970). (See also the analyses in Fals-Borda and

Rahman, 1991.) As a result, we have also learned to look for opportunities to help build capacity for autonomous action among those with whom we work. In this regard, a series of questions posed by Caroline Baillie (2006) can serve as a template for self-examination. In thinking about any project, it is important to ask an open-ended set of questions, beginning with:

1. Who benefits and who pays?
2. Who stands to gain?
3. Who stands to lose? (we added this one)
4. Who needs what and when?
5. Who decided on what was needed?
6. How will the project be sustained?
7. Who contributed to the planning and execution?

Finally, it is worth noting that humanitarian engineering education can have benefits beyond the humanitarian context. One need even within industry in the developed but globalizing world is increased sensitivity to societal and cultural issues. Such can easily be a byproduct of humanitarian engineering learning. In the field of government service as well, the development of skills associated with humanitarian engineering can be beneficial. And for students who seek to practice humanitarian engineering directly, it can be projected that numerous NGOs will increasingly depend on the abilities of students who have contributed to and graduated from such programs. The context of engineering in the future will almost certainly include the humanitarian context.

Closure

Engineers have long been focused on meeting the needs of humanity. During the past century, however, we have become increasingly aware of new dimensions of human need not always addressed by engineering practice and education. Though we have been to the moon, sent robots to Mars, and can do marvelous things on the mega and nano scales, the fact remains that on our unique planet more than a billion people lack access to clean water and 11 million children under the age of five die every year from malnutrition and disease (Kandachar and Halme, 2008). Indeed, even the engineered infrastructure of the developed world will need to change in order to secure a sustainable future. Our energy and water consumption, food production, and patterns of material consumption will need to change to accommodate a habitable world for our descendents. Our graduates must understand the global (physical, social, political, cultural, environmental, and economic) constraints that they face and how to use all available tools as they work toward sustainable solutions. This is a challenge to which humanitarian engineering can make a meaningful contribution.

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Chapter 10

Diversity in Engineering: Tinkering, tailoring, transforming

Jane Grimson & Caroline Roughneen

Abstract: Diversity is essential for creativity and innovation, which are at the heart of engineering. Thus engineering can benefit from the richness and varied perspectives and expertise which individuals from different ethnicity, culture and gender can bring to problem-solving. Furthermore promoting diversity in the workforce provides greater access to talent by increasing the pool of qualified and skilled professionals. This chapter focuses on gender diversity as an area which has received considerable attention for many years from both the research community and policy makers. Researchers seek to explore the reasons for the continued under-representation of women in engineering in spite of numerous policies, initiatives and interventions. The subject will be explored through the role of female engineers in academia as it is the education sector which has the most critical influence on recruitment and retention, not just in academia itself but in the public and private sector generally. Using the "tinkering, tailoring, transforming" model developed by Rees (1995), the chapter will explore the history of women in engineering, highlighting those interventions which appear to be having the greatest positive impact. In spite of the dearth of rigorous evaluation in terms of sustainability and scaleability, there is a growing body of evidence pointing to best practice in this area. This indicates that a significant shift in attitudes and culture is required in order to reach the critical mass of 30% when the process becomes embedded and sustainable.

Keywords: Diversity in Engineering, Women in Engineering

Introduction

Engineering is concerned with the application of scientific and mathematical principles towards practical ends. It seeks to create cost-effective solutions to practical problems by applying scientific knowledge to building "things" or systems. It is about solving problems using a systematic approach, subject to economic, environmental, social and other constraints. It deals with problems – whether it is concerned with building a bridge or designing a heart pace-maker – whose solutions matter to ordinary people. Thus engineering lies at the interface between science on the one hand and society on the other. Traditionally engineers have concentrated on the interface with science, and in the rapidly accelerating speed of scientific advancement, this continues to be a fundamental part of the engineer's approach to problem-solving. And this is challenging as in the past decade more scientific knowledge has been created than in all of human history (Kaku, 1998). Almost daily, the headlines herald new advances in computers, telecommunications and biotechnology. However, while applying engineering and scientific principles can solve the technical problems of, say, designing a new road, the real challenges for engineering are increasingly non-technical. Rather they are concerned with the broader context in which the road is being built and its impact on the environment and people. It is the engineer who has the knowledge and skills to address the environmental, regulatory, economic and human constraints and to put forward creative and innovative solutions which take account of these wider issues within the context of what is technically feasible. Thus engineers must address increasingly the other side of the interface – the interface with society – and gain an understanding of the language and principles of the so-called "softer" sciences.

This new climate of engineering practice, together with evidence of a threatening skills shortage, requires us to look beyond our traditional pool of talent in order to capture new perspectives and build a stronger, more diverse, but nevertheless synergistic workforce. Promoting diversity in the workforce, that is, promoting a workforce which includes diversity of ethnicity, gender and culture, is seen as providing both the public and private sector with greater access to talent by increasing the pool of qualified and skilled professionals. Furthermore, it increases innovation in research, provides a better match with clients and the market-place and the private sector, and encourages a wider range of approaches, problem definitions and strategies, all of which can only improve the quality of outputs.

The twentieth century showed great variation in respect of women's participation and acceptance into the engineering profession. Prior to the World Wars, women were generally excluded from becoming engineers yet were actively encouraged, applauded and accepted into the engineering profession and activities during both wars when male labour was unavailable. Subsequently, in the UK for example, a policy was adopted which once again excluded women from engineering activities so the returning men would have jobs to go to (Wightman, 1999). As Katherine Parsons, wife of Charles Parsons, inventor of the steam turbine, so eloquently put it: "It has been a strange perversion of women's sphere – to make them work at producing the implements of war and destruction, and to deny them the privilege of fashioning munitions of peace...women are merely told to go back to doing what they were doing before" (Scaife, 2000, p.462). C.P. Snow, the English physicist and novelist observed in his book "The Two Cultures" that "It is one of our major follies that, whatever we may say, we don't really regard women as suitable for scientific careers. We thus neatly divide our pool of potential talent by two" (Snow, 1959, p.103).

It was not until the 1970's that women began to pursue engineering careers to any significant degree. Numbers have slowly increased since then, though there has been evidence of plateauing and even a reduction in recent years. Internationally the proportion of women graduating with an engineering degree is approximately 20% (European Commission, 2006) with very few countries attracting women to the critical mass level of at least 30% as suggested by Byrne (1991).

In the 25 member states of the European Union (EU-25) in 2004, women accounted for 44% of the total labour force. Between 1998 and 2004 their participation rate rose faster than that of men (1.5% for women; 0.4% for men). Yet, for scientists and engineers, female participation was markedly lower, at 29%, with the participation rate between 1998 and 2004 increasing much more slowly than that of men (0.3% for women; 2.0% for men). This is a worrying trend since, if it persists, women's participation in the field of science and engineering will decrease in relative terms (European Commission, 2006). Critically, these figures indicate that there will never be sufficient numbers of women engineers to reach the critical mass. Below the critical mass "a minority group within a population (especially one that has traditionally been discriminated against) is easily marginalized; its continued presence and survival is in constant jeopardy often requiring outside intervention and assistance to prevent extinction" (Etzkowitz *et al*., 1994). As the level of participation increases, a tipping point is reached, generally regarded as being between 25-30%, at which the perspectives of members of both groups change and the character of the relations between the groups begins to change qualitatively.

Turning to academia, the percentage of women in tenured academic positions in the EU-25 is 35% (European Commission, 2008a). Figures for the numbers applying for positions and the numbers being promoted are difficult to obtain. Anecdotal evidence would indicate that especially for senior positions in engineering (full professorships) there are often few if any female applicants. Valian (1998) describes many studies that illustrate that women candidates will be more fairly evaluated when they become more than 25% of the applicant pool, which is consistent with the overall effect on culture within an organisation when the percentage of women reaches a critical mass. Similarly more women will be granted tenure in faculties where there is already a high proportion of tenured women. The contention is that where there is a better balance of numbers, female applicants are no longer identified as women applying for traditionally men's positions.

This chapter examines the issues surrounding the under-representation of women in academic engineering. The recruitment and retention of women in academia is of crucial importance for the entire engineering sector. Universities determine who has access to engineering programmes and hence to engineering careers. They provide role models not just for engineering students but also for students training to be teachers who in turn will influence the career choices of the next generation. The chapter begins by looking at the number of women entering engineering, examining the extent to which girls have traditionally been excluded from engineering. Current data on the position of women in engineering in academia is presented followed by a discussion of a number of key reports and policy studies which have sought to understand and propose solutions to the problem of the under-representation of women in engineering. The central section of the chapter provides a detailed analysis and examples of a variety of interventions across many different countries under the "tinkering, tailoring, transforming" model proposed by Rees (1995). The chapter concludes with a set of recommendations in relation to best practice based on those interventions which appear to have the greatest impact.

Entering Engineering

The metaphor of the "leaky pipeline" (Alper, 1993) has been used for many years to describe the progressive loss of women on the career ladder. The phenomenon is clearly visible in the higher education sector with women accounting for 20% of engineering graduates but 6% of professors in engineering and technology (European Commission, 2006, p.60). The pipeline metaphor has been increasingly criticised for being too simplistic and encourages solutions which are based solely on plugging the leaks. It ignores the numbers entering the pipeline which is an important factor in engineering and also ignores those factors which might draw men and women out of the pipe. These "pull" factors can be just as important as the "push" factors which propel people along the pipe. A study by the economist Anne Preston (Preston, 2004) showed that the primary reason (35%) women left science was that they preferred other positions (pull), closely followed (34%) by the lack of career opportunities (push) and better pay (33%) in non-science positions (pull). By contrast, the main reason why men left science was overwhelming (68%) due to the better pay offered outside science (pull) closely followed (64%) by the lack of career opportunities (push). Nevertheless, the leaky pipeline metaphor has proved useful in highlighting the problem provided that it is not the exclusive driver of solutions.

In most developed countries today, a career in engineering is equally accessible in principle at least to both men and women provided a reasonable level of mathematics has been reached in high school. This was not always the case. For example, in Ireland between the 1930s and 1968, special mathematics examinations were provided – "Arithmetic – girls only" and later "Elementary mathematics (for girls only)". The rationale was presumably based on the assumption that girls were either less mathematically capable than boys or that the subject was less relevant to their subsequent careers (O'Connor, 2007). It is worth noting that at that time the majority of students attended single sex schools, thus helping to reinforce the gender stereotyping of subjects.

In Ireland the proportion of girls sitting for the higher-level mathematics examination required for entry to engineering programmes remained very low up until the 1960s (e.g. 1% of girls in 1952 compared to 26% of boys). For most female pupils at that time, higher-level mathematics was simply not an option that they were offered (O'Connor, 2007). The gender imbalance in the proportions taking higher-level mathematics has persisted over time. In 1991 boys were still twice as likely as girls to sit the higher-level paper (16.1% versus 8.2%). However, the gap has narrowed significantly in recent years where in 2008, 22% of boys and 15% of girls took higher level mathematics (Department of Education and Science, 2008). This historical gender segregation of the subject has reduced access to engineering by girls and reinforced the stereotype that mathematics and engineering are for boys. Drew & Roughneen (2004) noted that mothers can have a negative influence on girls" decisions to study engineering, which may in part exist because of the social stereotypes and expectations relating to girls being passed from generation to generation. While the Irish educational system may be unusual compared to those of other countries in that there remains a significant number of single sex schools, the overall figures for those entering engineering programmes at third level are comparable. Girls are consistently over-represented in the highly competitive programmes such as medicine and law and under-represented in less competitive programmes such as engineering and the physical sciences. Girls with good performance in mathematics are proportionately less likely than boys with the same performance level to enter mathematically oriented programmes (Department of Education and Science, 2008).

Current Position of Women in Engineering in Academia

The leaky pipeline referred to above is a feature of the career path of women in many domains, not just engineering in academia. Figure 10.1 – the so-called "scissors diagram" – illustrates the way in which the gender gap changes throughout the stages of an academic career, beginning with undergraduate level (ISCED 5A) through to senior grades. The slope of the graph may vary from country to country and from discipline to discipline, but the overall shape is the same. Engineering disciplines are slightly different in that there are never more female than male undergraduate students and therefore the two lines never intersect.

Figure 10.1: Scissors Diagram: Percentage of men and women in a typical academic career in science and engineering, students and academic staff, EU-25, 1999-2003.
(European Commission, 2006, p.55)

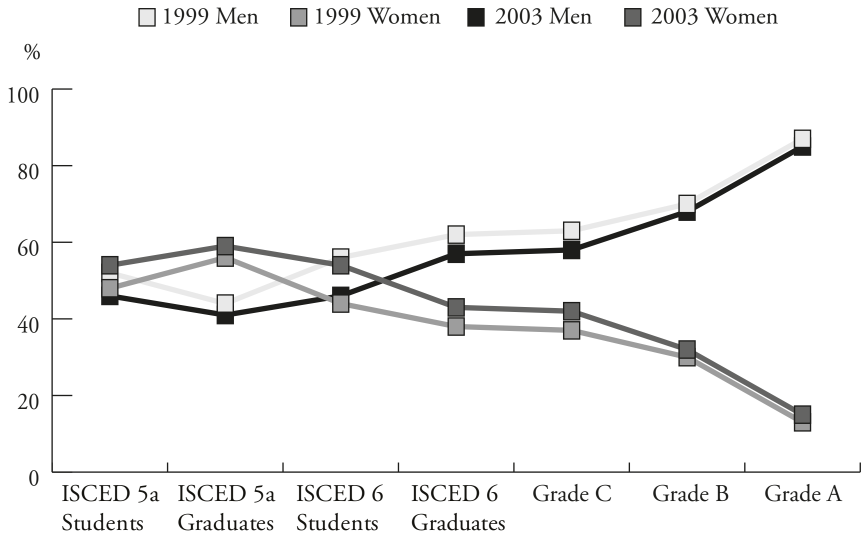
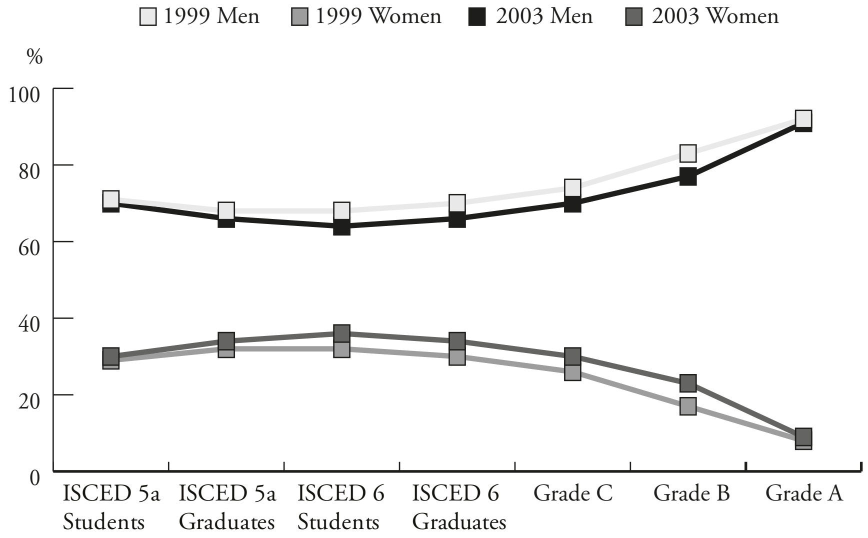


Figure 10.2 illustrates the Europe-wide percentage representation of women and men in science and engineering in 1999 and 2003 from undergraduate students (ISCED 5A) though to grade A – full professorship or equivalent.

Figure 10.2: Percentage of men and women in a typical academic career in science and engineering, students and academic staff, EU-25, 1999-2003
(European Commission, 2006, p.56)



The vertical dimensions of patterns of employment – relative distribution of women and men at different levels of seniority within the engineering hierarchy – are vital as it is at these senior levels that decisions are made and leadership is defined and carried forward into the research agenda. Those in senior positions also act as role models for future leaders. In the EU in higher education, only 15% of those at the highest academic grade (grade A, equivalent to professor) are women yet the gender imbalance at this senior grade is even greater in engineering and science where the proportion of women is just 9% (European Commission, 2006).

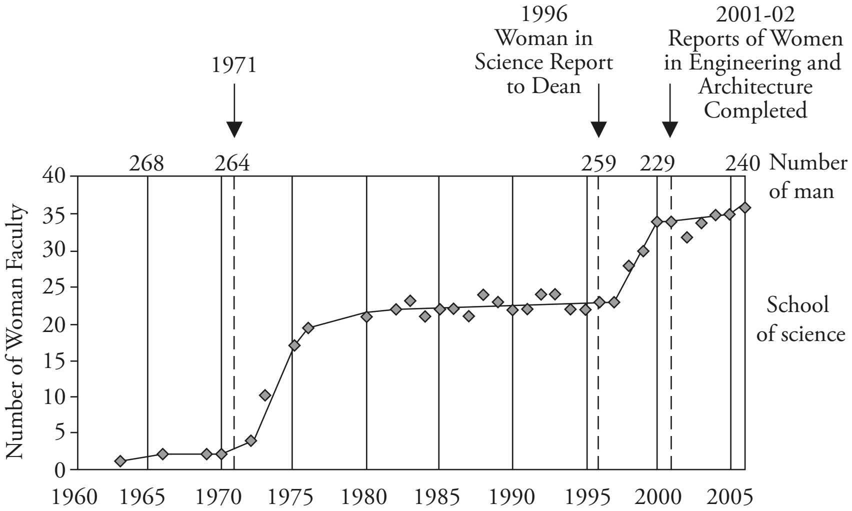
History of Research Informing Policy: Key Studies

The under-representation of women in science and engineering has been extensively studied in the research literature and the realisation has grown that the waste of talent involved in this "leaky pipeline" has to be addressed and not simply for reasons of equity and social justice. Rather the matter is being increasingly viewed as an economic imperative. This economic imperative to increase the participation and retention of women in Science, Engineering and Technology (SET) is not only about increasing the pool of available labour, although this is clearly important in the context of the skills shortage in engineering, it is also a question of increased diversity fuelling creativity and innovation. It is not simply a matter of attracting more women into careers in SET. It is also a matter of retention and advancement. Furthermore, enriching the research agenda of an institution through greater diversity is of critical strategic importance. Women often ask different questions in research, use alternative approaches, and may take a more interdisciplinary approach (Mitchell, 1999). The European Technology Assessment Network – ETAN – Report (2000) highlighted the fact that the principal determinant of academic success, namely peer review, can disadvantage women in subtle ways. A key paper published by Wennerås & Wold (1997) demonstrated that women had to be 2.2 more productive than their male counterparts in order to be successful in the competition for research fellowships offered by the Medical Research Council in Sweden. These findings attracted considerable attention across the world and triggered a series of similar studies including the UK's Research Councils and Wellcome Trust study on gender equality in UK grant applications (Blake & La Valle, 2000), Denmark (Vestergaard *et al.*, 1998), and Finland (Peltonen, 1999).

While not all these studies were conclusive, they did bring about a number of changes in the review process. However, there still appear to be some subtle effects at work which are difficult to explain and therefore difficult to address. A recent study by the European Molecular Biology Organization (Ledin *et al.*, 2007) tested whether unconscious gender bias influences the decisions made by the selection committee for fellowships, where women had lower than average success rates. The application process was gender blind, including external sources such as letters of recommendations. A review of citations noted that women had a lower average number of publications, lower impact factors and lower citation counts (for first and last author publications). Further results showed that when investigating the cohort of researchers, they found that women, on average, have less time available at work and have a greater burden to carry outside the laboratory; they tended to receive less professional support than men; and felt, more so than their male counterparts, discriminated against because of their gender.

Another important study conducted at the Massachussetts Institute of Technology (MIT) by the Committee on Women Faculty in the School of Science (1999) showed that women faculty appeared to be marginally discriminated against in many different often minor ways which on their own could not explain why so few women made it to the top as full professors but which together had a significantly detrimental effect on their careers. As a result of this report, several policies were put in place and the number of women appointed increased significantly. However, there is evidence of a plateauing in recent years suggesting that the interventions have not yet been fully absorbed into the culture of the organisation (Figure 10.3). Hopkins (2006) deduced that the first sharp rise in the number of women faculty in science beginning in 1972, was the result of pressures associated with the Civil Rights Act and affirmative action regulations in the United States. The second sharp rise, between 1997-2000, directly resulted from MIT's response to the 1996 Report on Women Faculty. However, the progress was not sustained and a number of women faculty in SET have left after failing to get tenure.

Figure 10.3: Number of Women faculty in the School of Science (1963-2006) at the Massachusetts Institute of Technology (Hopkins, 2006)



At the European level, two influential groups were supported by the European Commission to undertake studies on women's under-representation in science, including engineering, namely the Helsinki Group on Women in Science and the ETAN Expert Working Group (European Commission, 2000). The Helsinki group reviewed policies established in 30 countries (Rees, 2002). While the report acknowledges that there is considerable diversity in terms of infrastructure surrounding women in science among the countries examined, it concludes that a gender imbalance in decision-making about science policy is a common factor. It calls for the integration of gender mainstreaming into policy and decision making in all areas.

The ETAN Expert Working Group on Women in Science identified numerous barriers which contribute to the relative absence of women from academic careers in science, particularly at higher levels. The report highlighted the need for close gender monitoring and readily available statistics, as well as the provision of grants and networks specifically for women researchers. The report concludes that "the under-representation of women threatens the goals of science in achieving excellence, as well as being wasteful and unjust" (European Commission, 2000).

From these reports, key initiatives have been born at a European level. A sub-group of statistical correspondents was formed within the Helsinki Group with the aim of gathering extensive and internationally comparable statistics on women in SET across Europe. The results of this group are the production of statistical reports: She Figures 2003 and 2006 (European Commission, 2003 and 2006). Interestingly the 2003 Report suggests that countries such as Portugal, Ireland, Greece and Finland which have a higher (>40%) than the average (33%) of female public researchers are countries in which "scientific professions are less developed and where the institutions are relatively new… In other words, countries where traditions run less deep" (European Commission, 2003).

Intervention Programmes

Over the past two to three decades there have been many initiatives addressing the under-representation of women in science and engineering – some operating at the departmental level, others at the institutional level and a growing number at the national level. Very few have been subjected to rigorous evaluation which makes the identification of best practice at best difficult and at worst impossible. Many of the initiatives are neither sustainable nor scaleable. In order to try to understand the history of these programmes and their targets, Rees (1995) developed a useful taxonomy through which to analyse these programmes for equal opportunities under the headings of "tinkering, tailoring and transforming".

The "tinkering" (legislative approach) argues that everyone should be treated the same and aims to remove any direct form of gender discrimination which leads to the unequal treatment of men and women. The "tinkering" approach is enshrined in law while the "tailoring" (or positive action) equal opportunity approach recognises that the differences between men and women which exist are due to a complex range of social, historical and economic reasons and have led to unequal choices of and access to careers. The tailoring approach seeks to address these differences by ensuring a "level playing field" in the competition for jobs, promotions and career advancement. Underpinning the "transforming" (gender mainstreaming) approach is the idea that existing structures and institutions are not gender-neutral but favour one sex over another, usually men, in a variety of subtle and often invisible ways such as those identified in the MIT study (Committee on Women Faculty in the School of Science, 1999). The "transforming" approach also recognises that differences exist between the sexes yet embraces these differences as bringing added value to the engineering environment and also recognises the vital contribution that women, as women, can make to engineering.

In short, while equal treatment is about addressing individuals' rights to equality, and positive action addresses group disadvantage, mainstreaming focuses on systems and structures themselves – those much institutionalised practices that cause both individual and group disadvantage in the first place (Rees, 2000). The next sections of this paper will examine the history of the development of programmes to support diversity by examining equal opportunity measures that have been identified to tackle gender imbalance in the workplace according to the "tinkering, tailoring, transforming" taxonomy.

Tinkering: a Legislative Approach

The strategy of equal opportunities is pursuing "equal rights and equal treatment". The aim is to establish formal equality between the sexes with a focus on legislation, rules and procedures in order to ensure that men and women are treated equally and includes mechanisms to ban all forms of discrimination. This approach is enshrined in legal terms and is designed to emancipate all subordinate groups in society, providing them with grounds to appeal in cases of direct discrimination. The key actors for the tinkering strategy are legislative authorities and all persons responsible for establishing official rules and procedures (Stevens & Van Lamoen, 2001).

Anti-discrimination legislation in the context of gender was introduced in many countries including Canada (Canadian Human Rights Act, 1977); Germany (General Equal Treatment, 2006); United Kingdom (Equal Pay Act, 1970; Sex Discrimination Act, 1975); United States (Civil Rights Act, 1964; Pregnancy Discrimination

Act, 1978); and Ireland (Employment Equality Act, 1998 & 2004; Equal Status Act, 2000 & 2004). In the European Union, the Equal Treatment Directive (1976) established the principle of equal treatment for men and women with regard to access to employment, vocational training and promotion, and working conditions. This was followed by the Council Directive in 2006 (2006/54/EC) which adopted the "implementation of the principle of equal opportunities and equal treatment of men and women in matters of employment and occupation".

All good employment policies benefit women in engineering. The "tinkering" approach provides open advertising for all jobs (such as including the statement that the company is "an equal opportunities employer" in advertisements), fair and effective recruitment and promotion procedures, and good work/life balance policies to ensure that women are treated equally (Rees, 2000). Ensuring the operation of the highest standards in appointments, promotion and in peer review procedures is an essential element of equal treatment. The development and use of the concept of "academic" rather than chronological age has been helpful in this regard. Thus, for example, the clock stops ticking during periods of maternity leave.

The tinkering, or legislative, approach seeks to ensure equal rights and equal treatment for both sexes but does not guarantee that there is actual equality between the sexes as it does not take into account any real differences that exist due to historical, social and cultural behaviours. Some countries have recognised this and enacted further legislation in order to recognise the differences. Equal treatment legislation in some countries has been reformed to broaden the concept of discrimination and the sphere of application – such as public services and facilities, education and the workplace (Daly, 2005). For example, the Gender Equality Duty introduced in the UK in 2007 requires public authorities, including education providers and all other statutory services, to promote gender equality and eliminate sex discrimination. They are required to consult their service users and have a gender action plan. Previous legislation in the UK relied on individuals to complain about discrimination. The new law imposes a duty on all public sector managers to make their sector more efficient, effective and responsive to the realities of how we live our lives.

However, the crucial flaw in "tinkering" (equal treatment) is that it takes the male as the norm. Women are legally entitled, in effect, to be treated not as equal to, but as the same as a man. There is a need for a more sophisticated understanding of the issues in the "sameness" and "difference" debate, whereby the principle of the legal right to equal treatment is upheld, but that differences are accommodated (Liff & Wacjman, 1996). Sometimes treating men and women equally does not necessarily mean treating them the same. Hence, the law on equal treatment is a vital principle and an effective tool in combating overt discrimination, but it is not a sufficient measure to ensure equality (Rees, 2000). This realisation has led to the development of tailoring strategies.

Tailoring: a Positive Action Approach

Tailoring strategies seek to address the persistent inequalities by establishing specific measures and actions for women. The main focus of this approach is to target women who are under-represented or those who occupy disadvantaged positions. Strategies include positive action (providing support for women to compensate for their unequal starting positions due to historical, cultural and social reasons) and positive discrimination where preferential treatment for women exists to ensure not only equality of access but also equality of outcomes.

Positive action measures are effective if they tackle blockages in the system and/or focus on the development of good practice that can then be mainstreamed (Rees, 2000). In this context, there are examples in the EU member states of measures to assist women scientists who have had career breaks (Germany); the funding of chairs directed at women (Sweden); and fellowships designed to suit women (UK), in particular on their return from a career break. Table 10.1 presents a summary of number of key positive action initiatives in a number of countries.

Table 10.1: Some recent key positive actions by selected countries to promote women in science (European Commission, 2008b)

Country	Key Actions
Belgium	Creation of the Institute for the Equality of Women and Men in 2002.
Canada	Council for Research in the National Sciences and Engineering created a number of chairs for women in science and engineering from 1989
Denmark	Female Researchers in Joint Action programmes to finance specific research projects conducted by highly qualified women in 1998.
Estonia	Parental leave (and military service) is now taken into account in the evaluation of eligibility of applicants for Estonian Science Foundation grants since 2006 and targeted research funding grants since 2007.
Finland	Gender quota principle where all government committees, advisory boards and Research Councils, must by law comprise at least 40% women (currently 43%). Since 2002 research councils are required to make every effort to ensure that the under-represented gender occupies at least 40% of research positions.

Germany	There is a university ranking based on gender justice criteria. There are grants and awards that can be used in part to pay for childcare or to support part-time research (Christiane Nusselein Foundation).
Greece	Creation of the PERIKTIONI network of women scientists through EU funding. The Ministry of Education allocated €4.475m for research on gender related topics (37 projects).
Ireland	Science Foundation Ireland established the Women in Science and Engineering Programme (2005). This included research grants for women who had taken a career break (generally maternity leave); 3 University led projects (including the Centre for Women in Science and Engineering Research, Trinity College); and scholarships for girls studying engineering. A returners' scheme for women in science and engineering as recently been introduced by Women in Technology and Science (WITS).
Norway	The Norwegian Ministry for Education and Research founded the Committee for Mainstreaming – Women in Science in 2004. In the University of Oslo activities include: headhunting female candidates for a post; affirmative action where if 2 candidates are equally qualified, the less represented sex may be favoured; gender-budgeting to ensure fair and effective uses of resources, and economic incentives to departments. The Minister for Education and Research has committed funding for earmarking of posts for women in academia which will be included in the National Budget for 2009.
Slovenia	A Women in Science section has been established within the Ministry of Higher Education, Science and Technology. One year maternity leave (paid); "freezing" the contracted period for young researchers when they take maternity or paternity leave; rules on academic promotion including the "freezing" period.
Spain	Gender Equality Units must be created in universities; reports on the application of the principle of equality must be produced; boards for hiring and promotion must have a balanced representation of women and men, by law. Research fellowships allow one year maternity leave.

Sweden	The Minister for Integration and Gender Equality coordinates the government's gender equality policy as gender equality is seen as a policy area affecting all citizens.
Switzerland	Program for Gender Equality at Swiss Universities supports positive actions such as mentoring, childcare and incentive system for newly hired female professors.
United Kingdom	Establishment of the UK Resource Centre for Women in Science, Engineering and Technology (UKRC) as part of the government's Strategy for Women in SET in 2003. Positive action activities include good practice guides, funding opportunities; dissemination of activities by networks and collection of statistics. The Athena Swan charter was signed by 34 universities under which they committed to advancing women in SET in academia. Positive actions include collection of statistics and data; mentoring programmes; personal and career development programmes; role model exposure; networking opportunities and return-to-work schemes. Since 2007, a Gender Equality Duty has been introduced in the UK shifting the focus of gender equality from the individual to the institution.
United States	The National Science Foundation funds the ADVANCE programme-Increasing the Advancement of Women in Academic Science and Engineering Careers. Since 2001, 41 universities and higher education institutions have been funded. Positive action activities also include collection of statistics and data; mentoring programmes; personal and career development programmes; role model exposure; networking opportunities; return-to-work schemes; and quotas,

Table 10.1 gives examples of a wide range of interventions, details of which can be found in a report by the European Commission (20008b). Typical of the type of positive actions at individual institutional level is WiSER at Trinity College Dublin and at national level the Tham professorship scheme in Sweden. WiSER is the Centre for Women in Science and Engineering Research, Trinity College Dublin (http://www.tcd.ie/wiser/) supported and financed by government, through Science Foundation Ireland. The centre supports women directly through a personal and professional career development programme; a mentoring scheme for junior female staff and researchers; a specific fund for women researchers who are trying to establish their research career; role model speakers; and networking opportunities. In Sweden, the

proportion of women among new professors was 7% in 1985-92 and 12% in 1993-95. This led to the Tham Initiative by the Government (Margolis & Fisher, 2002) which established a number of professorships (32) ear-marked for women. Also, the goals set for each university added up to a national goal of 19% of women among new professors for the period 1997-1999. In actuality, the proportion of women among new professors for all universities together was 21% in this period as well as in the next period for which goals were set (2001-04). A number of factors may have influenced this outcome but the goals set by the government are generally seen as having played a major role (European Commission, 2008a). However, after complaints in 2000, the European court ruled these professorships to be unlawful.

The criticism of the tailoring strategies is that they target women specifically and encourage women to make changes, improve themselves and address what could be considered "their deficiencies" in order to fit the organisation. Women are expected to assimilate into the status quo of that organisation without addressing the working practices and culture of the organisation. These strategies work on the assumption that gender under-representation in engineering is a woman's issue rather than an issue that concerns the organisation as a whole, i.e., they are concerned with "fixing" the women rather than fixing the system. Measures are put in place to facilitate the lack of opportunity women face due to gender differences. As they are directed specifically at women, they do not usually address the culture or masculine social construct of the engineering profession.

Transforming, a Gender Mainstreaming Approach

The Group of Specialists of the Council of Europe defines gender mainstreaming as the "(re)organisation, improvement, development and evaluation of policy processes, so that a gender equality perspective is incorporated in all policies, at all levels and at all stages, by the actors normally involved in policy-making" (Council of Europe, 1998, p.18). Gender mainstreaming recognises that differences exist between the sexes yet embraces these differences as bringing added value to the engineering environment, and recognises the vital contribution which women, as women, can make to engineering. Rather than seeking to "fit women" into the systems and structures as they are, the transformative approach of gender mainstreaming pursues a restructuring of an organisation in such a way that the demands and expectations of women and men are heard and respected equally. All policies and practices are informed by the knowledge of the diverse needs and perspectives of their beneficiaries, both male and female. The main focus is the organisation as a whole with all its structures, values, customs, policies and practices.

The aim in "transforming" is to develop systems and structures which not only value difference but which no longer underpin hierarchies and power relations based on gender (Rees, 2005). Mainstreaming gender equality in universities and research institutes entails a wholesale programme of assessment of the gender impact of existing and new policies. Monitoring and evaluation mechanisms of new procedures need to be instigated. Awareness raising and training for staff is a prerequisite. Building ownership through performance review and line management systems is a requirement. Targets are needed for moving towards a gender balance in decision-making throughout the organisation. These tools need to be animated by the "visioning" of gender mainstreaming, the development of ways of seeing and doing things differently, challenging and changing the organisation and its culture. This needs expertise that can be brought in to assist organisations to change (Rees, 2000).

Daly's (2005) findings of an eight-country (Sweden, Ireland, Belgium, United Kingdom, France, Greece, Spain, and Lithuania) review of gender mainstreaming approaches noted three varieties of gender mainstreaming. Sweden takes an "integrated" approach where gender mainstreaming is employed in a global fashion and is embedded across institutions in society. Ireland and Belgium take a "mainstreaming light" indicating little more than the involvement of different government departments in the implementation of a plan or programme around gender equality. In the remaining countries, gender mainstreaming is highly fragmented, confined to either a small number of policy domains or to a specific programme within a domain and disconnected from general governmental policy on gender.

A potentially useful framework for applying gender mainstreaming in the university setting was proposed by Stevens & Van Lamoen (2001). They developed a Manual on Gender Mainstreaming at Universities which provided four toolkits or sets of instruments:

1. measurement and monitoring;
2. gender proofing and evaluation;
3. implementation and organisation; and
4. building awareness and ownership.

Measurement and monitoring is the systematic collection and dissemination of data on the position and opportunities of women and men and is indispensable to the identification of those areas which need to be addressed most urgently and to check the impact of policies, measures and processes that have been implemented. Gender proofing tools are designed to trace the causes of existing gender biases (research studies, feminist theory) and provide guidelines for changing structures and procedures aiming at promoting gender diversity. Specific individuals must be assigned with responsibility and accountability for gender mainstreaming. The fourth toolkit requires academic leaders and managers and those who will have been assigned responsibility for gender mainstreaming to be trained in order to reach a degree of gender awareness and gender expertise. Monitoring statistics can form the basis for setting equality targets.

From 2001 to 2004 the European Social Fund supported the EQUAL project "Bridging the Gender Gap at Universities" in the Netherlands. The main objective of this project was to systematically introduce the principles of gender mainstreaming into Dutch universities. The idea was that by introducing a new framework for policy-making, namely gender mainstreaming, not only would the number of women in higher scientific positions increase, but that it would become possible to change the (masculine) university culture and increase the diversity of academic leadership and the quality of the management and policy making as a whole. The project was based on Stevens & Van Lamoen's Manual and they followed the four toolkits. Their findings concluded that gender mainstreaming as a concept and as a practice turned out to be too difficult to grasp for most of the policy- and decision-makers. The project was successful in putting the issue of women's under representation on the agenda of the universities, but the result was a renewed call for positive action and measures that were visible and would lead to quick results (Van der Horst & Visser, 2006).

Central to any gender mainstreaming policy is the ability to measure and monitor progress. Data must be gathered on a regular basis which reveals those factors that prevent men and women from accessing and advancing in all domains of academic life on an equal basis. Data on equality of participation can show whether resources are divided equally and whether decision making bodies are gender-balanced. Data on the equality of outcome can reveal the overall equality between different groups in the university, e.g., do women stand equal chances to men when applying for research funds. Data on employment conditions can show the extent to which men and women are paid equally and have the same access to career breaks. An example of the importance of measuring data was the MIT study whose findings showed that men had access to larger working spaces and better resources than their female counterparts (Massachussetts Institute of Technology, 1999). The She Figures 2003 and 2006 reports represent another example of good practice of measuring data (European Commission 2003 and 2006).

Gender impact assessment is another measurement tool which is designed to check whether or not specific practices affect women and men differently, with a view to adapting them to make sure that potential biases are eliminated. Gender impact assessments can be applied to all kinds of practices and processes including selection and recruitment procedures, financial resources and to the organisation's culture.

There are a number of specific issues that departments in universities have to address surrounding "openness and inclusivity" in order to transform the culture to the benefit of women – and men. These include, for example, how part-timers, those on maternity leave, career breaks and sabbatical are included in the ongoing life of the institution/department; identifying how departmental processes, procedures and practices impact on staff with caring responsibilities and part-time workers; ensuring senior staff are accessible to junior staff; and identifying social activities that are inclusive. The Athena SWAN Charter for Women in Science (www.athenaswan.org.uk) is an example of a national initiative which celebrates and rewards best practice for women working in SET in higher education and research. The Athena SWAN gold, silver and bronze awards are widely recognised and celebrated. Good initiatives include scheduling departmental meetings at times when staff with caring responsibilities can attend (Bristol Physiology and Pharmacology Department: Silver award); allowing part-time academics to supervise PhD students (Manchester University: bronze award); reducing workloads for maternity returners, giving them fewer projects, lower student allocations and lighter administration loads (Psychology School at Nottingham University: silver award) and introducing a range of part-time working strategies to support their staff, for example, extended lunch breaks to enable care of elderly relatives, variable hours to enable the staff to complete school pickup, and gradual changes in hours to facilitate the return to full-time working for new parents (Department of Mechanical, Materials and Manufacturing Engineering at Nottingham University: silver award).

Issues surrounding departmental roles and responsibilities can include whether committees are reviewed for gender balance, whether membership is reviewed and renewed, how to avoid "committee overload" on the small numbers of women available in SET, and identifying how committee decisions are communicated widely to all staff and researchers. Examples of good practice include publishing gender balance of committees (Reading University: bronze award).

Other areas of change at departmental level include improving the visibility of women in engineering. Increasing both the visibility of women in engineering and the work women contribute to engineering challenges "taken for granted beliefs" that men generally are engineers, not women. Areas to address include encouraging women at all levels to raise their profile externally and internally, monitoring the gender balance of speakers at conferences, seminars and events (York Chemistry department: gold medal), and also identifying whether the proportion of women applying for academic positions at all levels is representative of the recruitment pool.

The development of specific structures concerning equal opportunities (centres of expertise, networks, and responsible actors) is an important factor in sustaining the actions and measures of gender mainstreaming. It is also important to create commitment from stakeholders through activating all participatory bodies (e.g. university councils, boards) by placing gender mainstreaming on their agenda. An example which incorporates all steps to the gender mainstreaming process in education is the ADVANCE funded (NSF, 2008) STRIDE (Strategies and Tactics for Recruiting to Improve Diversity and Excellence) Committee in the University of Michigan (STRIDE, 2008). The STRIDE Committee provides information and advice about practices that will maximize the likelihood that diverse, well-qualified candidates for faculty positions will be identified, and, if selected for offers, recruited, retained, and promoted. The STRIDE programme appears to have had a positive impact on the recruitment of women. In 2001 only 13% of science and engineering hires were women (6 female and 41 male hires) compared with 29% in 2005, 15 female and 37 male hires (Stewart *et al*., 2007).

While gender mainstreaming has been developed by the EU to assess policies, practices and procedures to be implemented at a national and organisational level, an alternate view focuses directly on transforming the organisational culture. Organisational culture can be defined as "a pattern of shared basic assumptions that the group has learned as it solved problems … that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein, 1992, p.97). Under this model, the onus of change is not on an individual but on the change of culture and environment in which the individual works. There are three layers of culture that need to be addressed when "transforming academic culture". These are:

- Artefacts: visible structure and practices, such as policies and procedures, which can be monitored and changed if necessary;
- Espoused values: what people say they believe – these are not generally a problem; for example, most people believe that appointments and promotions should be fair and based on merit; and
- Underlying assumptions: unconscious, taken-for-granted beliefs, thoughts, and feelings, ultimate source of values and actions.

Transforming the academic culture alters the culture of the institution by changing select underlying assumptions and institutional behaviours, processes and products. In order for the culture of academic engineering to be altered, all three layers need to be addressed. Generally, universities are working at the artefact level while the remaining two levels are not consistently addressed (Trower, 2004). Aspects of the transforming academic culture relevant to advancing women in engineering can include institutional and department openness and inclusivity, institutional and departmental roles and responsibilities, visibility of women in engineering, valuing staff contribution, workload allocation and induction and training.

Conclusions

There have been many programmes, initiatives, advocacy groups funded from different sources including government and philanthropic sources to recruit, retain women in engineering, and offer support services to those who wish to return to engineering after a career break or maternity leave. The findings show that while these initiatives have targeted many different career stages, and have had very clear and hopeful objectives, the statistics over the past 30 years have not shown significant increases in the number of women in engineering.

The current policy of the EU is that it is pursuing positive action and gender mainstreaming as a twin-track approach to gender equality. Given that gender mainstreaming is a paradigmatic shift in approach that takes considerable time to embed, it is essential that equal treatment (tinkering) and positive action (tailoring) measures continue to be developed alongside it. The equal opportunities approaches are not separable in practice but are intertwined with and build on one another (Daly, 2005). The strategies involve removing obvious and invisible barriers by incorporating a gender perspective in all policies transforming the organisation to increase room for different lifestyles, perspectives and competences, making it less homogenous. Those involved in transforming strategies include policy makers, supported by specialised units, centres or officers with specific expertise in gender mainstreaming (Stevens & Van Lamoen, 2001).

As with the leaky pipeline metaphor, the classification of "tinkering, tailoring and transforming" has been subject to some criticism. All along the transformational approach, tinkering and tailoring strategies need to be continued. The chronological aspect of the approaches does not necessarily imply that one follows another or that one should replace the other. The strategies focus on different aspects of equal opportunities which are important in themselves. Booth & Bennett (2002) interpret the trilogy of models of "equal treatment perspective", the "women's perspective", and the "gender perspective" are complementary rather than mutually exclusive, challenging the compartmentalising of different types of equality strategies. This suggests that they are better conceptualised as components of a "three-legged stool" in that they are interconnected and each needs the other.

While a lot of money, time, resources and goodwill have been injected into addressing the imbalance of women in engineering, there are still critical reasons for the lack of overall success in the majority of countries. Most of the initiatives have targeted the more attainable and visible tasks such as networking, mentoring, and career development for women. Often, these areas are targeted because funding is limited and justification and evidence has to be given for continued funding.

Diversity is seen as a fringe activity. It is viewed as something to be added on to the day-to-day activities and decision making. When compared to other demands of a university, institution or company, diversity and gender generally do not reach the priority list. Other actions will always take precedence and the issue remains on the fringes. However, the leaky pipeline is a feature not simply of academia and the research system but also of the corporate world. There are signs that the corporate world is beginning to see the under-representation of women, especially in senior positions, as an issue which affects the "bottom line". Research from a number of countries has shown strong correlation between shareholder returns and the proportion of women in the higher executive echelons. Of course this does not establish a causal relationship but it does suggest that a corporate culture which fosters women's careers can also foster profitability (Women in Business, 2005). It is not clear that academia has made this transition and continues to view the under-representation of women as largely an issue of social justice and equality. In spite of years of equal opportunities in academia there is still evidence than women and men are not treated equally resulting in very few women making it to the top. The days of active, overt discrimination are gone, but as both the MIT and a similar more recent study at Harvard University (Task Force on Women in Science and Engineering, 2005) reports have shown, there is often a series of minor issues which together add up to make it more difficult from women to climb the ladder of academe.

Likewise, while gender mainstreaming potentially has the capacity to transform policy making processes, positive action implemented by grass roots community organisations, can ensure a connectedness with the people and the issues that policies are seeking to address. Gender mainstreaming, as an institutionalised approach to equality can change systems, but positive action can ensure that the aspirations and needs of women on the ground are fully taken into account.

Unless gender and diversity in institutions is adopted through legislation this action will remain on the fringes. Without legislation, it is left to individual people, be it the head of a university, school, or department to understand the importance and benefit of diversity and to take action to improve the situation. This puts an onus on the individual rather than the organisation. Some of those who are in positions of authority have considered positive action as "social re-engineering" and rebel against any actions put forward. Unless positive measures are understood, actions will simply be seen as "paper ticking" or just "that the university is seen to be doing the right and expected thing".

What then is the answer to the problem of the under-representation of women in engineering? This chapter has attempted to show that the problem is a complex historical, cultural and organisational one for which there is no single solution – no silver bullet. Virtually all the interventions and initiatives presented here have had a positive impact at the local level. The challenge is to develop programmes which are sustainable and scalable across all universities and beyond. There is insufficient evidence to point to a single set of solutions which if not guaranteeing total success can at least be reasonably expected to improve the situation for women. However, such evidence that there is points to a number of areas of best practice.

Firstly, there is a fundamental requirement for strong legislation, such as the UK Gender Duty, which is much more than just aspirational. The Gender Duty legislation of the UK places a legal obligation on institutions to address gender imbalance. Institutions including universities must therefore respond. If a public authority does not comply with the general duty, its actions or failure to act can also be challenged through an application to the High Court/Court of Session for judicial review i.e. legal action from government (Equal Opportunities Commission, 2007).

Secondly, in order to be able to respond, universities need professional gender expertise and support which goes beyond the token Equality Officer whose remit tends to be very broad and whose role if often very peripheral to the mainstream of academia.

Thirdly, there must be a senior individual who is responsible and accountable for the implementation of gender mainstreaming within the institution. This individual must be fully empowered to make decisions and take action. They must carry sufficient "academic weight" to command the respect of peers and to overcome the traditional resistance to change.

Fourthly, national initiatives such as Athena SWAN (http://www.athenaswan.org.uk) and ADVANCE (NSF, 2008) are vital to support and drive change and which focus on addressing the practical issues at departmental, faculty and institutional level. By taking a holistic or in engineering parlance a system view, they can tackle the problem in a systematic and comprehensive way.

Finally, it is vital to monitor progress. Therefore initiatives which ensure the collection of complete and accurate statistics, both quantitative and qualitative, are essential. Critically, these can then provide the foundation on which to set realistic targets for the recruitment and retention of women in engineering at all levels. Academic units and institutions which fail to meet these targets should be required to provide a detailed explanation including what direct actions they took to try to meet the targets. It is no longer acceptable to simply shrug one's shoulders and say "no women applied".

Ultimately perhaps it is only when the international rankings of universities include, as one of their criteria, the percentage of women at senior level within the institution is there likely to be a major and radical shift in attitude which will bring the problem centre stage.

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Section 3

Engineering Design

Introduction

Matthias Heymann

A key task of engineers is the creation of new technical artefacts. This process is in modern engineering called engineering design. Engineering design is a demanding task and represents a core discipline within the broad field of engineering. Engineering designers have to integrate many different pieces of information and apply manifold forms of knowledge to solve engineering problems and come up with suitable technical solutions. Far into the 19th century engineering design represented mostly an empirical and practical task. In the course of the 19th century it became an academic discipline developed and taught at the newly founded technical schools and universities. The professionalisation of engineering brought about a host of new knowledge, approaches and scientific techniques, which contributed to an ever accelerating rate of technical innovation, which historian of technology Thomas Parke Hughes called a "gigantic tidal wave of human ingenuity" (Hughes 1989, 13).

In the popular understanding the engineer is portrayed as a powerful and energetic person changing the world for the good of man. In this picture the means of science provided him with the power to produce an avalanche of technical innovations, which opened up ever more opportunities, such as moving more than one hundred times as fast as horse carriages, communicating instantaneously over the whole planet or bringing out five million times as much energy from a kilogram of uranium than from a kilogram of wood. Though abundant these success and progress stories are, historians and philosophers of technology, as well as engineers, have shown that popular myths like these convey much too simple a picture. The essays in this section contribute to analyzing and understanding characteristics, conditions and needs of engineering design in more detail.

While new scientific knowledge and scientific methods, in fact, increased the range of technical opportunities enormously, the very process of exploring these opportunities has not become easier or in any sense clearcut. Quite to the contrary: Science did not only provide the engineer with power. It also produced uncertainty. The engineering designer today is confronted with a huge amount of information and a large number of methods and approaches to be applied to problems in an ever more complex world. It has become increasingly difficult to teach, learn and practice engineering design in all its breadth. While the craftsman in preindustrial times controlled a limited set of methods and technologies, the engineering designer of today has to command an immense repertoire of knowledge and approaches. The range of methods and the variety of approaches gave rise to many debates and conflicts about how best to pursue engineering design. Engineering design methodology still is a highly relevant question, which the first three papers in this section address.

The power of scientific knowledge and methodology caused another problem for the engineer. While science certainly creates many opportunities, it can never give an answer to the question of which of these opportunities to pursue. In recent decades it has become obvious that technological change does not only increase the wealth of humankind. At the same time it produces risks, such as the accumulation of destructive technologies, environmental pollution, the depletion of resoures, or a loss of human autonomy and control. Problems like these raise the question of ethics in engineering design. How can moral values be incorporated in engineering methodology and work? How can it be made part of engineering education? The engineering designer of today needs appropriate support to tackle ill-defined problems in a complex world, in which engineering decisions may have significant repercussions on the well-being of the wider society. The problem of ethics in engineering design will be addressed by a second group of three papers.

The first two chapters in this section address the question of appropriate methodologies for problem solving in engineering design. Matthias Heymann contrasts practical, experience-based approaches (“art”) with scientific approaches (“science”). He argues that both these types of approaches involve fundamentally different forms of knowledge. While it was not contested by the majority of engineering designers that both forms of knowledge play an important role in engineering design, it caused considerable debate to decide on the relative importance of practical or scientific approaches. Heymann shows that the history of academic engineering design in the German speaking countries is characterized by ongoing debates and changing preferences for either practical or scientific approaches. This observation leads to the description of a pendulum model of the history of engineering design.

Wilhelm Bomke shows that systematic design methods like drawing plans or building models have been used since the times of Ancient Mesopotamia and Egypt, more than 5000 years ago. He provides ample evidence for the ongoing importance of such design methods. Only in recent times, the traditionally important craft of drawing design plans has come under pressure by the increased use of Computer Aided Design (CAD). Bomke strongly argues for the need of sound drawing skills even today. First, CAD methods also cause significant problems, because they may hamper an overall overview in the case of complex design tasks. Second, only sound drawing skills provide the engineer with a broader and sounder knowledge and enable him to judge developments with greater authority.

The popular myth that engineering designers create totally new technologies in revolutionary leaps is countered by William Grimson. A world with aircraft may look like a revolution compared to a world without aircraft. But looking at the practice and methods applied in engineering design, it has more in common with evolution than revolution. It is built on existing knowledge and experience. Most innovations are incremental, not radical. Grimson shows that the theory of evolution by Darwin and in its interpretation by Dawkins fits in many regards quite well to engineering design. The selection of good designs has much in common with natural selection. Genetic information represented by the RNA can be compared to the information in blueprints. And processes of adaptation in nature can just as well be described in engineering. Grimson is fully aware of the limits of this analogy, especially with regard to the purposeful activity of the engineer in contrast to coincidental selection in nature. But the evolutionary perspective, he argues, allows a deeper understanding of how designs come to be and how designs are subsequently developed.

In recent years the ethical dimension of engineering design has also received increasing attention. Javier Cañavate, Josep M. Casasus and Manuel J. Lis provide an instructive overview over the challenges of including ethical considerations in the design process. They distinguish several levels of ethical challenges. Technical ethics covers the technical side of ethical demands, such as meeting codes and regulations, e. g. safety regulations. Professional ethics are directed towards meeting ethical standards associated with the distribution and implementation of technical products. Social ethics, finally, represents the most diffuse level of ethical demands. It is needed to ensure social responsibility of the engineer and best serve social interest in the wider society. According to the authors all these levels of ethics have to be incorporated in the very process of engineering design. This is to a large extent the case for technical ethics, but still lacking for social ethics. The representation of society in the design process still is quite poor and needs to be improved.

Fernand Doridot carries on the arguments of the preceding paper for the special case of nanotechnology. He summarizes the strong debates provoked by developments and expectations in this field, which either highlight enormous chances or emphasize significant risks. Do nano systems in medicine promise self-replicating systems to fight, for example, cancer cells? Or would such systems rather represent a peril because they may involve a loss of control and problems of misuse? Doridot argues that existing conceptions of ethics for technology development do not suffice to master the challenges posed by nanotechnology. Stronger approaches than conventional risk analysis or the like are needed to build up long term public confidence. He suggests the development of new processes to integrate ethical demands in nanotechnology development and translate them into concrete plans of assessment and governance. These could include participative methods, hybrid forums, public debates and conceptions like “ongoing normative assessment” (Dupuy and Grinbaum).

A similar stance is adopted by Eugene Coyle and Marek Rebow. They argue for the need of design for sustainable development and suggest practical approaches for meeting this goal. According to them, environmental problems are due in no small part to poor designs. So, processes of design have to be improved in order to incorporate the goals of sustainable development. The authors argue that ethical considerations of social and environmental impacts need to be addressed at all stages in the sustainable design process, which may also be called Deep Design (David Wann). Such a goal can be accomplished by moving from a more product-oriented design to a more solution-oriented design. Such a shift will require new evaluation tools in order to ensure minimal negative effect of designs on the environment. Coyle and Rebow suggest ensuring guidance by using sustainable indices, such as provided by methods like life-cycle-assessment, ecological footprints, material flux analysis, risk assessment or exergy analysis. They finally describe the efforts of curricula development in sustainable design at the Dublin Institute of Technology.

Chapter 11

“Art” or Science? Competing Claims in the History of Engineering Design

Matthias Heymann

Abstract: Historians of technology have interpreted the institutionalization of fields of engineering as academic disciplines in technical schools and universities as a merging of technical practice and scientific approaches. A prominent example of such an interpretation is the Dresden Model of the emergence of the technical sciences. But a closer investigation of the history of engineering design shows that in contrast to this model, an ongoing debate about engineering design methodology emerged. Is engineering design an “art”, mainly drawing from personal skills, intuition and experience of the engineer? Or is it a science, drawing from scientific knowledge and rational methodology which the engineer applies? And should it be developed, trained and taught like an “art’ or like a science? In academic engineering design these questions always remained high on the agenda and never could be fully resolved. These methodological debates will be analyzed and interpreted in the Munich Model of the history of engineering design methodology.

Key words: Engineering Design, Engineering Design Methodology, Engineering History, “Art” and Science in Engineering Design

Introduction

The history of engineering design has been characterized by numerous, sometimes fierce methodological debates. It is a striking feature of this academic field that full agreement on fundamental methodological questions has never been reached. In some time periods, the ideas about which methodology to apply to solve an engineering design problem differed sharply while at other times there has been more agreement, although such agreement never lasted long. It is the aim of this article to describe these methodological conflicts and provide an explanation for them. In addition to throwing light on the past, it is notable that this explanation also has consequences for the future. It suggests that methodological debates in engineering design are likely to continue, and it seems unlikely that there will ever be a definite, unified and unambiguous methodology in engineering design.

The emergence of engineering design as an academic discipline occurred in the 19th century and is part of a process that is generally referred to as the scientification of technology and the emergence of "engineering science" or the "technical sciences"[1]. The scientification of technology changed processes of technical creativity and innovation dramatically. It was the basis for an avalanche of innovations and a radical change in the human lifeworld. Another implication of this process, however, received much less attention: the fundamental methodological debate and the uneasiness many engineering designers have felt with regard to the methodology of their field following this scientification of technology and the emergence of engineering science.

In the first section of this article I will summarize the interpretation of the scientification of technology based on one of the most elaborated theories, the so-called Dresden Model of the emergence of the technical sciences. This model was developed in the 1980s by the Dresden school of the history of technology, which was responsible for making the most comprehensive effort to gain an understanding of the history of the technical sciences. This school began detailed research into the development of all fields of the technical sciences and all time periods. A large part of the knowledge on the history of technical science we owe to this comprehensive research effort.

In the second section I will narrow down the wide perspective of the Dresden school and analyze the development of engineering design as an academic discipline in the 19th and 20th centuries. Based on this analysis the Munich Model of the history of engineering design methodology will be developed. A concluding section attempts to develop a general interpretation of the history of engineering methodology according to the Munich Model. The hope is that this interpretation will help answer questions such as: Why did engineering designers engage so heavily in methodological debates? And why did these debates never come to a definite end?[2]

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[1] ”Engineering science” is the common term developed by American historians of technology (e.g. Layton, 1971). The Dresden school of the history of technology, in contrast, favoured the term "technical sciences", which is a translation of the common Russian term. Both terms are considered equivalent in this account (Buchheim & Sonnemann, 1990).

[2] This article draws on the historical investigation of engineering design in Heymann (2005).

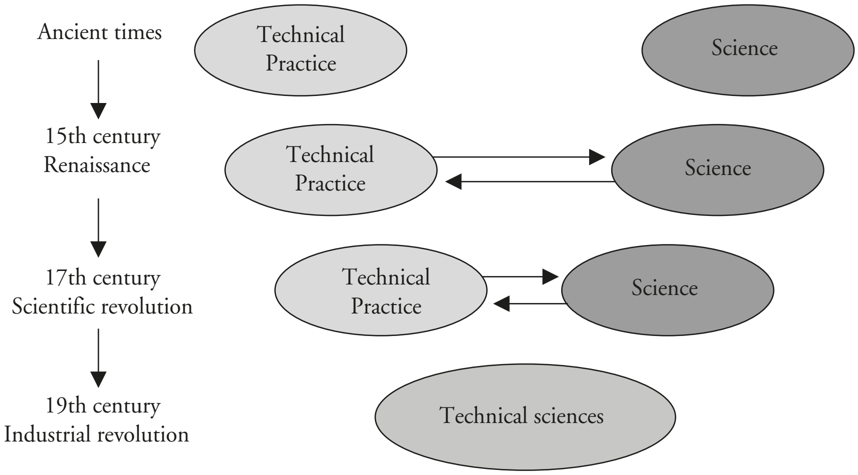
The Emergence of the Technical Sciences

Until well into the 19th century, the creation of technical artifacts was dominated by craftsmen and their technical experience and skills. A technical design problem usually consisted of tasks like copying known technical solutions, maybe in a different size or with minor variations. Technical production largely remained within known domains and existing expertise. It was guided by known examples and personal masters, as well as collections of drafts and drawings and technical tables, which were valuable when designing components and devices like the parts of a pump or a windmill. However, the most important aid in designing technical artifacts was personal experience. A good craftsman had a sense and feeling for the technology he produced. He could feel how strong axes, shafts, spindles and many other components needed to be to resist the forces and loads to which they would be subjected.

The creation of technical products, the work of craftsmen, did not interfere much with science for most of its history. In ancient times science and technical practice represented completely separate social spheres, a separation that lasted until modern times. Craftsmen followed their business without much consideration for the theories of philosophers and scientists. The constructs of ideas of philosophers and scientists, on the other hand, floated in spheres far above the practical demands of the crafts. According to the interpretation of the Dresden school, practice-based technical production and theory-oriented science represented separate social spheres, which only over a long-term process of mutual rapprochement developed connections and growing exchange. Important leaps in this process of rapprochement occurred in the renaissance of the 15th century, in the scientific revolution of the 17th century and in the Industrial Revolution of the late 18th and early 19th centuries. During these periods, communication and exchange between the spheres of science and of technical practice increased (Figure 11.1).

But, despite these periods of communication, the separation of science and of technical practice was not overcome prior to the 19th century. According to the Dresden interpretation, an earlier merging of science and technical practice failed for two reasons: On one hand, the state of scientific knowledge was too underdeveloped to provide a deeper understanding of complex technical problems, and on the other hand, the crafts were dominated by an empirical and practical tradition and characterized by little interest in or understanding of theoretical and mathematical knowledge. It was the expansion and perfection of scientific knowledge as well as the expansion of technical education that enabled a "unification" of science and technical practice (Buchheim, 1980, p.19; Buchheim & Sonnemann, 1990). This "unification" proceeded through the establishment of polytechnical schools in the early 19th century, the predecessors of technical universities. Technical schools employed teachers, who assimilated technical experience and demands and, at the same time, developed and expanded scientific and technical knowledge.

Figure 11.1: The Dresden Model of the emergence of the technical sciences by a rapprochement and merging of technical practice and science.



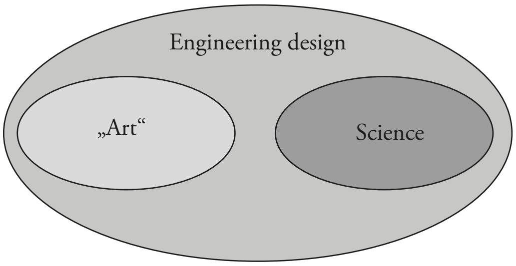
Thomas Hänseroth and Klaus Mauersberger, historians of technology of the Dresden school, described the technical sciences as a "reaction space". Natural sciences and technical practice both entered this space and productively interacted. This interaction produced a double-sided transformation, "the transformation of scientific knowledge and methods into a form applicable in technical practice", and "the communication of demands in the technical practice to scientific research". The technical sciences, thus, represent a space in which the characteristic ways of thinking in the natural sciences and in technical practice "merge". This merging process in the technical sciences has been described in the Dresden Model as the creation of a new and higher "unity" of practice and science (Hänseroth & Mauersberger, 1996, pp.24-26).

On the History of Engineering Design Methodology

Academic engineering design, as represented at technical universities, exemplifies such a technical science. It is concerned with the development, improvement and teaching of engineering design and engineering design methodology. In the interpretation of the Dresden school, it represents a "reaction space" in which practical craft and theoretical science merge to produce an efficient new methodology. At least this is the perspective from the outside; as to what really happens in this "reaction space", how forms of practical and scientific knowledge relate, change and – as suggested by the Dresden Model – merge, still remains unclear. In this section I will look into this "reaction space" of engineering design.

While experiences and demands of technical practice as well as relevant elements of scientific knowledge and scientific methodology enter the "reaction space" of engineering design, these originally different spheres do, in fact, not totally merge into something new, but remain different spheres within this "reaction space". Technical experience, developed by empirical investigation, trial and error tests and continual creativity, continues to represent a sphere of its own. Likewise, theoretical knowledge does not merge completely with practical demands and considerations, but keeps a certain autonomy. Within a unified "reaction space" of engineering design "art" and science are still fundamentally different forms of knowledge (Figure 11.2).

Figure 11.2: "Art" and science representing different forms of knowledge in engineering design.



Practical knowledge and experience is intuitive, embodied, and thus bound to the person. It is a form of knowledge that cannot be written down and communicated easily or explicitly. It has to be acquired through personal practice. An often-cited example for such "tacit" or "personal knowledge" is the ability to ride a bycicle, which cannot be explained in words or books, but only by practical trial (Polanyi 1958, 1967). The constructive feeling of the engineering designer, the sensitivity for forces and structures or the practical skills in manipulating technical artifacts provide examples of such tacit forms of knowledge. These forms of tacit knowledge can be characterized as "art", as used in expressions like "the art of building a windmill".[3] Theoretical scientific knowledge, in contrast, is objective and not bound to the person. It can be written down, communicated and transferred from one person to the next. Examples of written knowledge are facts, formulas, laws of nature, mathemati-

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[3] The term "art" will be used in quotation marks, because it relates to a premodern understanding of the term as in the "art of the craftsman". It does not imply the modern term developed during the Romantic period, when art came to be seen as a special faculty of the human mind (Gadamer, 1994).

cal relations and so on, pieces of knowledge which can be read and studied. In brief, these objective forms of knowledge can be characterized as “science”. “Art” and science, thus, represent two fundamentally different poles in engineering design, which on principal cannot be merged. The existence of these poles is the starting point for the Munich Model (Figure 11.3).

That “art” and science were often considered to be poles apart means that methodological conflict in engineering design was inevitable. Ferdinand Redtenbacher, one of the founders of scientific engineering design, clearly recognized this point. Redtenbacher started out in 1841 as professor for mechanical engineering at the Karlsruhe Polytechnical School and became its director in 1857. Redtenbacher sought to establish rules and principles to guide the solution of engineering design problems. In his text book “Principles of Mechanics and Mechanical Engineering”, published in 1852, he explicitly brought up the major problem: “The forms and dimensions of the parts [of a device or a machine] can either be determined by intuition or by calculation, or, alternatively, by partly intuition and partly calculation. The first way is based on a sense for forms, size and relations, with which the engineer must be gifted to accomplish something in engineering design.”[4]

Redtenbacher already distinguished “art” (intuition) and science (calculation) very clearly. He rated the “art” of an engineer as an indispensible ability and was doubtful whether science alone could lead the engineer to solutions in engineering design: “The second way, which intends to utilze only the means of calculation to reach to the determination of forms and measures [of a technical device] has never ever led to any success and will never lead to success. For there are thousands of things, which can either never be determined by calculation or would take so much effort and time and scholarly knowledge to be calculated that the relation of means and ends is not appropriate. (…) The exclusively calculating method has to be refused completely.“

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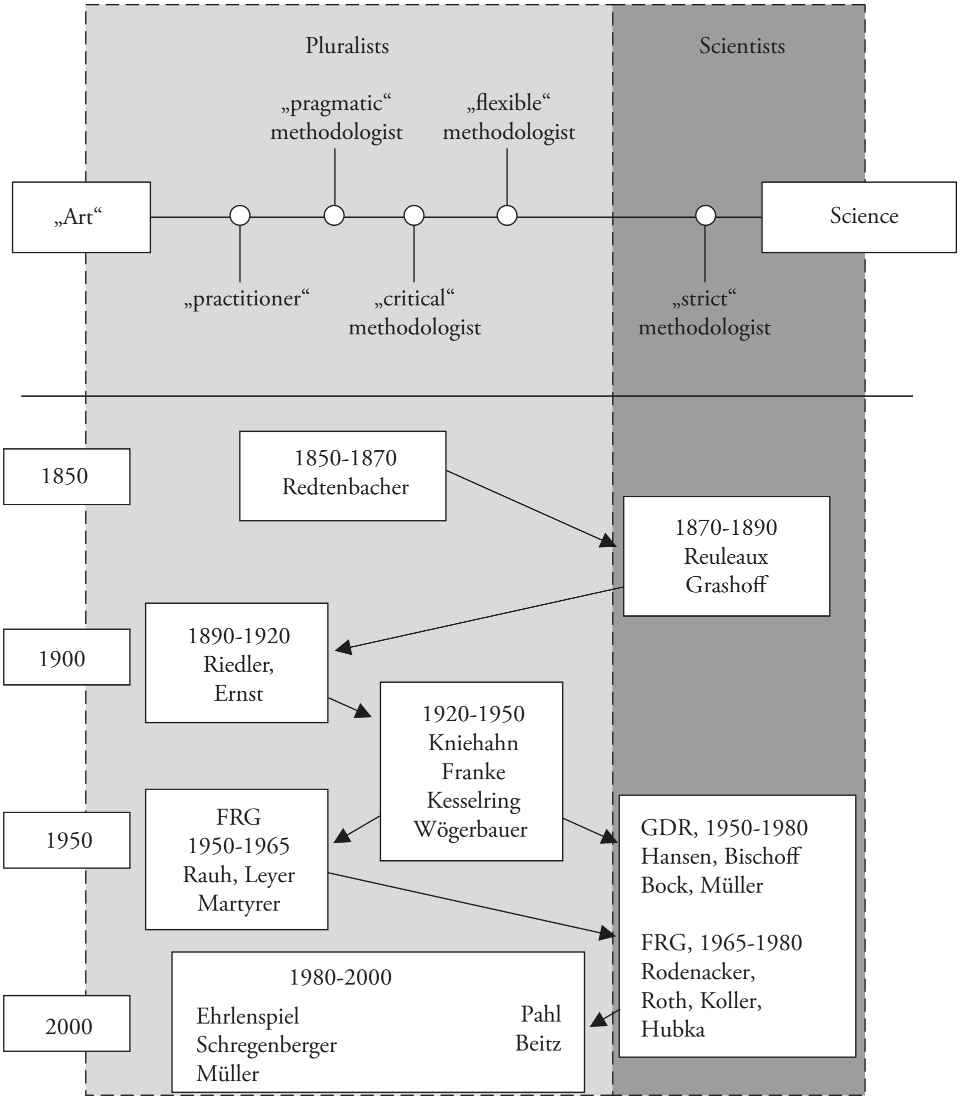
[4] Translations from German into English have been made by the author.

Figure 11.3: "Munich Model" of the history of engineering design methodology: "Art" and science as methodological poles, allowing numerous different methodological positions in engineering design.



Redtenbacher, in contrast, recommended a combination of "art" and science: "The third way, which attempts to combine calculation and feeling, applies in any case the means to reach success in the simplest, quickest and safest way. It calculates, what is easiest and safest to be determined by calculation, keeps to experience, where it exists, and relies on feeling, where it knows best to help itself on. It was always my conviction that this third method is in every respect to be preferred from the other methods." (Redtenbacher, 1852, pp.290-91). Redtenbacher's methodological conviction acknowledges "art" as well as science. He appreciated the development and teaching of mathematics and theoretical knowledge and their application to engineering design problems. At the same time, he recognized the limits of scientific approaches and emphasized the role of practical experience and of a feeling for technical matters. In his eyes, "art" and science both involved a multitude of approaches and methods, which the engineering designer could profitably use. In this sense, he was a pragmatic methodical pluralist or, perhaps, a, "pragmatic methodologist" (Figure 11.3). In fact, most engineering designers agreed on recommending Redtenbacher's combined method in engineering design. Throughout the history of engineering design it was the most common view that engineering design involves "art" as well as science. But this also posed a fundamental problem: To what extent should engineering design be conceived and practiced as an "art" or as a science? And – even more importantly – in what direction should engineering design be developed? Should it be made a science, or should it be cultivated as an "art"?

Redtenbacher's student, Franz Reuleaux, adopted his teacher's methodological convictions during his early studies, only to depart from them quite radically a few years later. Reuleaux taught mechanical engineering at the Federal Polytechnical School in Zurich, Switzerland, from 1856 before moving to the Business School (Gewerbeinstitut, later Technical University Charlottenburg) in Berlin in 1864 to become one of the most influential engineers in the German Empire. In 1864 Reuleaux published his ambitious theoretical claims, and then in 1875 he put forward a comprehensive account of these claims in his Theoretical Kinematics, which he considered a comprehensive theory of kinematic mechanisms. Reuleaux objected to Redtenbachers encyclopedical methodology, which in his eyes represented a "mingle-mangle" of descriptions, methods and rules, but lacked a coherent scientific structure (Reuleaux, 1875, VIII). His Kinematics was conceived to precisely provide such a structure, a unified and comprehensive theory of the mechanical sciences, which was logically based on a few theoretical axioms. This theory would not only cover the scientific laws of technical mechanisms, but also the laws of technical creation and invention (Reuleaux, 1875, X): "Have the processes of thinking, which lead to the development of known technical mechanisms, correctly been explored, then these processes must also be applicable for similar problems: these processes must include the means to reach to new mechanisms, hence, these processes must be suited to substitute the role of the inventor in its hitherto existing meaning." (Reuleaux, 1875, p.23, also cited in Mayr, 1968, p.232).

Reuleaux, thus, envisaged an automatic process of invention informed and guided by theory and logic, a "machine science of deduction", as he called it. Instead of building on a mingle-mangle of methods with little clarity about when and where to use which methods, Reuleaux wanted to base engineering design on a strong methodological foundation. He preferred the calculating scientist to tackle the problems and tasks of engineering design, rather than the intuitive designer. He believed that his scientific approach had no fundamental limitation and was in principle suited to solve all engineering design problems. In comparison to Redtenbacher, this methodological conviction represented scientism, and as such Reuleaux can be regarded as a "strict methodologist".

Reuleaux's scientific ambition attracted a lot of attention at first. A few years later, however, it was criticised, and a violent theory-practice debate ensued throughout the 1890s. Critics like Alois Riedler, professor of mechanical engineering and colleague of Reuleaux at the Technical University Charlottenburg and Adolf Ernst, professor of mechanical engineering at Technical University Stuttgart, raised strong objections against the theoretical and mathematical orientation in engineering design. Ernst emphasized in a lecture in 1894 that a technical design "is no calculation, which could be achieved by way of mathematical treatment of given data (…) until the unknown solution is reached". He was rather sceptical about the use of theoretical methods. "Doctrinary theory and book learning do not provide the engineer with sufficient compensation of missing own observation and lacking practical skills" (Ernst, 1894, pp.1352 and 1355).

Riedler complained vehemently about the desastrous consequences of an excessively scientific education. Neophytes would be fooled by getting the impression that "everything can be solved from initial premises with precision (…) and what cannot be calculated with any precision is not scientific" (Riedler 1896, 302f). In contrast to scientism, Riedler emphasized the importance of a practical education, the application of learned knowledge and skills, the development of experience and a vivid sense for technical matters. "Only application leads to a full understanding [of reality], application represents a higher level of knowledge, for which scientific knowledge only provides a pre-stage (…) Knowledge is a daughter of application, not to the contrary" (Riedler, 1896, pp.305f). Riedler considered himself a "practitioner". And he understood this term as an "honorary title for men, who got beyond theory and applied knowledge in a responsible manner, in contrast to irresponsible and fruitless knowledge hucksters" (Riedler, 1896, p.308). Both Riedler and Ernst, whose methodological conviction ranged much closer to "art" than to science, may be regarded as "practitioners".

The theory-practice debate of the 1890s has been interpreted as a successful struggle for a common professional identity of engineering science. As an outcome of this debate, mechanical engineering was generally conceived as an experimental science with a specific methodology of its own. This methodology included theory building and theoretical calculation as well as practical experimentation. According to the Dresden Model, the technical sciences succeeded in bringing scientific claims and practical demands "increasingly into accordance" by the end of the 19th century. The theory-practice debate represented a breakthrough for the unification of science and practice (Buchheim & Sonnemann, 1990, p.231). Historian of technology Wolfgang König basically came to the same interpretation and cited the theory-practice debate as a precondition for overcoming the contradiction of theory and practice (König, 1999, p.76).

The historical investigation of engineering design methodology shows, however, that a conflict between "art" and science continued throughout the 20th century. Although unlike the 1890s when this conflict was played out in the broader engineering and public arenas, the 20th century saw a more localised conflict dominated by specialized experts. Influential mechanical engineers like Fritz Kesselring (Siemens, Berlin), Rudolf Franke (University of Technology Berlin) and Hugo Wögerbauer (University of Technology Munich) clearly expressed their objections about the state of engineering design methodology in the 1930s and 1940s. Kesselring complained about the lack of standardisation and systematic procedures in engineering design. He wanted to base design decisions on a solid scientific foundation to "be as independent as possible from conjectures and opinions formed by feelings" (Kesselring, 1942, p.322).

Rudolf Franke, a specialist in gear mechanisms, pursued similar ideas as Kesselring. Starting out from Franz Reuleaux's Kinematics, he attempted to conceive a "simple, strictly scientifically justified theory" of gear mechanisms (Franke, 1943, Preface). Franke defined the components of a gear as abstract elements, represented by symbols, which can be varied and composed systematically and according to scientific rules in order to produce gear mechanisms with the desired characteristics. Franke took over Reuleaux's scientific ideals, but still differed from him in his perception of the engineer. In Franke's view, the engineer still represented an "artist" rather than a scientist.

The most comprehensive foundation for a science of engineering design in the first half of the 20th century was created by the Austrian professor of mechanical engineering Hugo Wögerbauer. Wögerbauer considered the cumbersome and protracted search for a design solution as unsatisfactory. He raised the question, "whether engineering design cannot be grasped theoretically somehow (…) with the goal to increase the efficiency and intensity of engineering design, reduce the learning time and avoid a misdirection of the creative and talented engineer". Wögerbauer wanted to create "a teachable, logically coherent system" which enabled the engineering designer to come to a "systematic, prudential and complete design" (Wögerbauer, 1942, p.24). Soon, however, he realized the difficulties of creating such a system, which in the end proved impossible. In his textbook he systematically analyzed the multiple factors and influences, which determined the process of designing. This analysis clearly showed the complexity of the process. A straightforward and fully logical design process proved impossible. "An ideal method", Wögerbauer concluded, "which requires little creative reasoning, can never be expected." (Wögerbauer, 1942, pp.73f).

Kesselring, Franke and Wögerbauer were all committed to scientific methods in engineering design, but acknowledged the limits of such methods. They recognized the role of "art" in design and explicitly endorsed a multiplicity of methods – be they scientific or not. They can be regarded as "critical methodologists" with a somewhat stronger emphasis on scientific methods than in the case of Riedler, Ernst or Redtenbacher (see Figure 11.3).

After World War II, the history of engineering design in the German speaking countries followed different paths. The separation of the two German countries had a significant impact on the further development of engineering design. In the Federal Republic of Germany, engineering designers complained about little esteem for their field and a shortage of engineering designers. In the German Democratic Republic, in contrast, the technical sciences, and among them engineering design, experienced a rapid expansion in the 1950s. New institutes and universities were founded, among them the University of Electrical Engineering in Ilmenau, which included a department of engineering design. Here, the engineering designers Werner Bischoff, Friedrich Hansen and Artur Bock conceived the so-called "Construction-Systematic" ("Konstruktionssystematik") and founded the Ilmenau school of engineering design.

It was the goal of Bischoff, Hansen and Bock to turn the largely intuitive work of engineering designers into a science. "A useful construction systematic must guide the way through the whole process of design. It must be usable for all people, which are technically educated in design, and it must logically lead to the best solution or close to the best solution at the least expenses," Bischoff and Hansen explained in 1953. "The designer deals with matters that are determined by strict scientific laws". Hence, it should be possible to guide the design process through a sequence of logical steps using scientific laws (Bischoff, Hansen 1953, 3, 6). The needed guidance could be accomplished by the Construction Systematic. "The Construction Systematic gives the scientific laws of the design process." (Bischoff & Hansen, 1953, p.7).

Hansen did not believe in an "art in the sense of a god-given gift". What others called "art" was in his eyes simply an irrational process for the lack of better knowledge and guidance. The Construction Systematic was conceived to "overcome the irrationalisation and mystification of creative work" (Hansen 1968, i). With their strong belief in the possibility of scientifically-based engineering design Bischoff, Hansen and Bock subscribed to scientism and belonged to the group of strict methodologists, like Reuleaux.

At the same time, in the Federal Republic of Germany engineering design was heading in a completely different direction. Here, the "artists" among the engineering designers dominated the debates and shunned scientism, which in their eyes didn't help engineering design and – even worse – distorted engineering students to become theoreticians unfit for practice. One of the eloquent critics was Kurt Rauh, professor for mechanical engineering at the Technical University Aachen. In an article published in 1951 he maintained: "The most distinguished engineering task, the creative design, is in no way a scientific work, yes, we can even say, design is not at all feasible with scientific methods alone (…) The largest, if not the decisive part of a machine design is rather the artistic creation. (…) The great importance of art, the creation from unexplored depths of the human mind, from values of life and experience and from a vivid imagination, the importance of these forms of art has not been recognized by most and is neither considered in the curricula of our technical universities." (Rauh, 1951, p.5).

The Swiss mechanical engineer Albert Leyer, professor at the Confederate Technical University Zurich and after 1964 at the Technical University Stuttgart, published his objections against a scientification of engineering design with similar markedness. In his eyes engineering design "is considered an art, and the engineering designer is reckoned among the artists." "The basic foundation of engineering design is designing. Designing is the proper creative process, the forming of mechanisms in the mind's eye based on intuition, reasoning and imagination." While scientific methods can help the art in the design process, they cannot at all substitute art (Leyer, 1963, 8, 13). In Leyer's opinion the main problem was the overestimation of science. He believed that the fascination of science had seduced "whole generations of young engineers". The result of this fascination produced in his eyes a degeneration and decline of engineering design. "This art is since decades in an emergency, which can hardly be outbidden", he complained. In his opinion universities suffocated the creative interest of their engineering students with an overload of scientific facts and methods and an underestimation of the role of practice and practical experience (Leyer, 1962, pp.1-2).

Engineers like Rauh and Leyer campaigned against a scientific methodology in a similarly radical manner to Riedler and Ernst more than half a century earlier. Likewise, they can be considered as "practitioners" with regard to their methodological conviction. Particularly Leyers engagement was important for an increased appreciation of engineering design in the 1960s, which – 10 years later than in the GDR – led to a marked expansion of engineering design education in the Federal Republic of Germany. At almost all technical universities new professorships for engineering design were established, 1963 in Berlin and Darmstadt, 1964 in Stuttgart, 1965 in Munich, Darmstadt and Braunschweig, 1969 at the University of Bochum, 1970 in Aachen, 1973 in Hannover etc. Ironically, this wave of expansion did not lead engineering design in the direction Leyer had demanded. Quite to the contrary, it reinvigorated ambitions in the area of scientific design methodology.

Particularly ambitious were four of these new professors, Wolf Rodenacker in Munich, Karlheinz Roth in Braunschweig, Rudolf Koller in Aachen and Vladimir Hubka in Zurich. Rodenacker developed a "physically oriented design method", as he called it. The most important idea of this method was the foundation of design on machine functions instead of traditional machine elements (Rodenacker, 1966). Rodenacker explicitly objected to Leyer's understanding of engineering design as an "art". He, instead, sought a "rational, scientific" as well as "coherent and complete method of design". "With the introduction of rational conceptions the feeling for design will be substituted by systematic learning of the necessary working steps." (Rodenacker, 1970, p.4). "Work originally based on 'art' will become a work based on scientific methodology." (Rodenacker, 1970a, p.1329).

Roth, Koller and Hubka pursued strategies similar to Rodenacker. They all wanted to make engineering design a logical sequence of working steps guided by scientific laws. Their long-term vision was the formulation of an engineering design process in the form of an algorithm, which could be performed by a computer so that an automated computer-based design of technical devices became possible. A strong belief in the scientific basis of engineering and the abandonment of any form of "art" represented a scientism similar to that of Reuleaux, Bischoff, Hansen and Bock. Hence, Rodenacker, Roth and Koller also have to be regarded "strict methodologists".

Around this time, however, the expectations of the "strict methodologists" did not materialize. Leading engineering designers like Gerhard Pahl, professor in Darmstadt and Klaus Ehrlenspiel, professor in Hanover and later in Munich, both noted in the mid-1970s that the use of strict methodologies did not speed up the engineering design process, as had been predicted by the "strict methodologists". Quite to the contrary, a strict methodology appeared to increase the time needed to reach a design solution. Hans-Joachim Franke, who was a student of Karlheinz Roth in Braunschweig and later became his successor, drew a critical conclusion about automatized design processes in his PhD thesis in 1976. He wrote of such a process: "That this goal will not be efficiently realized is beyond any doubt." (Franke, 1976, p.106). The clash of scientific ambitions and their criticism caused a lot of debate. The failure of strict scientific methodologies in the industrial practice of engineering design finally resolved the confrontation in favour of the critics. Strict engineering design methodologies did not become generally accepted.

Much more successful was a "softened" form of a scientific methodology as proposed by engineering designers Gerhard Pahl and Wolfgang Beitz in their enormously successful textbook, which appeared in 1977 and in 1984 in an English translation (Pahl & Beitz, 1977 and 1984). Pahl and Beitz clearly supported a systematic scientific methodology of engineering design, but acknowledged the importance of a flexible application of such methodology and the role of intuitive working processes. In their view, engineering design required "art", but at the same time had to look forwards and apply science for the process to be effective and the designs of high quality. In their relative appreciation of "art" and science, Pahl and Beitz can be regarded as "flexible methodologists" who had a strong appreciation of science without neglecting the importance of "art".

This influential work by Pahl and Beitz was not welcomed in all parts of the engineering design community. Engineering designers like Johann Schregenberger and Klaus Ehrlenspiel, and also the philosopher Johannes Müller demanded the recognition of a far more prominent role for intuitive approaches in engineering design. Since the mid-1980s, the empirical investigation of the design process provided strong evidence that engineering design in practical contexts is mostly characterized by intuitive trial and error steps and strongly guided by factors like the personal experience of the designer. Practical design appeared to be a spontaneous and intuitive process, while systematic scientific methodology only played a very limited role. Ehrlenspiel drew the fundamental conclusion that engineering design normally is intuitive and only exceptionally guided by scientific methods. This intuitive "normal operation", as he called it, turned out to be much more efficient than systematic scientific methods. According to this view, only in instances when engineers encountered problems in the design process that stopped progress, should they turn to systematic scientific methodology. Ehrlenspiel, Schregenberger and the late Johannes Müller can all be considered as "pragmatic methodologists" in our model.

Understanding the History of Engineering Design Methodology

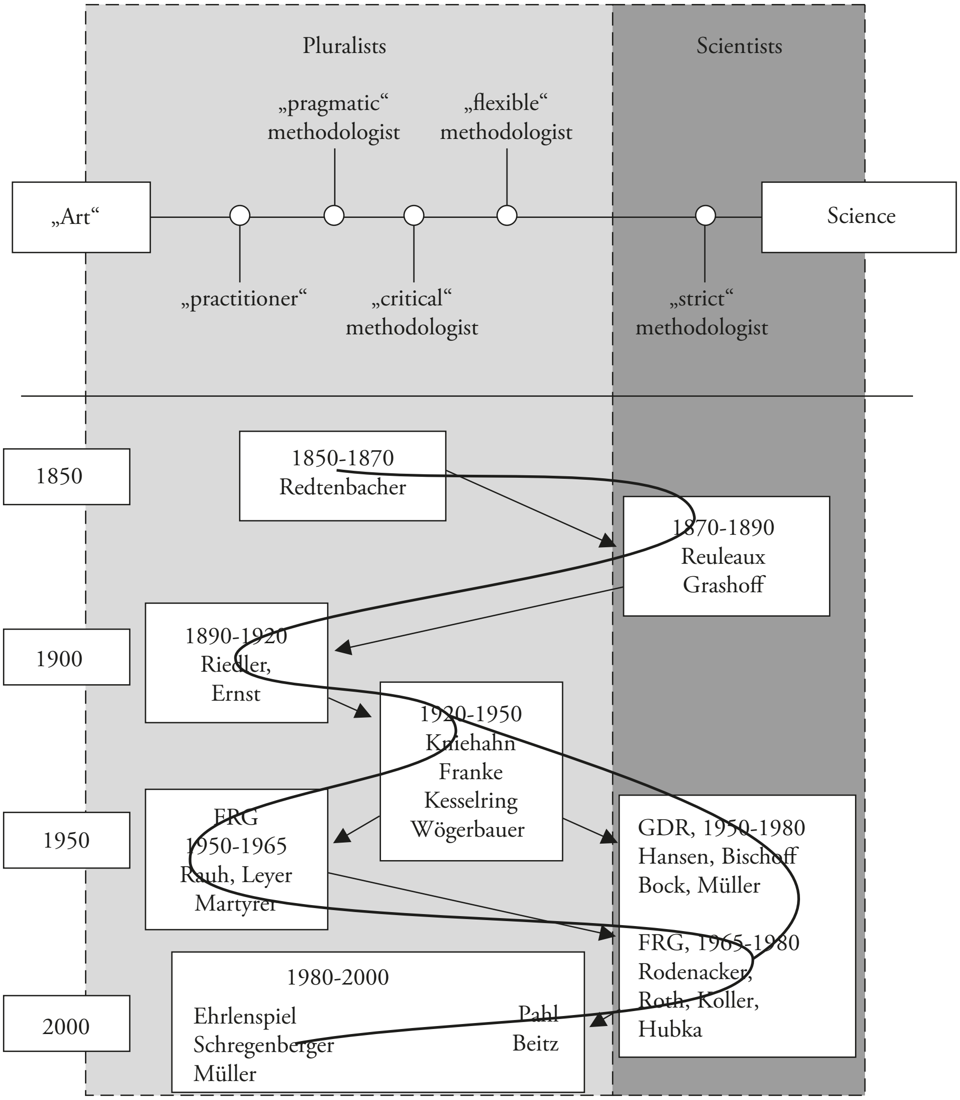
According to the Dresden Model, engineering practice and science merged in the "reaction space" of the technical sciences at the technical universities. In this space new knowledge, new methods and new professional identities emerged, which were interpreted as a synthesis of practical knowledge and scientific knowledge. However, a closer view of the history of engineering design shows that the scientification of engineering in fact produced the opposite effect: continuous debate and conflict and ever changing convictions about the relative status of practical knowledge or "art" and scientific knowledge or science. Seen from this perspective, the coexistence of two fundamentally different forms of knowledge, perceived as having little in common, rather destroyed any clarity, unity and unambiguousness, which may have existed in the age of the craftsmen. The crafts tradition was rooted in the copying of known mechanisms, a clear and unambiguous strategy. Only with the intrusion of science into technical creativity did a multitude of methodological approaches become available, which in turn led to increasing ambiguity. As Redtenbacher rightly observed:

instead of one approach, "art", the engineer now could make use of several approaches in engineering design, "art" or science or any mixture of the two.

This extension of the methodological repertoire inevitably created the problem of how to decide how much "art" and how much science would be needed in engineering design – which signaled the beginning of more debate and conflict. The two poles of "art" and science opened up a number of possibilities and created a fundamental openness and uncertainty in engineering science, which could never be resolved. As a consequence a great number of engineering designers engaged in methodological work and also in debate on methodology. The historical sequence of methodological convictions effectively reveals a kind of pendulum movement swinging between the poles of "art" and science (Figure 11.4). The openness of engineering methodology was regarded by a number of designers as an unsatisfactory and unfinished state, which they sought to overcome by developing strict scientific methods. The attraction of the virtues of science was repeatedly felt in engineering design and produced an inclination towards scientism. Strict methodologies as developed by Reuleaux, Hansen, Rodenacker and other, however, failed. They did not enter industrial practice, and never lived up to efficiency and effectiveness expectations. As a reaction to scientism, a strong counter-movement of pragmatism often occurred, e.g., in the case of Riedler, Leyer or Ehrlenspiel.

Most methodologies in the history of engineering design involved a multitude of methods and approaches both from "art" and science. These methodologies may be regarded as pluralistic. The opposite of this pluralism was represented by a strict scientism, which, in contrast, stuck to fighting openness and ambiguousness and aimed at a unified theory in engineering design. The pendulum model reflects the fact that the openness of engineering design proved to be insurmountable. The openness of the design process repeatedly created uneasiness and frustration. It seemed unsatisfactory from a methodical, esthetic and emotional point of view, because it caused a mingle-mangle of rules (Reuleaux) and a lack of structure and systematic procedures (Hansen, Rodenacker). Vladimir Hubka demanded a "coherent edifice" in engineering design, which could provide clarity, unity and security. But, despite these efforts it seems that the methodological openness will remain for some time. It is difficult to overcome, in principle, because "art" and science represent incompatible forms of knowledge, and so it is likely that the methodological debates will continue. Indeed, when considering the historical investigation, there is little evidence to suggest the swinging of the pendulum between "art" and science will stop any time soon.

Figure 11.4: Pendulum movement of engineering design methodology between “art” and science.



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Chapter 12

A Historical Perspective of Engineering Design

Wilhelm Bomke

Abstract: Many engineering designs have perished over the centuries. Only few but highly developed examples are preserved, the earliest from the Mesopotamian and Egyptian era. Intricate buildings, impossible without prior plans, survived the centuries in many cultures. From the Renaissance onwards engineering designs are preserved in numerous examples. This chapter illustrates the close connection between designs and engineering. It also aims at showing the role design played in civil engineering, how it influenced all engineering disciplines and keeps doing so to the present. Today, design methods and tools change more rapidly than in the last centuries. But engineering design's basic purpose, basic influence and seminal importance is still rather unchallenged by current progress.

Key words: Engineering Design in History, Importance of Vitruvius, Modern Developments in Engineering Design

Introduction

All creative action necessitates prior planning and thinking. Human beings are able to draw and to communicate through language and, later in history, through writing. These means have long been used to make the creation of engineering products possible.

Most designs have been lost and often only the final results based originally on engineering design can still be seen and analyzed. Cave paintings are some of the earliest traces of human artistic activities. They may have served as plans for hunting expeditions, even if it cannot be denied that their magical significance was certainly much more important. Their location in rather inaccessible places and the importance of the mastery of fire in their creation and use testifies to that.

The erection of stone circles, dolmen and henges was hardly possible without initial plan and design. The fact that their construction took a long time and called for the collaboration of many people makes it unlikely that the final realization was reached without the help of drawings, models or markers devised at the beginning of the construction activities. Already the decision to build such structures may have called for a model depicting the envisaged structure as well as its uses. The exact position of the elements of many of these buildings in relationship to the sun's movements or to stars must have been fixed before construction began. Some of the graves dating from the Stone Age were constructed using a technique of vaulting which survives in rural areas today. Similarities between Ireland and Mykene are striking (Küpper, 1996). There may even have been an exchange of information concerning building techniques transcending frontiers of cultures and languages. Maybe even specialists were mobile in that early age. Only few Neolithic buildings survive. Pictures used for their construction or their plans do not. But the Nebra disc, for example, shows that plans and maps were within the intellectual and artistic range of our ancestors in Europe (Hansen, 2007).

There are many more uses of engineering design today than can be traced in history. The emphasis on building in the following chapters is mainly due to the lack of surviving sources for other engineering areas.

Ancient Mesopotamia and Egypt

Ancient Mesopotamia and Egypt are the first civilizations in history where proof of the existence of engineering design survives. Egypt had a very well developed measuring system and a huge number of specialists trained to do exact measurements. This originated in yearly floods of the Nile, which annually made a new definition of the field boundaries necessary. Lines were drawn in the mud after the fields had been remeasured in the scale of 1:1. Plans of the fields drawn to scale are likely to have existed as well (Sellenriek 1987, p.27).

In Mesopotamia, plans of cities, of fields and of watering systems survive sketched on clay plates (Sellenriek, 1987, p.27). Especially from the third millennium up to the new Babylonian period numerous floor plans have been recovered. During the Akkadian predominance (24th to the 22nd century BC) these include room measurements and denotations. These plans show all walls as single lines without details of their thickness, only the doors and their measurements are usually given (Mislin, 1997, p.44). In those days, a special rank or professional group of builders existed. One statue, preserved in the Louvre in Paris, even shows a Babylonian architect with his plan in hand (Sellenriek, 1987, p.31).

The fact that so many Mesopotamian layouts were preserved is a result of the materials they were made of. The practice of using clay guaranteed the survival of numerous plans. In Egypt, where papyrus was the medium of choice, frequent use and limited usefulness made their survival very unlikely.

In some Egyptian temples one can still see the markings which give in a 1:1 scale the positions and dimensions of columns and architectural elements, used by the builders to copy elements and to guarantee the correct site of structures (Mislin, 1997, p.44). In most cases these markings are hidden below the finished edifices or were extinguished after they had served their purpose. Whether a version of these outlines or a plan drawn to a smaller scale existed before these rather basic engineering designs were made is open to conjecture. But the existence of downscaled models of buildings is a fact. They served as a means to demonstrate building ideas to those financing the projects and as assistance to builders. This suggests that Egypt may in actual fact have had a much more abundant wealth of engineering drawings and models than Mesopotamia.

The greater longevity of the Mesopotamian clay tablets compared to papyrus and the resulting higher preservation rate is further supplemented by other factors. The climate in Iraq and Iran is more favorable to a survival of antiquities than that of Egypt. Many antique sites in the Nile valley have been in constant use over the centuries. This eradicated many traces from the past. Mesopotamian ruins were usually preserved in very barren landscapes with hardly any population. Even more influential was the different purpose of the libraries in both cultures. The Mesopotamian ones served as archives. Their purpose was to document and preserve information of technical, administrative and economical nature. The famous Egyptian library in Alexandria focused on collecting literary, technical and cultural texts. It aimed at serving as a repository of human knowledge and culture.

Many majestic buildings in Egypt, for example the pyramids, suggest an original plan. Especially the intricate passageways and trap systems were clearly not built without prior design and accurate plan. Their secrecy was another reason why plans did not survive. Also the organization of the workers and the logistics of supplies are inconceivable without a planning phase. Its traces are, however, lost due to the distance in time and due to the uselessness of plans after the completion of the work. But it is to be expected that they were very detailed and developed and not much different from the versions used at large construction sites today. The fact that no pharaoh constructed his buildings and monuments without the help of specialists may prove that proposals in the form of drawings or models must have existed to choose one version over another for realization.

A few examples of plans did survive the centuries. An Egyptian map of a gold mine in Nubia (Sellenriek, 1987, p.28), a plan for a storage building in a grave in Tell-el-Amarna (Sellenriek, 1987, p.32), a drawing of a building plan on a papyrus from Ghorab (Sellenriek 1987, p.34) and a vertical plan for a pyramid engraved in a stone wall in Meroe (Sellenriek 1987, p.38).

Egyptian architects are also known. Imhotep (2650-2600 BC) is the first, supervising the construction of the grave of pharaoh Djoser (2667-2648 BC) and other major buildings. He was also chancellor of the realm, priest, inventor, polymath, medical doctor and many things more. In particular his medical fame led to his deification. Senemut, active in the 15th century BC, again combined the office of chancellor with the construction of buildings, especially the funerary temple of pharaoh Hatshepsut. His reputation is mainly based on the surviving buildings and the well preserved grave of his parents, which he constructed. The building tasks were not the main occupation of these architects but their offices gave them the power and wealth necessary to complete their projects.

Ancient Greece

The Greek culture offers a varied picture of architecture, theory of architecture and architectural design. The oldest monuments were not the least difficult to construct. Mycenaean architecture, for example, made grave vaults and city walls possible, which matched in intricacy similar constructions from the rest of Europe. But the most cherished architecture of temples and other public buildings financed by the state relied on rather simple forms and construction principles.

Ancient Greece contributed little progress to building techniques. The basic structure of official buildings was based on columns and straight connecting stone slabs. The wooden structures common up to the 5th century were rebuilt or replaced by stone buildings of similar construction. However, we know of numerous Greek architects. They were more specialized than their predecessors in Mesopotamia and Egypt, who usually had held religious or political offices as well. In its English version, Wikipedia gives 4632 entries for Greek architects. To give but a few prominent names: Phaeax, who was active in Agrigentum (around 480 BC), Kallikrates (middle of the 5th century BC), who worked in Athens, for example at the Parthenon, Sostratos of Cnidus (3rd century BC), who created the Pharos of Alexandria, Pythis and Satyros (4th century BC), who built the Mausoleum in Halicarnassos. The reputation of these architects was high. They very often were artists and inventors of mechanical apparatuses as well. Inscriptions on buildings also show that they were proud of what they did. People were impressed by their work and held them in high esteem. It was very common for these specialists to get commissions from outside their native cities and often they were active on several building sites all over the Hellenistic world. This in many aspects resembles the professional situation today.

In addition, there are a lot of theoretical writings concerning building and building techniques, for example from Ktesibios (ca. 285-222 BC), Philon of Byzantium (ca. 280 – ca. 220 BC), Aristotle (384-322 BC), Heron from Alexandria (ca. 10-70 AD), Plato (428/27-348/47 BC) and Theophrastos (370 to ca. 285 BC), to name but a few (Tzonis, 2004, p.23; Mislin, 1997, p.51)

The concept of the perspective was developed by Greek thinkers from the 6th century BC onwards (Bärtschi, 1976, p.9). In 460 BC Anaxagoras published a theory of the perspective which was based on the decoration of theatres and the theory of light (Bärtschi, 1976, p.11).

Much of Greek knowledge was lost in the Middle Ages and only rediscovered in the Renaissance. Some was available in the libraries of monasteries but not put to practical use (Tzonis, 2004, p.23-24). Various Greek ideas came back to Europe via Arabic writers, some from Constantinople, where they had been kept alive until its fall to the Turks 1453.

The sources are scarce, too. Not a single Greek original plan exists (Sellenriek, 1987, p.39). This is again mainly due to the decay of the materials used. Wax tablets, the likely medium for planning sketches, were certainly reused after the aim had been accomplished. Again the surviving structures are proof that plans must have been used (Sellenriek, 1987, p.40-43).

Vitruvius writes that the Romans learnt from the "ichnographia" and "orthographia" in architectural design from the Greeks (Book I, Chapter II, 2):

"*2] 2. Order gives due measure to the members of a work considered separately, and symmetrical agreement to the proportions of the whole. It is an adjustment according to quantity (in Greek posotês). By this I mean the selection of modules from the members of the work itself and, starting from these individual parts of members, constructing the whole work to correspond. Arrangement includes the putting of things in their proper places and the elegance of effect which is due to adjustments appropriate to the character of the work. Its forms of expression (in Greek ideai) are these: groundplan, elevation, and perspective. [p. 14] A groundplan is made by the proper successive use of compasses and rule, through which we get outlines for the plane surfaces of buildings. An elevation is a picture of the front of a building, set upright and properly drawn in the proportions of the contemplated work. Perspective is the method of sketching a front with the sides withdrawing into the background, the lines all meeting in the centre of a circle. All three come of reflexion and invention. Reflexion is careful and laborious thought, and watchful attention directed to the agreeable effect of one's plan. Invention, on the other hand, is the solving of intricate problems and the discovery of new principles by means of brilliancy and versatility. These are the departments belonging under Arrangement"* (www.perseus.tufts.edu)

This proves that plans were used and that they were similar to much we do today. In few examples, as in the temple of Apollo in Didyma in Turkey, dating from around 250 BC, the sketches of architectural details were made in stone and survived (Sellenriek, 1987, p.42-43). Only the fact that the temple was never finished may have prevented the elimination of the sketches. They remained to be useful. Usually the eradication of such plans was part of the finishing process of a building in classical

Greece. Thus again, as in Egypt, the sketch for the actual building parts within a building in progress is documented.

Rome

Rome was very much influenced by Greek architecture and most of the practises, tools and styles are similar (Tzonis, 2004, p.23). Yet there were other influences as well. The Etruscan heritage, for example, can be traced in some aspects of graves or canalisation work.

The importance of the army as a pillar of Roman expansion and lifestyle led to many military buildings not known to Greece. Also, the Romans were less dependent on water for their transport system. They favoured the construction of roads and the high professionalism of these is impressive even today.

Engineering designs from Roman times did not survive often, but impressive fragments of a marble plan of Rome from the 1st century AD have been found, showing detailed architectural elements on a scale of 1:120, and a fragment of the plan of the tomb of Claudia Peloris, the daughter of emperor Claudius with the room dimensions given on a scale referring to the Roman foot (Mislin, 1997, p.109). In the amphitheatre of Capua drafts of arches survive for the construction workers on the scale of 1:1 (ibid.). In Roman times estimates of the costs had to be made and building contracts gave detailed description of the work to be performed (Mislin, 1997, p.111). These few examples suggest a much greater wealth of engineering designs lost in time. Once more, libraries or archives have been lost and the writings we know today have all been preserved for us by constant copying in Medieval monasteries. Usually the copying led to the loss of images or to redoing them in the mode of the time of the copyist.

Our knowledge of Greek and Roman building practice and theory is, to a considerable extent, derived from *The Ten Books On Architecture* by Marcus Vitruvius Pollio preserved in this way. The author, an engineer working under Ceasar and Augustus in the 1st century BC, was intent on collecting all relevant knowledge of his time.

Book I deals mainly with landscape architecture. Included is a chapter on the education of an engineer, which stresses the necessary interplay of theory and praxis:

> "*1. The architect should be equipped with knowledge of many branches of study and varied kinds of learning, for it is by his judgement that all work done by the other arts is put to test. This knowledge is the child of practice and theory. Practice is the continuous and regular exercise of employment where manual work is done with any necessary material according to the design of a drawing. Theory, on the other hand, is the ability to demonstrate and explain the productions of dexterity on the principles of proportion.*

2. *It follows, therefore, that architects who have aimed at acquiring manual skill without scholarship have never been able to reach a position of authority to correspond to their pains, while those who relied only upon theories and scholarship were obviously hunting the shadow, not the substance. But those who have a thorough knowledge of both, like men armed at all points, have the sooner attained their object and carried authority with them.*"
   (Marcus Vitruvius Pollio, Book I, Chapter 1, www.lih.gre.ac.uk/histhe/vitruvius).

This argument very much resembles arguments put forwards for modern course syllabi and it has lost little of its relevance. The fact that engineering design was vital to Roman architectural practice is clearly stated in Chapter 1, Paragraph 4 of Book I:

"*An architect ought to be an educated man so as to leave a more lasting remembrance in his treatises. Secondly, he must have a knowledge of drawing so that he can readily make sketches to show the appearance of the work which he proposes. Geometry, also, is of much assistance in architecture, and in particular it teaches us the use of the rule and compasses, by which especially we acquire readiness in making plans for buildings in their grounds, and rightly apply the square, the level, and the plummet. By means of optics, again, the light in buildings can be drawn from fixed quarters of the sky. It is true that it is by arithmetic that the total cost of buildings is calculated and measurements are computed, but difficult questions involving symmetry are solved by means of geometrical theories and methods.*" (ibid., www.lih.gre.ac.uk/histhe/vitruvius).

Vitruvius goes on to recommend a broader education of the architect, comprising history, philosophy, music and medicine. Book I also includes information on city planning, town walls, gardens and parks.

In Chapter 3 of Book I he gives his opinion on the three subdivisions of architecture. His understanding of architecture is closer to what is today understood by engineering in general:

"*1. There are three departments of architecture: the art of building, the making of timepieces, and the construction of machinery. Building is, in its turn, divided into two parts, of which the first is the construction of fortified towns and of works for general use in public places, and the second is the putting up of structures for private individuals. There are three classes of public buildings: the first for defensive, the second for religious, and the third for utilitarian purposes. Under defence comes the planning of walls towers, and gates, permanent devices for resistance against hostile attacks; under religion, the erection of fanes and temples to the immortal gods; under utility, the provision of meeting places for public use, such as harbours, markets, colonnades, baths, theatres, promenades, and all other similar arrangements in public places.*

2. *All these must be built with due reference to durability, convenience, and beauty. [Note: the better-known translation of these values "Commodity, Firmness and Delight", comes Henry Wotton's 1624 Principles of Architecture) Durability will be assured when foundations are carried down to the solid ground and materials wisely and liberally selected; convenience, when the arrangement of the apartments is faultless and presents no hindrance to use, and when each class of building is assigned to its suitable and appropriate exposure; and beauty, when the appearance of the work is pleasing and in good taste, and when its members are in due proportion according to correct principles of symmetry.*" (ibid., www.lih.gre.ac.uk/histhe/vitruvius).

Today, machinery and clocks are no longer the responsibility of architects, but the rest of the quote, with its emphasis on the combination of aesthetics with both practicality and stability, may still find many followers.

Book II covers building materials, Book III and IV temples, Book V public places (including theatres, harbours, baths), Book VI private houses, Book VII finishes and colours, Book VIII water (including aqueducts, wells and cisterns), Book IX sundials and clocks and Book X mechanical engineering (covering among other things water clocks, siege machines, hoisting machines, water wheels and water mills).

The influence of Vitruvius' work in Rome is highlighted by references in other antique works. He describes, however, a mode of construction that was much modernised by new materials and styles just a few years after his death. Yet his books were even more influential in the Renaissance, where the rediscovery, republication and translation of his writings stood at the very outset, shaping the aesthetic concepts and building theory of the whole period all over Europe.

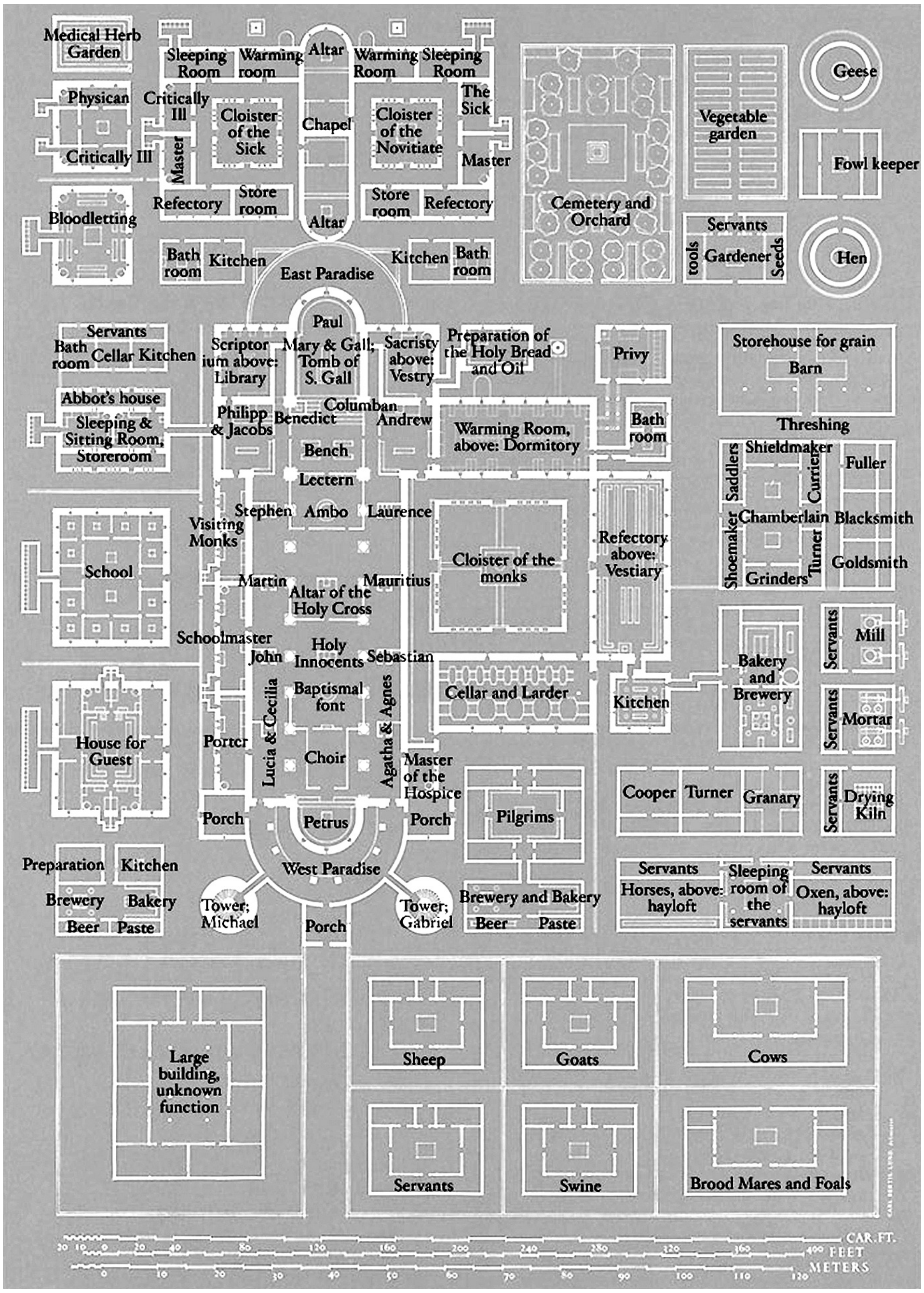
In the 1st century AD concrete was introduced as the basic building material for larger buildings in Italy. It was different from what we know today by this name and some modern uses were not possible then (Schild, 1983, pp.173-191). The Roman material was dependent on a kind of soil only available in Italy and this led to the development of a special method of building in Italy which was not common in the rest of the Roman Empire. The first major building documenting the use of concrete is the Domus Aurea of Nero. But many other buildings in Rome show its very versatile use by Roman architects. Among them are the baths of Caracalla and most prominently the Pantheon. This temple combines the Roman art of building arches with that of using the new material (Mack, 1989; Ball, 2003). Concrete's durability and the fact that it could not be reused for later buildings are the reasons for the relatively high number of surviving Roman concrete buildings. The material was forgotten after the fall of the Roman Empire, and it was only rediscovered in 1756 by the British engineer John Smeaton. The kind of concrete used by builders today, Portland cement, only came into use in the 1840s.

Byzantium kept alive many of the Roman building techniques (Mislin, 1997, pp.133-156). The most impressive surviving example of its architecture is the Hagia Sophia (Thode, 1997). But also in Ravenna impressive monuments survive. A frieze of the Ostrogothic palace in Ravenna even depicts an early Byzantine palace (http://en.wikipedia.org/wiki/ Byzantine_architecture). Sources show that the patrons of buildings often included plans in the instructions to the builders which were meant to be transferred to the ground in the form of a 1:1 or scaled chart. This served as the outline for the workers building the foundations and structures (Mislin, 1997, p.153). Many architects who worked in Constantinople are still known, for example Isidore of Miletus and Anthemius of Tralles, who built the Hagia Sophia. The Arab world kept some of the knowledge and practises learnt from the Eastern Roman empire alive, while they were forgotten in the West (Andrews 1989). Some elements of Roman knowledge of building also survived in Eastern Europe, Sicily and Ravenna.

The Middle Ages

The deep divide between the end of the Roman Empire and the Middle Ages may not have been so severe in everyday life as we may expect. Most everyday buildings in antiquity were built of wood and stone and this continued to be so in the Middle Ages. However, the use of wood was definitely growing and this material is very perishable. The Germanic tribes north of the Alps had favoured wood and their conquests spread their techniques. Little survives until today. But wood was also a major element of Greek buildings, and it is not necessarily a weakness of the medieval builders to use this material. It is just a consequence of the availability of materials and of their durability that some cultures have left more permanent constructions than others. The quality of the building is not necessarily linked to its longevity. Building with wood was often complicated and very refined (Mark, 1995, pp.192-241).

Early in the Middle Ages, around 820, a ground plan of an ideal monastery was drawn for the library of the monastery of St. Gall. It survived rather by accident, as fires, pillaging in wars, decay and theft diminished the treasures of this renowned library considerably. This plan was, despite its model character, meant as a building plan (Sellenriek, 1987, pp.82-83). The drawing was made for abbot Gozbert (in power 816-837), but it was not suitable for St. Gall's grounds. It may very well have been designed in order to realize the ideal of Benedictine monasticism in a real building program. Thus the Early Middle Ages have left us an engineering design even more complex and meaningful than the more technically and culturally advanced ages before. The effort, expenditure and thought that went into this work are very impressive. It is 112*77.5 cm in size and comprises five expensive pieces of parchment sewn together. It gives a scale, 1:192 in Carolingian feet (Mislin, 1997, p.163). The plan even depicts the columns of the ambulatory in vertical form to give more detailed information to builders (Mislin, 1997, p.193).



http://www.stgallplan.org/en/index.html

Many of the following centuries did not leave engineering designs. This may once more be due to their perishability and limited usefulness. But surviving buildings prove that models and plans must have existed. Scattered images of buildings and mechanical constructions are preserved in manuscripts, but they were meant to show the finished work or its functions. They were not designs for the construction of something new (Sellenriek, 1987, pp.88-99). The first technical drawings which do survive date from the Middle Ages. Vitruvius, however, already described machines and may have included illustrations in his work which have been lost in tradition. Herrad of Landsberg around 1160 wrote the *Hortus Deliciarum* including many illustrations, some of technical objects. In the 13th century Villard de Honnecourt wrote *Le carnet de villard <http://villarddehonnecourt.free.fr/carnet.htm>* comprising many drawings of architectural and technical details.

The practitioners active at the building sites of cathedrals and other major edifices were often called "Magistri operis" (Sellenriek, 1987, pp.91-115). They usually had the training of stonemasons. These also acquired construction and planning abilities during their long apprenticeship (Sellenriek, 1987, pp.95-99). But very few of their plans survive.

Much of the practical knowledge of builders was transmitted from Antiquity to the Middle Ages notwithstanding the cultural change. But the more theoretical aspects were lost and erecting stone buildings made a new start necessary (Sellenriek, 1987, p.90). Some knowledge about arches, mathematics and the practical side of building was handed on and was developed further. Many engineering designs for churches survive, often hidden on reused parchments where they can now be restored by modern technology (Sellenriek 1987, 101-105). It is apparent that much of the knowledge of builders was passed on orally at the construction sites of cathedrals and other mayor buildings. It was not necessary or useful to write it down. Only at the end of the Middle Ages a few specialists decided to publish aspects of their trade. Matthäus Roritzer, active as architect at the cathedral of Regensburg, published *Das Büchlein von der fialen Gerechtigkeit* 1486 and *geometria deutsch* (written 1487/88) 1498, Hans Schmuttermayer the *Fialenbüchlein* between 1485 and 1488, Lorenz Lechler *Von des Chores Maß und Gerechtigkeit* 1516 and an unknown author *Das Wiener Werkmeisterbuch* 1490 (Mislin, 1997, pp.175-193; Sellenriek, 1987, pp.101-113). What had been handed down from generation to generation of masons and architects becomes tangible through these publications. But the late 15th century, when this happened, already marked the start of a new era.

The Renaissance

Philibert de l'Orme (ca. 1510 – 1570) and Albrecht Dürer (1471-1528) simultaneously published works on building inspired by the rebirth of antique knowledge and science. It was not an abrupt change. Many traditions with Medieval roots remained valid. But the new way of thinking also brought far reaching changes.

The perspective was rediscovered and developed further. Brunellesci, Leon Battista Alberti, Piero della Francesca, Michelangelo, Leonardo are just a few of the most prominent figures involved (Sellenriek, 1987, pp.105-144; Bomke, 2007, pp.29-40). Alongside the reappraisal of Antique knowledge new theories were developed and appreciated in their own right. Trade, technology, art and science were advanced considerably. Kepler, Galilei and others created a new world view. Laws of nature were detected which allowed one to calculate and plan things without the risks inherent in the trial and error method, which had dominated the preceding centuries. Experience could now be transcended to make new developments possible. These were not limited to architecture and building. New methods and new engines became possible and progress gained speed. Engineering lost its close association to building and conquered new areas. Vitruvius was rediscovered and soon his ideas were developed further. New subjects and university courses were introduced. Religion as the dominant academic discipline was gradually pushed aside. The training of architects became more theoretical and the practical side was depreciated. Mathematics and physics gained a vital role in the education of builders. The academic training gave them a new self-image and divided them from the workers and craftsmen which had dominated the construction sites until then. Civil engineering and architecture developed apart. By and by, their common roots were lost from sight. Electrical and mechanical engineering as well as many other engineering disciplines developed. Mathematics and science started to occupy a central position in the training and work of engineers.

Modern Times

All the new developments, however, were not able to transform the everyday work of building substantially. Many tools and building materials remained the same. Many work processes and the work of craftsmen continued unchanged.

From the 19th century onwards, the use of concrete increased tremendously. At the same time glass, iron and steel entered the stage as materials for construction (Graefe, 1989). For the last 200 years innovation in civil engineering meant developing new ways to juxtapose, mix and combine the available materials (Mislin, 1988, pp.205-334). Plastics found their way into building and they replaced more traditional materials in some areas.

The concept of engineering design was considerably altered in the 20th century by new modes of operation, new fields of application, new theories and new technical equipment. The strongly felt dominance of civil engineering and architecture in the eighteenth century was replaced by the ascendancy of mechanical engineering in the academic world which started in the nineteenth century (Heymann, 2001, p.109). Currently sub-areas or new combinations of the established engineering disciplines are developing and the role of engineering design is, for many members of the profession, one of the mayor dividing lines between "true" engineering subjects and more "exotic" branches. Even as a prerequisite for the access to master programmes engineering design experiences a restitution of importance. Often only the first cycle degrees incorporating engineering design allow access to second cycle degree programmes. This is illustrated by the policy of my own institution, the University of Applied Sciences of Regensburg.

This thinking guaranteed the survival of design courses in rather packed syllabi of engineering degrees which would prepare students for working life even without this requirement. But the fact that engineering design is held in high esteem as an essence of engineering still safeguards its survival.

Computer aided design and the continual development of new tools and programmes also strongly influence the current situation of the discipline (e.g., Flemming, 2005). There still are a diminishing number of defenders of the paper and ruler version of design in engineering. They claim that the ability to draw by hand is a prerequisite to proper engineering work. The more modern dependence on computers creates, in their opinion, the continual need to keep up with new tools, whereas the old methods were tested and practised for centuries. The ability to work without the help of modern aids also leads to a better mastery of the core knowledge of a discipline. This traditionalist position also values the independence from computer tools as freedom. Many students oppose this time-consuming and old fashioned point of view. They are supported by companies and some (in Germany still a minority) professors, who consider the training in computer aided design (CAD) and computer numerical control (CNC) manufacturing as more vital and the time spent on the drawing board as a waste. This conflict divides engineering disciplines, universities, even departments, courses and teachers. The importance of engineering design per se is not really disputed. But the importance attributed to technical drawing or CAD in study programmes can vary considerably between institutions or courses. Practise usually supports modern media and the universities are keeping up the traditional methods and fundamental requirements. This was also the case during the Renaissance, when universities defended the supremacy of theology and the traditional syllabi against new developments. The traditionalists may once more be fighting a losing battle. Many of the reasons Vitruvius gave for acquiring sound drawing skills are still valid today. Few will deny that drawing skills and an education, which transcends subject boundaries, provide engineers with a broader and sounder approach and enable them to judge developments with greater authority.

The growth of knowledge since Roman times increased the number of subjects taught. Since these additions are very important there is an ever growing need in university education to substitute expendable elements by more vital ones. In my opinion, engineering design should not be discarded. It can be modernised to a considerable extent and thus become more relevant to everyday needs. But the work and time going into a design is a valuable safeguard against rash or ill-conceived action. The simple use of a computer program will neither allow progress beyond its limits nor a sound critical appraisal of its results. This is, for example, illustrated by the severe problems of the Airbus 380. It had been designed with incompatible software by different teams, and in addition the problem of suitable runways for the plane had not been taken seriously enough. Sometimes cars were constructed for non-existing markets. High tech trains were developed which were too costly to be built.

The argument that economic pressures call for a reduction of the role of engineering design in engineering education is contradicted by the fact that even Vitruvius was aware of and defended the importance of both design and economic aspects:

> *"8. Economy denotes the proper management of materials and of site, as well as a thrifty balancing of cost and common sense in the construction of works. This will be observed if, in the first place, the architect does not demand things which cannot be found or made ready without great expense. For example: it is not everywhere that there is plenty of pitsand, rubble, fir, clear fir, and marble, since they are produced in different places and to assemble them is difficult and costly. Where there is no pitsand, we must use the kinds washed up by rivers or by the sea; the lack of fir and clear fir may be evaded by using cypress, poplar, elm, or pine; and other problems we must solve in similar ways.*
>
> *9. A second stage in Economy is reached when we have to plan the different kinds of dwellings suitable for ordinary householders, for great wealth, or for the high position of the statesman. A house in town obviously calls for one form of construction; that into which stream the products of country estates requires another; this will not be the same in the case of money-lenders and still different for the opulent and luxurious; for the powers under whose deliberations the commonwealth is guided dwellings are to be provided according to their special needs: and, in a word, the proper form of economy must be observed in building houses for each and every class."* (Marcus Vitruvius Pollio, Book I, chapter 2, http://www.perseus.tufts.edu).

Courses combining engineering and business elements seem to be modern. But this quote shows that even in Roman times awareness of both aspects was deemed necessary for a good engineer.

Specialisation, easier course loads, new technical tools and the aesthetic demands of specialists should never result in engineering designs losing touch with basic engineering principles and cost effectiveness (Reese, 2005). Teamwork can help to keep the balance if single team members are no longer able to consider all relevant influences.

The admittedly conservative intention of this contribution is to state that not much has changed in engineering design over the centuries and that it may be detrimental to change too much too fast for modernisation's sake. There are other specialised disciplines within the computer studies area devoted to the support and development of up to date tools and programmes. If engineers should be required to invest too much of their energy in these details this will prove detrimental to their traditional engineering design skills. The teamwork approach with other specialists is appropriate. Engineers should possess a design training to cooperate with, to advise and, to a certain extent, to control these specialists.

The need to recruit more engineering students has resulted in a reduction of design courses in curricula. It has been hoped that team members with design knowledge might counterbalance the absence of design skills in their colleagues. These tendencies will eventually lead to a majority of engineering graduates without engineering design knowledge. The discarding of traditional engineering skills for the sake of modern ones may steer the profession into a dependency of other disciplines which is likely to limit the awareness of problems and the ability to react to them. The separation of civil engineering and architecture starting in the 18th century, unknown in Vitruvius' time, led to misunderstandings and mutual distrust making the achievement of common aims more difficult (Polonyi, 1989, pp.237-238). This trend is currently continued by the subdivision of engineering subjects. Vitruvius' ideal of a broadly educated engineer is gradually sacrificed to a more specialised training. Natural sciences often dominate the course loads. This means risking the loss of a common framework of values and abilities in engineering. Engineering design is at the core of this framework.

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Chapter 13

An Evolutionary Perspective on Engineering Design

William Grimson & Mike Murphy

Abstract: Natural Selection has provided a powerful explanation of how life evolved and evolution has been used as metaphor and model to provide insight into how technology and artifacts have developed. While recognising that Darwinian evolution does not proceed on the basis of a target or particular design outcome, the activity of engineering does proceed within what might be called an intelligent design framework. Evolution provides interesting parallels as to how engineering design has developed and is carried out. In particular the identification of useful traits, in a post hoc and natural selection-like manner, is a powerful mechanism that drives improvement. Further, serendipity plays a role in engineering as it does in biological systems. The mechanisms might be different but the characteristics of how "chance" influences outcome share many features. The mimicking of biological systems in engineering design is currently a vibrant research activity. In another parallel with evolution, Darwinian principles can be used to explain how ideas are propagated. This chapter summarises the main concepts of Darwinian evolution and finds examples in engineering where evolution-like behaviour can be observed, and where such material could be included to good effect in the engineering curriculum.

Key words: Evolution, Adaptation, Vestigial, Meme, Design, Technology

Introduction

Charles Robert Darwin was born 200 years ago on the 12th February, 1809, and it is now 150 years since his book *The Origin of Species by Means of Natural Selection* was first published. In Darwin's words

"As many more individuals of each species are born than can possibly survive, and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and

sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form".

By any measure Darwin's book and the central idea it contains ranks amongst the most important ever published and its impact has transcended its biological domain. The words evolution and evolutionary, used in both everyday language and more specialist fora, often carry meanings sometimes hidden but which nevertheless are connected to the ideas formulated by Darwin. Engineering and technology are not excluded. It is observed that engineering techniques and "know-how" come about by a process of inheritance, proceeding in a sequence of often small steps that involves a process of selection. Likewise for the physical products and artifacts designed by the engineer, and for which it appears impossible to avoid using that powerful word *evolution*. Engineers naturally use expressions such as "the design of the combustion engine evolved slowly at first", "the evolution of software design paradigms was influenced by practitioners favouring those that met their needs", "early designs of transistor amplifier circuits evolved from their pre-cursor vacuum tube counterparts". Although in each case what exactly evolved, what mechanisms were involved, and under what circumstances might or might not be clear, but undeniably there exists the sense that a number of evolutionary concepts such as inheritance, incremental change and adaptability apply. We will see later in this chapter that a number of writers have described evolutionary theories of technology where concepts and associations are both inspired by, and are linked to, biological evolution.

To anchor some initial thoughts by way of a tangible and visual example, consider two bridges: the first is a rope suspension bridge spanning a deep canyon in South America and the second is a modern steel and concrete suspension bridge. The catenary geometries of the main cables are similar, both have decks to carry traffic (whether it be people, cars or trains). Both use vertical suspension ties supporting the deck that are joined to the main suspension cable and which are identical in function and similar in form. It is natural to consider whether primitive but effective rope bridges contributed to the development of modern suspension bridges (Ochsendorf, 2005). Specifically, how were design ideas communicated amongst bridge builders, what techniques were shared, what were the circumstances under which new ideas or techniques were brought to bear, how did developments in other technologies influence the progression of bridge design, what selection processes were involved, etc.? These and other questions would provide insight as to the validity of any theory of evolution of technology. Other design "spaces" could be considered, such as bicycles, aircraft, cars and even the humble paperclip (Petroski, 1996). The contention is, very simply, that by examining the history of technology and engineering it is almost inevitable that an evolutionary perspective emerges.

The aim of this chapter is to examine the parallels and similarities of how things evolve in the biological sense and the artificial sense (resulting from engineering design) with the intention of gaining another perspective of the process by which engineering outcomes are achieved. The hypothesis that is being explored is whether it would be beneficial to educate engineers in evolutionary theory not just as part of a liberal education but as an instrument to making them more aware of the general milieu in which they work.

Revolution or Evolution?

Elements making up the evidence to support evolution as a process of development in the general sense pre-date Darwin. As Isaac Newton wrote to Robert Hooke in 1676, "What Descartes did was a good step. You have added much several ways, and especially in taking the colours of thin plates into philosophical consideration. If I have seen a little further it is by standing on the shoulders of Giants". Newton uses the metaphor of seeing a little further on the shoulders of others to illustrate that progress is based on inherited knowledge and does not necessarily proceed by mighty leaps, rather it advances in small increments, i.e., *a little further*. Also, by looking back in time, Newton acknowledges that the action of selection is involved in the process of scientists recognizing the value or fitness of the work of their predecessors.

According to Kuhn, "successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science", but over time this view was modified to accommodate what might be called a gradualist model (Kuhn, 1962). Retrospectively and at some distance, many revolutions seem less revolutionary and more evolutionary in character. If this is true for science then perhaps it is also valid for the artificial, the artifacts created by, amongst others, engineers. In a minor way, the debate within the realm of science that followed Kuhn's book was mirrored in the biological world when it was argued by Stephen Gould that evolutionary change in the fossil record came in fits and starts rather than in a steady process of slow change, what was termed punctuated equilibrium (Gould, 2007), which stands against orthodox evolutionary views (Dennett, 1996).

Whatever stance one takes on revolution versus evolution, borrowing ideas from one domain and examining them in a different context may lead to an enriched understanding either through a rejection of the applicability of the "carried over" concepts or through a validation of at least some of the concepts.

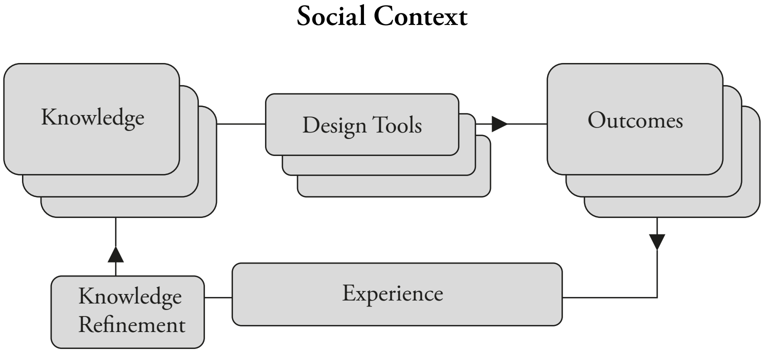
To support either side of the debate (revolution or evolution) a model of engineering design is first presented against which the various points that emerge can be referenced. Second, some criteria are stated that facilitate judgment as to what extent a theory is considered to be "weakly" or "strongly" evolutionary. In addition we consider a set of "projections" by which the validity of the claim can be tested that evolutionary theory can contribute to understanding how engineering design takes place. The projections chosen for reflection are Selection, Vestigiality, Memes, Adaptation, and Biomimetics where in each case there is supportable evidence for the conceptual links between the biological and artificial world.

Dawkins characterises a complex object as one that is statistically improbable in a direction that is specified not with hindsight (Dawkins, 1996, p.24) and many technological artifacts display a degree of complexity that almost defy comprehension (certainly for the average man or woman). The temptation can not be resisted to reverse William Paley's famous watch argument and suggest that nature, like technically complex artifacts, could only have resulted from a process of incremental development! A major difference being the time scales involved and which are so different.

A Model of Engineering Design

To provide a framework for the ideas in this chapter a basic model of engineering design is depicted in Figure 13.1 (Christensen *et al.*, 2007, p.144). To begin at the end: a new generation of knowledge (knowledge refinement) results from the wisdom gained by the experience of evaluating the outcomes of the current generation of knowledge. Typically what existed at the start of the design process was a new generation of knowledge but which is now augmented as a result of having completed the design and having carried out an evaluation of its fitness for purpose. The new knowledge might be in mathematics, science, technology, methods (including know-how), as well as a richer insight into the context in which the design is taking place.

Figure 13.1: A Basic Model of Engineering Design



If we loosely equate evolution with change we note that change is typically manifested everywhere in the design cycle. Requirements shift and change; methods to gather, assess and specify requirements change; the knowledge on which a design is based changes; the methods used to carry out a design change; the methods used to evaluate outcomes change; the context in which outcomes are evaluated by end-users change; the tools used in refining knowledge (including the methods used) change; and the outcomes can cause the requirements to change. At each point in the design process selections are made. Given the engineering goal of a target or particular design outcome, the safest way all such potential change can be managed is by adopting an "evolution and not revolution" approach, and consequently much of engineering is based on that cautious conservative dictum.

The next section presents three evolutionary theories of technology that are referenced back to the model presented above and provides criteria by which they can be judged as being weakly or strongly evolutionary.

Evolutionary Theories of Technology

"Could it be that technology, too, is really the outcome of evolutionary processes rather than intelligent design?" asks Philip Brey writing in the book *Philosophy and Design*. Brey questions whether the origins of biological organisms and artifacts are radically different (Vermaas, 2008, p.61). To examine this, the most direct approach is to set out reference points or criteria by which the analogy between the natural and man-made world can be discussed. Brey suggests three but this is adapted here to four criteria as follows:

Genotype: coded information in genes by which cells and organisms can be replicated

Phenotype: observable characteristic of an organism that results from an expression of a gene

Inheritance: variation that is expressed and capable of being passed on to a succeeding generation

Fitness: process by which the differential fitness of a member of a species to adapt to an environment can be identified.

In the case of a technology that has resulted from processes that can be compared to all four of the above criteria, then there is evidence to support a strong evolutionary theory of technology. Alternatively, if there is only a match with one or two of the above criteria, then only a weak evolutionary theory can be supported.

Brey summarises three evolutionary theories of technology due to Basalla, Mokyr and Aunger and which are briefly re-stated here (Aunger, 2002; Basalla, 1988; Moykr, 1996). Basalla's key point is that it is artifacts that are central to a theory of evolution of technology. Artifacts are the analogue of phenotypes and selective pressures operate to promote one artifact over another. The selective pressures could arise from a range of factors that we experience such as economic, social, climatic or cultural. Mokyr's theory on the other hand takes technical knowledge as the unit of analysis, which includes scientific and engineering know-how or craft. Mokyr's view is that mathematics and science are essentially analogous to the genotype and that it is craft and know-how that allows an artifact to be created or expressed and therefore is analogous to the phenotype. Aunger centres his theory on memetics and therefore attributes technical change to how ideas are communicated within and outside of a social grouping over time.

"*According to memetic theory, human culture is realized and transmitted through cultural units called memes, which are units of meaning that can express any culturally determined idea, behavior, or design. Memes are like genes in that they can replicate and can be transmitted, and they compete with other memes for survival according to Darwinian principles*" (Vermaas, 2008, p. 63).

These three evolutionary theories are really three viewpoints of the same thing: they are complementary regarding the artifact, the know-how and the meme and together lead to a more complete understanding of how technology evolves. It is important to note, first, that it is only a human that could distinguish between the artifact, the know-how and the memes. For example, a skilled craftsperson picking up a piece of work by an individual will not only know how it was made but often, with high probability, who made it and hence the ideas that were behind its production. All three of these aspects co-exist; there is a unity between the artifact, the know-how, and the memes. Second, each theory has weaknesses. Basalla's doesn't deal adequately with mutation; Mokyr's finds no room for serendipity and is weak with respect to innovation; and Aunger's fails to adequately explain the links between memes and artifacts.

Consequently there is the prospect that the above theories can be unified into a single theory. Referring back to Figure 13.1, the outcomes can be considered to be essentially the artifacts of Basalla, the design tools can be the know-how of Mokyr, and knowledge the memes of Aunger. That leaves the experience and knowledge-refinement to be positioned within the unified theory. Taking the three theories together, the missing dimension is how experience and knowledge refinement (a combination of evaluation and selection) is to be included in such a unified theory. The ideas of Langrish, who introduced three types of memes, add to the ideas of Aunger and provide the moderation mechanism by which the stages of the design model in Figure 13.1 become connected as will be discussed later in the chapter (Langrish, 1999). To conclude – the three theories introduced above are compatible with the basic model of engineering design presented and this constitutes therefore to some extent a dual form of validation. Also, it should be emphasised that the social context background, in which any design process is situated, highly moderates the overall operation through a complex flux of memes.

Natural Selection and Selection in Engineering

Natural selection is the process by which heritable traits, which are favourable in the sense of enhancing survival, become more common in successive generations, as described by Darwin. The word "natural" serves to distinguish the blind selection of nature from the selection controlled by man and which might be termed artificial on which Darwin commented "how great is the power of man in accumulating by his selection successive slight variations" (Darwin, 1859). The word "artificial" here comes with a warning as its use might by some be restricted to man-made non-biological artifacts consistent with the dictionary definition "an object made or modified by human workmanship, as opposed to one formed by natural processes" (Oxford English Dictionary). There is a need for care in the meaning and use of "artificial" as the actions and capabilities of man close in on those of nature. Consider selective breeding, a term used to denote an artificial selection wherein its employment is mainly associated with the domestication of animals (cattle, horses, cats, dogs) and plants (wheat, vines, rice). In these cases the process of reproduction is natural but the selection is controlled by man and with a purpose in mind. Going further, with genetic engineering artificial selection is possible and this involves having an impact on the reproductive processes themselves.

Artificial selection is a characteristic of engineering and in particular engineering design. The identification of traits and subsequently their retention in succeeding generations of devices and products are commonplace in engineering even when the underlying cause or explanation of why a trait exists is not always fully understood. In fact it might not be going too far to state that progress in engineering would have been slower if such selection had not been allowed. There is one very significant difference between natural and artificial selection: natural selection has no target and it has no mechanism by which a target design could be considered; whereas artificial selection, through the involvement of a human designer, has the capability of envisioning an outcome in which a particular trait is retained or indeed enhanced. After the event of having completed an engineering design, "selection" will either recognise the advantage of the required trait and allow it to be retained or the trait will be missing and the design rejected. Here "selection" is the act of observing and choosing. Serendipity is a special case of artificial selection where an unplanned or untargeted result is recognised and which in turn forms the basis of future products. Examples include the X-ray machine, thermionic valves, and the world-wide-web.

And what of the failure of particular designs? In nature, survival of the fittest is the default mechanism which allows poor "designs" to be eliminated or marginalised. Whilst nature does not design in the sense that an engineer does, the retrospective judgment, albeit by different means, is similar between nature and engineering. But there is an important difference and Petroski has written about the role of failure in engineering and how important it is in accumulating knowledge about specific design environments (Petroski, 1985). Nature does not appear to have the same ability, rather its investment is in what survives. Engineering, on the other hand, has a collective memory contained in a set of memes which can be inherited and modified in the light of further experience. Nevertheless it is worth considering failure in engineering as an evolutionary process and to examine over a period of time the main trunk of progress and the branches that led nowhere.

Vestigiality

Vestigiality, in the biological sense, refers to the situation in which organs or organisms have lost all of their original function in a species, but nevertheless have been retained through evolution (they have not been de-selected). The issue is not without dispute but it is commonly held that the appendix and the coccyx in the human are vestigial. The wings of flightless birds are vestigial. It can be imagined that deselecting such vestigial elements carries no great advantage and could only be warranted if survival was an issue. The question for this section is whether vestigiality is in evidence in engineering or in general man-made objects. Some examples follow to show this to be the case.

The computer system on which this text is being typed uses a QWERTY keyboard. In old mechanical typewriters it was not uncommon, if the typist was too fast, for the thin metal arms carrying the typeface to clash and jam, and consequently fail to hit the inked ribbon by which a letter could be printed on a line of a page. To slow down the process, and hence make such jamming more infrequent, the distribution of the letters on the typewriter were deliberately arranged to minimize this jamming; hence the odd and inefficient design of our modern keyboard. Deselecting the QWERTY layout of the keyboard appeared to be too costly and so it remains in use even though the original reason for it (function) is no longer valid. Alternative keyboards do exist but they are not in common use.

Another example of vestigiality are serif fonts. A serif font is one that exhibits little hooks or strokes at the beginning or end of a letter (for example the little bar at the end of the letter q, and the little stroke at the top of the letter b). The origin is not uncontested but one explanation is that the stone masons of antiquity had to work down into the stone with their chisels before the main body of the material forming the letter could be removed. This leading-into and out-of the stone with the chisel caused tell-tale little hooks and strokes. With modern print technology this original reason is no longer necessary, but we associate the serif font with something desirable by virtue of its classical origins. Here function has transformed into form.

Marooning is a word occasionally used to describe something that is very close to being vestigial but where there is a new reason for retention, usually of a form replacing a function. An example is the use of lampshades which originally were a safety device and a means of protecting naked light from drafts. The need for this protective function of lampshades is no longer necessary; however they are retained for ornamental and possibly conservative reasons (i.e. not wanting to do away with the old).

But why would engineering retain a redundant element? Consider a car engine block which is expensive to design and produce and needs to have a certain life-span to justify the cost involved. The block is complex and will have apertures, lugs, chambers, etc. which all serve to house other components that collectively form the engine. Over the life-span of the block new components become available which might replace original ones and possibly make other components redundant. In the latter case the original block, if possible, would be retained and the particular function associated with the redundant component would be retained. The cost of de-selecting by producing a new block might be prohibitive. To exaggerate, perhaps, the very survival of the model would outweigh the need to tidy up the block design.

Consider next a computer program having many thousands of lines of code. The program might be critical with respect to some operation and will have been tested as thoroughly as possible. Suppose, because of changing circumstances in the overall program operation, that some part of the functionality of the program is no longer required. The question will arise as to whether the code should be modified. A conservative approach would leave the now-redundant code in the program as any change made would result in the necessity to carry out an extensive and possibly expensive set of software tests.

As a final example, consider a dual-decked bridge designed to carry trains on one level and cars on the other. In the event that changes in the rail network mean that rail traffic is no longer routed over the bridge, then the original function of that deck is removed. Thus changes made to one part of a greater system (bridge and rail network) have made one feature of the bridge redundant. It may be prohibitive to re-engineer the train deck and a decision might be made to simply preserve the deck but not to use it.

As in nature the ability to have vestigiality is an essential prerequisite for having the ability to change. It is one level of difficulty to select on the basis of a single trait but it is more difficult and rare to select on two different traits at the same time (within the same generation). So it is not too surprising if in natural selection a single aspect that improves survival is chosen and something that is essentially survival-neutral is simply left alone: it is clear where the advantage lies. In engineering the same feature is observed. The earliest motor powered vehicles looked very much like horse-drawn carriages simply because that is what they were. The designer had a difficult enough task in proving that a mechanical means of providing "horsepower" would work without trying to optimise the whole system simultaneously. The improvement in wheels, advances in suspension, weather-proofing, enhanced aerodynamics would all wait for successive generations of design. Trying to do all at once could result in multiple failures. If in the process something becomes redundant or marooned then that vestigial aspect can be accommodated, at least for a period of time, as to do otherwise might jeopardize the whole system.

From Blueprint to Product

A parallel can be drawn between the role of RNA in producing proteins, having copied the essential information from DNA, and the engineering fabrication of a product from an engineering blueprint. DNA itself is not used directly in making these proteins. In engineering the blueprint might be a set of drawings or a physical master copy, both of which are readable and neither of which are used directly in mass production of whatever manufactured good is envisaged. In the case of RNA there are a number of regulatory mechanisms in place. Likewise in engineering, steps are taken to ensure that what is produced is a "fair" copy of what was intended. But small errors of transcription and production do occur and these will subsequently be found to be either of no consequence or seen as significant (desirable or otherwise) which can lead to product improvement or production improvement (additional regulation or control). Much of what happens within the world of DNA and RNA has characteristics that would be recognisable to a student of computer databases. It could also be said that reading, writing, deleting, editing, copying, modifying are all words that provide a link between the biological and computer engineering worlds.

Memes

Evolutionary principles can be extended to explain how ideas are distributed or spread. Richard Dawkins introduced the word *meme* in his book *The Selfish Gene* replacing the word gene with meme (Dawkins, 1989). Langrish added to the idea by proposing three types of meme: recipemes, selectemes and explanemes. They were then used within an evolutionary framework to discuss technological innovation (Langrish, 1999). As mentioned earlier it is attractive to import the concept of these three types of meme into the theory of Aunger.

“Recipemes” are a set of ideas for how to do things. And implicit in this is that the ideas are in competition, with the successful recipemes being the ones favoured for replication, perhaps with some small modifications over a period of time. Knowing how to do something might be considered a skill and might also be thought of in terms of a craft.

Langrish uses the word “selecteme” to mean ideas that form the basis of selection of a method or product. Selection must take place within a context in which criteria are chosen and decisions taken with respect to what is best or perhaps just better than an alternative. Langrish uses the word “betterness” to describe what this action is centred on. The communication or transmission of selectemes happens mainly between members of whatever group is directly concerned with making specific selection decisions.

The third type of memes Langrish called “explanemes” which are ideas that are used in helping to understand how things work or work better than alternatives. Again competition is a feature of explanemes – this is particularly the case where the subject matter is not strictly rational. Explanemes are communicated with the aid of a range of languages where mathematics might be considered to be a particular type of language. Engineering generally communicates its explanemes in a wide variety of ways: plain text, drawings, mathematics, models etc. Engineering journals of research and development abound in competing explanemes!

Referring back to Figure 13.1 it is easy to place recipemes, selectemes and explanemes within the model. Selectemes are involved in deciding what knowledge is appropriate in a specific case, recipemes are fundamental to carrying out a design using whatever tools have been chosen. The anticipated outcomes are a function of the explanemes used in designing and selectemes are used to determine the “betterness” of the product. Knowledge refinement is an evolutionary process by which the three types of memes are modified over time and in the light of experience and accumulated wisdom. Engineering schools and professional bodies amongst others play important roles in codifying, maintaining and communicating these memes within a community or society. And occasionally these memes are transferred to influence other groups and then take on a new life or evolutionary path as a mutation or as a crossing over to another species.

Adaptation

Adaptation in nature is largely about preferring changes that have in some way made it possible for a species to exist more easily, or survive in its environment. In nature adaptation is conferred after the event since there is no way of knowing in advance that survival is to be enhanced, whereas in technology the changes are made knowing that an improvement is being designed to generate a specific result. Adaptation occurs in many forms in engineering and just a few examples will be given here.

The Theory of Inventive Problem Solving (designated TRIZ) was developed by Altshuller and consists essentially of a methodology with a tool set by which innovative ideas can be explored and problems solved. The tool set includes the laws of evolution together with such expected elements as "standard solutions". Since its original development in 1946, it has been demonstrated that problems and solutions were repeated across industries and sciences, patterns of technical evolution were repeated across industries and sciences and that innovations used scientific effects outside the field where they were developed (TRIZ). According to Madara Ogot "the power of TRIZ … is its inherent ability to bring solutions from diverse and seemingly unrelated fields to bear on a particular design problem, yielding breakthrough solutions" (Ogot, 2004, p.194).

It is clear that the meme concept sits well with TRIZ as recipemes, selectemes and explanemes all have their place in logically sorting through the many possible ideas that eventually contribute to a good design. Ogot's model extends the black-box model used in TRIZ by explicitly including "harmful and insufficient energy, material and signal flows within the system." The end result is that, in part at least, a design process results that can improve a system with little or no change: in other words an adaptive process.

As a second example, adaptive digital filters can be designed that allow some changes to be made to the filter's parameters that result in a "better fit" with the environment in which it operates, such as in noise cancelling systems. But it is an outside agent and not the filter itself that judges whether the adaptation is good or otherwise, by setting criteria by which the adaptation is driven.

Biomimetics

Engineering is increasingly looking to living systems to help create new products or enhance existing designs. Biomimetics is the study of the structure and function of living things which are then used as models to inspire the creation of new materials or products. In part this study involves reverse engineering by which a function is inferred from a structure (Richardson, 2002). Whilst biological "designs" do not attempt to be optimum (there being no mechanism for biological systems to know, record or make use of the concept of optimality) they are over the course of time very good at exploiting environmental niches (Vincent *et al.,* 2006). It is this exploitation that is at the core of biomimetics' borrowing from nature.

"Engineers … are pondering the bumps on the leading edges of humpback whale flukes to learn how to make airplane wings for more agile flight. … the fingerlike primary feathers of raptors are inspiring engineers to develop wings that change shape aloft to reduce drag and increase fuel efficiency. Architects … are studying how termites regulate temperature, humidity, and airflow in their mounds in order to build more comfortable buildings" (Mueller, 2008).

Of course the manner in which an engineer exploits nature is almost impossible to imagine being paralleled biologically. Other examples of borrowing from nature include the invention of hook-and-loop fasteners (e.g., Velcro^{TM}) which was inspired by the burrs on a dog's coat; reducing drag on a water-borne vehicle by mimicking the structure of a shark's skin; anti-reflective coatings that owe their existence to the study of the eye of a moth; and human flight was certainly inspired by birds with early attempts as human flight centred on copying the wing structure of idealized birds.

A number of universities have research centres for biomimetic engineering, and the topic is beginning to appear in some undergraduate engineering curricula. It is hard to imagine that a serious exploitation of the wonders of the natural world could be contemplated without some understanding of the mechanisms involved in Darwinian evolution and by extension how we think about engineering design.

Conclusions

The evolutionary perspective presented in this chapter is not a rejection of the teleological process observed in engineering design but rather a statement that design is an "individual, solitary, and often after heroic activity, ending in a final and supposedly perfect result", and is at best an exception and not the rule (Yagou, 2005). Further, many of the characteristics that are associated with biological evolution are useful metaphors for many aspects of engineering design. From an educational viewpoint by including an evolutionary understanding of design, students should be enabled to place their efforts in a more general context encouraging a humbler attitude that helps in the development of being a good team player – a valued attribute in engineering bearing in mind the often multidisciplinary and heterogeneous nature of design teams (Yagou, 2005).

As part of an integrated studies approach, a historical treatment of engineering, science and technology, in particular with respect to design, that includes an evolutionary account coupled with themes picked up in technical subjects, could lead to a deeper understanding of how designs come to be and how designs are subsequently developed. Whilst the engineering literature is not rich in terms of pointing out the relevance of evolutionary theories to designed objects more general accounts are available (Dawkins, 1986; Michl, 2002). In the sense of a Liberal Education as discussed in Chapter 8 the reading of the books by Dawkins and Dennett, to name just two who have been to the forefront in explaining the relevance of Darwin, would be a good input to educating an engineer in the richness of evolution. To those could be added the works of biologists Peter Medawar and Stephen Gould who have written about technology from an evolutionary perspective.

To conclude, "if anybody were to start where Adam started, he would not get further than Adam did" a quotation given by Jan Michl and attributed to the philosopher Karl Popper (Michl, 2002). This is another and more direct way of stating what Newton expressed in his 1676 letter to Hooke.

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Chapter 14

Integrating Public Context Perception in Engineering Design

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Abstract: The public is often sceptical regarding the technological improvements provided by engineering design. Sometimes, it seems these products do not satisfy the public's requirements or the common welfare. Engineers are fully aware of technical issues during the design process but they are often not conscious enough of the socioe-thical implications of their work. That situation can lead to the inability to create positive mutual communication between society and engineers, which is necessary for a publically accepted outcome. In this chapter we first review the ethical issues involved in engineering design and the difficulties that engineers find for their application. Secondly, we discuss the common approach based on constraining the process of design through regulations and its efficiency in order to obtain a publicly-accepted outcome. Thirdly, we examine the possibilities for an application of the ethical principles based on the engineer as an individual, wherein members of the engineer's collective form a conception based on the social ethics paradigm in which other stakeholders can be integrated. Finally, some considerations regarding the relationship between design and policy are examined

Key words: Engineering Design, Ethics, Decision-Making, Social, Context

Introduction

At the beginning of the 21st century, engineering design has surpassed many of our expectations. Nowadays, it is accepted that technology deeply influences society, that technological improvements are present in our civilization, and that they are widely used by most individuals. Nevertheless, the positions of the public regarding those technological improvements are often plagued with scepticism (Fukugawa, 2000). Instead of being praised for their qualities and their ways of fulfilling social needs, engineering design products are in many cases perceived with mistrust. Engineering design should provide technical artefacts linked to human expectations, but sometimes the outcomes do not seem to be directed to satisfy the public requirements maintaining safety and promoting common wealth. Consequently, it is interesting to consider the process and the context of design, which are ethically relevant and closely related to the final characteristics of the product. On the other hand, engineers see their activity as both functionally and socially useful. Accordingly, they find public animosity quite incomprehensible and unacceptable. The results of this situation lead to a depreciation of the image of the engineering profession that can be related to the reduction of the number of students that enroll in engineering programs (Zukoski *et al.*, 2002).

Design processes are associated with complex combinations of variables that have been analyzed, modelled, and defined in several ways. The efforts for setting a common framework, a set of methods to successfully achieve the final objective, have been described in different approaches related to the proposed outcome and the characteristics of the production process (Seider *et al.*, 2003). Unfortunately, the ethical and social dimensions of every step of the design process are not included in the main engineering process layouts. However, these aspects are directly related to public perception and the evaluation of the final outcome and are relevant in the appreciation of the work performed by the designers. Furthermore, if the public had a better knowledge of the decisions made in the design process and at the same time had the opportunity to be represented or heard in design decisions, the products would be in better consonance with the social point of view and they would satisfy both engineers and receptors.

The Ethics of Engineering Design

Engineering ethics is present in all aspects of engineering design, so it would be impossible to review all ethical and social issues that are included in the process of design as applied by engineers. Starting from the idea of developing an engineering product, presenting it and delivering it to society, every stage would involve several levels of ethical questioning. Acknowledging the importance of ethical aspects of design, most universities tend to introduce content related to this subject in engineering courses. In the USA, the ABET criteria also include recommendations in this sense (ABET EC2000). There are many ways to achieve the goal of ethics education, including offering courses, incorporating case-studies, or integrating ethical considerations in engineering subjects (Jiménez *et al.,* 2006). Graduate engineers should be provided with a certain level of understanding of the ethical relevance of their profession and their implication as professionals in society in order to promote public welfare. Engineers are committed to practicing ethics in all their activities, but the specific case of design is particularly relevant, because design implies the creation of a new good, a new legal, commercial product, or as an artefact that may raise issues concerning its public integration, use, and acceptance. So it would appear that good design should include considerations related to the social implications of the produced outcome.

According to Mc Lean (1993), in their professional work, engineers will be confronted with different "levels" of ethics that are related to the building of the product, its delivery, and the service offered to client or consumers. These levels can be thought of as technical ethics, professional ethics, and social ethics. In order to discuss the ethical implications of the engineer's work we will take into consideration these classifications.

The technical ethics level includes all sorts of technical decisions that concern the production of the goods, the components, the method of fabrication, the safety and environmental issues, etc. This level would also include ethical considerations based on the process of design. As McLean points out, the ethical dictates of this level are partially defined by codes and regulations. The designer is not only supposed to provide a functional component but also a product that meets the standards defined by the common practice and the experience of previous engineers. In this case, engineers feel quite comfortable with their role as practitioners who work in a definite field of operation where variables are well defined. They feel satisfied by inventing solutions that meet the given standards, because that activity fits their training and their professional culture.

The professional ethics level is related to the distribution and implementation of the outcome. Engineers are compelled to extend their activity beyond their technical scope to engage in relationships with the public through the participation of other agents such as clients, managers, lawyers, economists etc. The framework of this activity is provided by contractual regulations, by cultural standards, and by other general agreements that are part of commercial and management procedures. At this level of ethics application, engineers are not so at ease, because they must communicate with other professional cultures. The conflicts derived from these interactions have been described in detail by other authors (Christensen & Ernø-Kjølhede, 2006). Fortunately, today's engineers are better prepared to face these situations than they were before. The frictions that appeared when business and management personnel had to communicate with technicians have receded in part due to the more managerial education of engineers and their improved ability to embrace points of view that are different from the purely technical. In any case, the engineers have a frame of regulated interactions that helps them to act ethically. Although their interpretation of the regulations may differ subtly considering their technical background, at that level their ethical actions are essentially the same as their actions at the technical level.

The role of engineers becomes more diffuse when entering the level of social ethics. They do not feel at ease when the question concerns the ability of their design to serve social interest, evaluating the public service of the delivered goods, considering the social groups that will benefit from it, the financing of the product or other complex issues that are difficult to solve in a clear or routine way. At this level engineers are not provided with clear regulations or requirements to fulfill. In this field, their professional background seems not to be so useful. On the other hand, this level deeply influences the whole project since it sums up the final objective that the design pursues. This implies that most of the public perception of the design will be precisely related to this crucial – and often uncomfortable – level. Other authors have also proposed similar classifications of ethical levels regarding engineers' work. Ladd (1980) uses the concepts of microethics and macroethics. Microethics refers to the close social context constituted by employers, clients and other actors directly related to the professional activity, and macroethics to the wider social environment of the performed task.

The differentiations between levels of ethics according to the internal characteristics of the profession, the social responsibility and the consequences of technology have also been discussed by O'Connell and Herkert (2004). These authors compare the classifications provided by Mc Lean and Ladd. If we confront both ethical divisions, Ladd's macroethics would be comparable to the social ethics level proposed by McLean. The problem of the actuation at a higher level of ethics described by McLean would be put, in Ladd's terms, as the difficulty of integrating micro- and macro-ethics in engineering activity. There is a common agreement about the disengagement of the engineers at the macroethics level (Herkert, 2004). Many engineering educators deliberately exclude higher ethical levels from their programs and some definitions of engineering ethics focus only on the close context of the engineering activity (Martin & Schinzinger, 1996, p.2-3). The truth is that a higher ethical reflection may result in questioning the engineer's job (a common situation when students are confronted with discussions about the ethical implications of their work). But avoiding coming to terms with macroethics results in a lack of appreciation of the subject and an inability to act ethically at higher levels.

It is significant that macroethics levels include engineer-social interaction beyond the technological activity. Engineers feel less comfortable when the ethical considerations involve engineers as a group confronted with society or when the decisions are at a societal level. But as O'Connell and Herkert point out (2004), society requires ethical policies and sensitivity to societal expectation. So it is clear that engineers need to find ways to manage ethics at different levels, in order to bring closer the technical concepts of design to societal requirements and needs. Both engineers and the public would benefit from the adjustment of their points of view; the appreciation of the outcome and the detection of the initial need will be improved. Engineers as individuals should correlate their understanding of personal ethics with their professional activities.

In order to improve the perception of their work, the connections between the different levels of ethics and the public integration in the design process should be enhanced, including presenting a more holistic view. However, including a wider perspective that integrates public perception in a design process is not easy. As stated previously, a common approach constrains the design process in order to limit the possibilities of the outcome inside the field of public acceptance. This practice consists mainly in regulations or stipulated good practices. Anyway, it does not avoid, as we will try to show, the need for broader ethical reflection.

Engineering Design and External Constraints

From the previous discussion we may conclude that engineers feel more comfortable about their ethical behaviour when they can relate to an existing framework where the requirements and regulations seem to decrease the ethical responsibility of their decisions. From the engineering point of view, a constrained context would mean less need for ethical reflection. This approach is in consonance with their education and vision of the engineering activity. However, the relation between constraint and need for ethical reflection is not obvious and has been a subject of discussion by several authors (van de Poel & van Gorp, 2006).

The design process is mainly described as several iterative steps. Basically, there is a first phase consisting of the generation of the design, including the creation of the concept, understanding of the problem and search for possible solutions, evaluation of the proposed alternatives, and finally the presentation to the customers responsible for the implementation. The whole process is iterative, and works in cycles: while evaluating a solution, the problem is presented in different ways that may create new ideas or redefine the requirements. It is such a vast field that it is difficult to study how constraints and ethical reflection are related. For this reason, some authors have classified the design processes according to criteria that implicate different kinds of ethical considerations.

Let us consider, for instance, the distinctions introduced by Vincenti (1990). He defines the types of design, taking into consideration the different levels of structuring and external constraints. Vincenti introduces the notion of two types of design: normal and radical.

Normal design refers to a configuration that is commonly agreed to best embody the operational principle. In terms of engineering, using any piece of equipment for its normal use would be within this range. A plant that follows an industrial method to obtain a product would also be included in this category. As very few new ideas either for improving existing processes or developing new processes achieve commercialization, most classical processes would be considered as normal design. An important feature arises from this consideration. A normal project has a conventional operational principle, is regulated by a set of norms and rules, and is the fruit of previous studies of similar cases.

In *radical design*, the operational principle is, at least in part, unknown. The regulations and principles are built according to the design process, since the previous experience is not completely applicable. These new projects are usually developed from laboratory research, through pilot plants to commercial processes. Even in these cases, the units of equipment of the process may operate following their normal configurations. If the operation of equipment is designed ouside its normal conditions for special production, that could also be considered a radical design.

According to Vincenti, normal design is more constrained by external requirements than radical design. Using the patent of a process for example could be an example of a normal design that is very restricted due to the regulated practice stated by the owner of the method. In other cases, patent contents can be useful process information for the engineer (Ulrich & Vasudevan, 2004) and constitute something like a good practice manual in which the knowledge of experts is shared to keep engineering design on the right path. Other types of constraints are provided by engineering societies, national regulations, certifying bodies, or other organizations. Engineers deal with these restrictions as part of their technical work, even if the regulations are developed to fulfill ethical requirements such as safety or environmental issues. They have been trained to stay within the limits of the restrictions.

Another distinction provided by Vincenti, which is relevant in terms of external constraints of the design process, makes reference to the hierarchy of design. The design of the system and the concept that will finally lead to the final product would be considered as high-level of design, the design of other important equipment would be considered as medium-level design, and lastly the units of operating devices would be the lowest level. The number of divisions of the design process may be higher depending on the complexity of the system. Engineers working in teams can have different assignments related to a certain hierarchy of the design process. In every case, they will approach their own design process following steps like those specified above.

Typically, the constraints of the design process are more clearly established in lower design processes. The higher the level of design, the less-structured the problems tend to be, and the lack of a framework makes ethical reflection especially significant. The hierarchical divisions, combined with the concepts of radical and normal design, provide a wide scope of possible situations.

The level of external constraint related to the importance of ethical reflection has been discussed by several authors. Grunwald (2000; 2001) has proposed that in cases of common procedures, ethical reflection could be obviated in the presence of an adequate normative framework. The proposed framework should meet defined conditions, basically including political and social regulations. This position would mean that in some cases related to the types of design subjected to external constraints (like normal and low level design), ethical reflection could be replaced by a set of obligations that avoided personal implication of the engineer designer.

This approach has been discussed by van de Poel and van Gorp (2006). They object that a normative framework as defined by Grunwald cannot be taken for granted in real situations. Consequently, the designer would never be completely discharged from ethical reflection. The division in normal and radical design constitutes a differentiation of the level of external constraint that is associated to the level of ethical reflection, but the total disentanglement of the ethical implications cannot be achieved by the designer. Eventually it seems that the idea of an automatic application of the ethical criteria is not possible in the real world and engineers should take the challenge of evaluating their decisions, not only through the technical point of view, but also considering a broader context. In other words, it is not possible to avoid the ethical involvement of the designer by merely adding regulations and norms.

We can relate this discussion to the engineer's position in front of the different levels of ethics. Engineers tend to assimilate their role as dependent on the external constraints, assuming intuitively Grunwald's approach. This means that when they try to provide the public or society with a service, they prefer to consider the constraints as external, acting themselves as operators that follow social indications. The consequence is that engineers feel that criticisms of their products are less founded, since they acted in a defined framework that is supposed to include societal needs and public demands. These assumptions are supported by the arguable common assumption that technology is neutral.

Considering the result of engineering activity as neutral is an implicit idea in many engineering activities, including design. This concept relates to external requirements. Once the requirements are set, designers are not ethically responsible for the outcome. Samuel C. Florman defended the idea that it is not engineers' responsibility to impose their morals on their practice, considering that they are not responsible for the initial requirements (Hallinan *et al.*, 2001). Customers decide and define the final objective and engineers contribute to try to orient the existing ideas to a realistically achievable goal. The ethical formulation of social needs should be defined by stakeholders, politicians and other actors external to the engineering profession. This position is also related to the notion of social responsibility developed by Milton Friedman for business (1983). But from that point of view, engineers seem to have a duty to shareholders or managers more than to society or putative stakeholders. As discussed above, when engineering outcomes are implemented or distributed, they are regulated by contracts, patents, or agreements that formalize the way in which the engineer maintains a relationship with a client. The nature of this interaction is similar to the business area, so that business ethics seems to be applicable to engineering activities at this level. Through those schemes, the concept of engineer as a problem solver is emphasized, technology is assimilated to a commodity and ethical values are left to other actors' consideration. Ethically, engineers are only responsible for the decisions during the project, in order to find the best solutions for the product within the proposed constraints.

The problem is that this approach, widely spread among engineering communities of practice, can affect the design process, focusing the attention of the performer on small contexts, and consequently losing the ability to evaluate the global process that inevitably produces an outcome in the societal environment where it will operate. On the other hand, the most common criticism applied to this conception is that the notion of engineer as a mere problem-solver is not clear when the problems involved in design cases are ill-structured. Most design proposals may be solved in several ways and the formulation of the problem (including requirements) can sometimes be dependent on the solution. Nowadays it seems to be a common assumption that broad ethical questioning is also part of good engineering. However, alternatives to the problem-solver profile are not clear from the engineering point of view.

The provisional conclusion seems to be that decisions in an engineering design process are, in most cases, ethically relevant. Ethical reflection cannot be avoided merely by establishing a set of regulations or norms. However, while most engineers tend to work in a way that is ethically acceptable and that should be in consonance with public expectations, the application on the field is not easy because they have to face several levels of complex ethical behaviour.

The Individualistic Approach

A classical way to apply ethics to a design process is based on an individualistic approach. This conception of the ethical responsibility of the engineering designers is based on their behaviour as individuals belonging to the collective of engineers and immersed in engineering culture.

The problem is that the education of engineers tends to separate their roles as professionals from their actuation as individual members of the society. When confronted with technological issues as part of the public, their opinions are not very different from the rest of the collective and they tend to show no special insight in cases where they could achieve better understanding than other citizens. Once the engineering cultural framework and the regulative constraints disappear, engineers do not feel qualified for a deeper ethical reflection any more than the general public, even in cases where their technical background could provide them with a unique perspective. As a result of this situation, engineers first typically feel disappointed because of the depreciation of their prestige and the apparent uselessness of their professional skills in social situations. Second, the public perceives them as mere technicians not able to assess the real needs of society. Finally, the whole collective cannot benefit from the positive social contribution of the engineers as professionals and citizens with a privileged vision of technology.

Thanks to the new programs directed at the education of the responsibility of engineers, this situation has changed these last years, because the social dimension of engineering is much more developed than it was in the past. A proof of this advance is the increase in the participation of engineers as designers in humanitarian projects and the impulse of engineering NGOs (van de Poel *et al*., 2001).

However, the application of the principles that would lead to a deeper implication of the engineers as designers in the public sphere meets a significant impediment. The expected ethical reflections beyond normative frameworks are performed by the engineer as an individual. We can distinguish several situations. If the ethical actuation is framed by regulations or common practice, the engineer works as a representative of the engineers' collective; therefore he has the support to act as recommended even in cases where pressures may exist. Most of these cases are related to the typical situations described in whistleblowing situations. When the framework constituted by the constraints is sufficiently defined, the engineer as a designer can embed his ethics in the organization.

The situation is different when engineers must use their own criteria beyond the regulations. In these cases, the application of an ethical principle is left to the engineer's design concept and the possible pressures apply only to the individual. Sometimes economic consequences or future career consequences can be at stake and the designer may feel that his individual appreciation of the case is not set well enough to face the costs of a loosely defined situation. The expectations of an engineer acting as a defender in situations of no support, only because of his moral convictions, may seem too optimistic for a professional that mainly sees himself or sees herself as an operator and not a promoter. Even in cases when the engineer is working independently, the applications of ethics beyond the regulations is left to the individual's consideration, and then the pressure of the decision is not relieved by the possibility of sharing the responsibility with other stakeholders. Somehow the individualistic approach could be understood as a discharge of the ethical responsibility of society because it is transferred to an individual. But it is not guaranteed; there is little support for decisions taken by an individual who is all alone in being responsible for them. To find a mechanism that provides support for the decisions beyond the designer as an individual requires a different proposal. An approach to a higher structure of decision-making is provided by the social ethics of technology.

The Social Ethics of Technology

The social ethics paradigm, as defined by Devon and van de Poel (2004), examines the social arrangements for making decisions. In the case of engineering design, the focus is neither on the designer nor on the outcome, but on the design process itself. A better design process would imply a better product. The way of achieving the final outcome has itself ethical connotations and its correct management will eventually lead to an ethically improved final product. The process of achieving the desired good design can also be manipulated in order to reach the ethical results that are considered more convenient.

Engineering design is the result of choices from the first stages of a project, and the organization of the several acts of decision is usually influenced by traditional structures. But the process should be improved through a revision of the mechanisms used to organize the design tasks, the way decisions are taken and also the stakeholders involved in the process. These improvements would review the responsibility of the design task, avoiding the schemes that rely only on the engineer's sense of individual responsibility. As a consequence, there would be a clear template for the distribution of responsibility that would ensure that acceptance is guaranteed by the participants in an correctly formulated way. The choices would follow a structured way designed to avoid implicit unacceptable choices, and to manage the explicit ones, including not only the possibility of revision but also the involvement of the appropriate participants.

The differences between the public perception of design products and the designers' achievements are in general reinforced by the lack of integration of the public, whether clients or consumers in general, in the design process. It is clear that while the final recipient of the design products is society, the representation of society during the creation or design stages is quite poor. It is possible to take into consideration the public concern, if the relevant groups involved in the social context of the products are incorporated in the design process. Social ethics includes new stakeholders that share ethical responsibility, bring different opinions to discussions and finally allow an outcome that is in better consonance with their needs and as close as technical requirements make it possible.

The perception of engineering design is also the result of the transformation that the new outcome produces in the society. It is difficult to exactly predict the impact resulting from the release of a determinate creation because it will be manipulated and operated in ways that often surpass the potential applications for which it was designed. The paradigm of social ethics would deal with these issues by guaranteeing the inclusion of relevant groups and stakeholders that may be affected by the design product. For instance, Martin and Schinzinger (Devon and van de Poel, 2004) propose the inclusion of the criterion of informed consent. In that sense, public perception of the designer's work should be improved and engineers would be rewarded by society's praise for their creations. From the society's point of view, this approach would use the ability of engineers to a further extent, since they would be compelled to find ways of producing better designs by using engineers' potential as professionals and individuals simultaneously.

Policy and Design

Konopásek *et al* (2008) describe a case related to the design of a highway bypass around Pilzen, in the Czech Republic. The story is interesting because the organization of the design process surpassed the individual responsibility of the engineers and involved other stakeholders outside the technical field. In this case, the initial procedure, directed to achieve a higher level of societal participation, apparently resulted in poor public perception and a negative impression of the process. But the case can also be read as an example of the need for a deeper integration of design and policy. The public was presented with two comparable designs, but it was only after ten years of appeals, pleading assessments by several commissions of experts, and a final decision of the Supreme Court that one of the proposals was approved and the highway bypass was eventually built.

As described by the authors, both design options were technically comparable; both had been supported by several stakeholders and governmental decisions. The justifications of the alternatives were presented by both sides in terms of decreased negative impact, cheaper price, technological convenience, etc. But, as Konopásek *et al*. point out, the supporters of both variants differed in their global approach to the problem. One of the parties was concerned with the importance of the best possible decision in the technical sense, seeing the "politicization" of the proposal as a flaw that "overrode rationality". On the other hand, the supporters of the other option were politically involved, had the support of the majority of residents and could benefit from the perspective of a political decision. In the long term, the supporters who had included politics as part of the mechanism of decision from the beginning were favoured by that approach, while the sympathizers of the separation of technical decisions from politics were at a disadvantage. The approach that emphasized a separation from politics became weaker. The conclusion of the case is that technical design and politics cannot be mutually exclusive. Design, like many other activities, is also a political activity. The political culture in which design is immersed must be considered as part of the process in order to improve technical design. Engineers as designers are implied in outcomes that will be generally related to political decisions. Designers' awareness of these situations would help to satisfy the expectations of citizens.

Concluding Remarks

In Engineering Design, the end is the creation of a system that satisfies customer needs. The achievement of the identification and integration of the needs beyond mere functionality is part of a good design. Public welfare and interest are included in the design process through the engineer's individual ethics and through the regulations directed to control professional practices. This approach is reinforced by the inclusion of ethical reflection in engineering education. However, in order to effectively link engineering designers and public perceptions, a higher level of integration would be desirable. Many design problems require a higher perspective that surpasses the microethics context. The constraints imposed on a design do not exclude the need for an ethical reflection by the designer, especially in radical design and high-level design. The complexity of the societal reception of the outcome of design and the issues that may result are too large to be left to a designer as an individual or a representative of a profession. The social ethics approach could provide a mechanism to harmonize societal and engineers' interests, especially because it would tend to fully exploit the bidirectional communication of technicians and other agents.

In any case, trying to maintain technical design as separate from politics is not possible. A policy of artefacts also relates to a policy of design, and considering technical design as only part of the designer's realm could be seen as an abdication of responsibility and an inappropriate simplification of the problem.

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Chapter 15

Nanotechnologies in Context

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Abstract: This chapter examines the topic of nanotechnologies. First it tries to relativize the polemic context in which they appear. Then it examines the arguments according to which they constitute a philosophical exception, as well as those according to which they would need specific ethics. It concludes on the need for new methods, adapted to the anticipation of the nanotechnological future.

Key words: Nanotechnology, Determinism, Nature, Ethics, Risk, Uncertainty

Introduction

A lot has already been said about the very fashionable topic of nanotechnology, and many books have been written on their philosophical, ethical and societal aspects. This article does not aim to be highly original, nor does it seek to provide a comprehensive overview of the ongoing discussions. But it does attempt to highlight some key points of the current debates from the literature available, and to open the way to a collective reflection. One assumes that everyone knows what nanotechnologies are, and what their main achievements and applications have been so far, but has society fully embraced and understood the risks and uncertainties that inevitably arise?

A Particular Context for an Emerging Technology

Great hopes and deep fears

In the history of nanotechnology, a very primary chronology would probably include Feynman's inaugural speech *There is Plenty of Room at the Bottom* at the American Physical Society in 1959 (Feynman, 1959), the appearance of the word "nanotechnology" coined by Norio Tanigushi in 1974, the invention of the scanning tunnelling microscope by Gerld Binnig and Heinrich Rohrer in 1981 – followed by the atomic force microscope in 1986 – and the discovery of fullerenes by Richard Smalley, Robert F. Curl and Harold W. Kroto in 1985, and then of carbon nanotubes in 1991.

But this history also has a parallel side, in the sense that an extensive discourse on nanotechnology developed when it was – and still is in most respects for many observers – only at the project stage. In particular, the combined expression of great hopes and deep fears has precociously accompanied their emergence. Thus, in 1986, scientist Eric K. Drexler published his famous book, *Engines of Creation: The Coming Era of Nanotechnology* (Drexler, 1986), in which he described a future of abundance, marked by the preservation of the environment, the saving of raw materials, the end of work and waste, all these made possible by the reproduction and control of biochemical processes and the acquired ability to synthesize and reproduce any molecule. However, this vision also mentioned some problems that could obstruct access to this golden age – including the dangers of losing control, like the risk of "gray goo" or self-replication of nano-robots, which was subsequently to become paradigmatic – and sought to anticipate them. It is in this spirit that in the same year Drexler founded his famous "Foresight Institute", aiming to guide nanotechnology in a manner that would improve the human condition.

Drexler's book opened up a utopian tradition to which the books of some writers can be linked, like the one published in 1999 by the transhumanist Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (Kurzweil, 1999), or that by John Storrs Hall, whose *Nanofuture: What's Next For Nanotechnology* (Hall, 2005) dates from 2005.

These prophetic visions culminate in the famous report of "transhumanist" inspiration that the U.S. National Science Foundation (NSF) dedicated in 2002 to Nano-Bio-Info-Cognosciences (NBIC) under the evocative title *Converging Technologies for Improving Human Performance* (Roco & Bainbridge, 2002). With the "convergence" of these technologies (also called "BANG" for "bits, atoms, neurons and genes"),

> *"the twenty-first century could end in world peace, universal prosperity, and evolution to a higher level of compassion and accomplishment. It is hard to find the right metaphor to see a century into the future, but it may be that humanity would become like a single, distributed and interconnected "brain" based in new core pathways of society. This will be an enhancement to the productivity and independence of individuals, giving them greater opportunities to achieve personal goals."* (Roco & Bainbridge, 2002, p.6).

In the face of these speeches, an opposed "catastrophist" tradition has nevertheless grown up, and expanded in the early 2000's. An important step in this process was the article *Why the future does not need us* that computer scientist Bill Joy published in 2000 in *Wired Magazine* (Joy, 2000), whose subtitle reads: "Our most powerful 21st-century technologies – robotics, genetic engineering, and nanotech – are threatening to make humans an endangered species". It draws attention to the magnitude of risks conveyed by new technologies, which must be assessed according to their power, including that of self-replication. This cautious vein has intensified in varying registers from 2002 onwards, when the number of writings on the topic skyrocketed. In science fiction, while the novel *The Diamond Age* by Neal Stephenson (1995) – in which Drexler was himself a character – had already imagined a nano-robot taking the control of the enemy's brain, Michael Crichton's novel, *Prey* (2002), illustrated the "gray goo" and described human beings becoming the preys of nano-robots which have run out of control of their creators. Some public or political personalities took hold of the issue, such as the British Green MEP Caroline Lucas (2003), and UK's Prince Charles, who was concerned about the risk of nanotechnologies in 2003 and sponsored a study that the Royal Society and the Royal Academy of Engineering published in 2004 (Royal Society, 2004). Finally some associations took a stand against the development of nanotechnologies, such as Greenpeace and the Canadian activist group ETC (the Action Group on Erosion, Technology and Concentration) which published in 2003 *The Big Down* (ETC Group, 2003), a report in which several levels of "risky" achievement of nanotechnology are distinguished, and in which the risk of "green goo" is also theorized. And while ETC calls for a moratorium, the issue of risk notably attached to nanoparticles won tremendous publicity through dissemination of the report of the reinsurance company SwissRe (2004): *Nanotechnology: Small Matter, Many Unknowns.*

A first relativization

Since these periods of turmoil, the debate has moved forward on some points. The risk of "gray goo" is no longer taken seriously by anybody – not even by Drexler himself, especially following the debate between him and Richard Smalley about the physical possibility of molecular assemblers (Baum *et al.*, 2003). However, a real "communication inflation" accompanies nanotechnology today. J. Schummer has made a typology of the actors who take part in it in the USA (Schummer, 2004); and Klein, Grinbaum and Bontems (2007, pp.22-23) summarize his analysis quite well:

"The authors of science fiction use 'nanos' as an excuse to tell good stories without claiming to present them in a realistic way. Among the scientists, those who speak the most are the toxicologists, who warn about the risks and defend at the same time the need to increase their budgets, and computer scientists, who recycle the futuristic theses that they defended some time ago on artificial intelligence. By contrast the researchers involved at the cutting edge (chemists, physicists and biologists) do not speak a lot. Policymakers warrant, on behalf of 'nanos', the policy guidelines of research for maximizing competitiveness. The business men assess the chances of profit for private investment, but also the risk of bursting

> *of the bubble which is formed around nanotechnology. The transhumanists are longing to 'change life' by releasing man from the natural limitations of his body. Social scientists try to understand the current dynamic, and defend the need to finance them for anticipating the social impacts. Finally the media amplify especially two of the previous speeches, the toxicologist's and the investor's, because they intend to inform the public about the foreseeable conflict between the contradictory interests of the economic development and of the natural and ecological safety."* [Translated by the author.]

The rhetoric emerging from all these actors offers a varied range of positions. Nevertheless it seems important to remember, first, that the expression of paradoxical speech is not the exclusive feature of nanotechnology. More or less, all the major modern inventions emerged in a polemical context (train, car, electricity, computer, etc.). Some authors argued that this phenomenon is characteristic of the introduction of recent technologies. Victor Scardigli (1992), for example, proposed to distinguish three recurring steps in the evolution of contemporary innovations: 1) one of fantasies of all kinds, including large hopes and fears; 2) the step of the beginning of the diffusion, which has very little to do with the announced revolution; 3) and finally a true diffusion, thirty or forty years later, accompanied by a full standardization. From this observation, he deduced that, paradoxically, new technologies make social change increasingly unlikely (Bourg, 1996, p.191).

More specifically, some authors have already sought to relativize the case of nanotechnology in comparison with other scientific fields which have also benefited from a gain in speech and enthusiasm. Claude Weisbuch (2006) points out that, in recent years, several scientific fields have benefited from a rapid growth of the number of their researchers:

> *"those of poly-water, of Raman Surface Effect, of recombinant DNA and biotechnology, of high temperature superconductivity, of cold fusion, of fullerenes, of nanotubes, and of nanotechnology in a wide sense. For all these areas a 'revolution' in terms of practical applications had been announced by the media (except for the Raman effect, and for the poly-water for which only a 'minor revolution' had been announced). Today, the results actually achieved are very nuanced: the ones of poly-water remain ambiguous, Raman Effect gave a lot of interesting science but only minor analytical applications, the field of recombinant DNA enabled major advances in biology and especially significant commercial applications, superconductivity is characterized by major scientific advances but possible applications are only foreseen, cold fusion must still demonstrate the possibility of any application, fullerenes and nanotubes have provided a lot of interesting science but the applications remain minor, and nanotechnology as such has provided many interesting sciences and technologies, as well as many applications, which however remain incremental for the time being. Anyway, the announced revolutions have not yet occurred in any of the areas."*

One can also compare today's promises about nanotechnology with those made in recent decades about biotechnology (Sciences Citoyennes, 2006, pp.16-17):

> *"For example, as well as supporters of nanotechnology expect, today for the future, targeted diagnostics and therapies in medicine, and improvement of deficient organs, biotechnology has been promising for fifteen years targeted gene therapy for correcting genetic diseases, with no real treatment available today. If one promises today that nanotechnology can cure diseases like cancer, biotechnology has been promising for twenty-five years remedies for countless diseases, while finally unicellular GMOs produce many costly drugs most of which could be obtained otherwise. While nanotechnology promises to promote sustainable development and protection of the environment by more efficient industrial processes, biotechnology has promised to promote sustainable development and, thanks to PGM, to increase yields and reduce pesticide use, whereas today this technology is imposed despite non-demonstrated benefits, and that according to recent studies organic farming would be able to feed the planet, and so on."*

Nanotechnology: a Philosophical Exception?

A necessary , autonomous, and deterministic technology?

The proponents of nanotechnologies, and those who develop them, have been the first to defend arguments suggesting a kind of exceptionalism concerning their discipline. And if this kind of rhetoric is often the prerogative of new technologies, it is true that it is founded, in the case of nanos, on certain characteristics that cannot be overlooked.

Cyrus C.M. Mody (2006) analyzes this phenomenon, and more generally the surrounding "determinism" of the usual speeches about nanos. First, he addresses the example of Drexler. The determinism of Drexler takes root in what Mody proposes to name his no-presentism, i.e. his conception of nanotechnology as a technology both mainly oriented towards the future and finding the proofs of its feasibility in the most distant past (Mody, 2006, p.103). Thus, for Drexler the advent of nanotechnology is described as both inevitable and deeply determining for society under the effect of two "proofs" taking the shape of two analogies. The first analogy links the artificial nanomachines to the biological nanomachines: the vision of biological organisms as more and more complex "molecular assemblers" emerging from an evolution of three billion years provides the proof of the feasibility of these assemblers, and assigns to the development of nanotechnologies a very determined path, leading them to mimic and to recreate the simplicity of the first assemblers. The second analogy links the artificial nanomachines to the macromachines built by common engineering, and it also indicates a very determined path, that of rebuilding at the nano-level what is already operating at the macro-level – and among others, the rebuilding at the molecular level of some elementary devices such as nuts, screws, springs, clutches, etc. (Mody, 2006, p.107). In this way, according to Mody (p.108), Drexler represents a kind of technological determinism characterized by the idea of a development of technologies according to an autonomous logic, which is a variant identified as such by Bijker (1995).

Although Drexler's successors have sometimes criticized his beliefs and his no-presentism (for example, Smalley has sought to demonstrate, on grounds related to chemistry, the unfeasibility of the assemblers described by Drexler), they have continued to use a very deterministic rhetoric. In particular, nanoscience and nanotechnology have been presented as the inevitable result of the convergence of two separate efforts: one which involves chemistry, which has progressed from the study of small molecules consisting of a few atoms to the study of macro-molecules of biological size, and one growing out of solid-state science, which has gradually reached down from the millimeter scale to the nanometer scale. This convergence gives the nanos their necessity and their personality of "final science", as the science of the relevant scale for the understanding of a very wide range of phenomena (Mody 2006, p.113-114).

More generally, for Mody, the various speeches aiming at placing nanos in relation to the scientific past often have a strongly deterministic connotation. Nanos are sometimes presented as the phase of explanation and understanding of some more ancient knowledge (the medieval stained-glass manufacturers made nanos "without knowing it", etc.). And in all cases, they are referred to major and decisive technological events of the past (they will inaugurate "the next industrial revolution", etc.). It is often a way of signifying that the nanofuture may still be or not be chosen, but that it is a full block which, once introduced, will impose itself in its many dimensions. Everything will be different, and society will have to adapt quickly to the changes brought about, even if the visions the authors have of it differ significantly. To Drexler for example, nanos very paradoxically could free society from technological determinism: the self-replicative systems will provide for the most basic needs, and a return to the Stone Age in small communities, for example, will become possible ... (Mody, 2006, p.118).

A radically new "metaphysical research program"?

Some authors, rather critical for that matter, went further and wanted to see in nanotechnology a quite unprecedented set of projects, methods, and more generally a "philosophy". Jean-Pierre Dupuy, for example, argues that nanotechnology differs from other disciplines by a radically new metaphysical research program (Dupuy, 2004; Dupuy & Grinbaum, 2006). This concept is borrowed from Popper: any scientific program (or *technological* program, Dupuy adds) is based on a set of assumptions regarding the structure of the world which, although not empirically testable and of course not falsifiable, plays a fundamental role in guiding research. One of the tasks of the historians and philosophers of science is thus to make these programs explicit, and to provide a critical review of them (Dupuy & Grinbaum, 2006, p.288). For Dupuy, the metaphysical research program of nanos goes back not to Feynman's famous lecture but to another lecture given at Caltech by John von Neumann in 1948 on complexity and self-reproductive automata. In this lecture, von Neumann criticized the cybernetical project aiming at theoretically reducing any mental function to a Turing machine or to a neural network capable of reproducing it. He argued that this ambition was nonsense since, due to growing complexity, the structure supposed to embody the function was in fact becoming the only way to characterize it. Thus in the case of complex systems, the classical engineering "top-down" approach becomes less interesting than a "bottom-up" approach, consisting in focusing the attention on the structure, and in exploring what a given automaton is capable of (Dupuy & Grinbaum, 2006, pp.289-290).

Dupuy sees in this reversal the origin of a new way of thinking that forms the core ideology of the "convergence" advocated today about nanos: rather than attempting to control complex systems *via* a top-down analysis of their sub-systems, the engineer-scientist of tomorrow will give himself some structures and will explore their functional properties, so that his success will be measured "by creations that will amaze his own self", for example in the fields of artificial life, genetic algorithms, robotics, distributed artificial intelligence, and so on. (He will be, Dupuy says, a "Sorcerer's Apprentice on purpose"). This ability to create complex and self-reproductive systems is closely akin to what is for Dupuy another underlying ambition of nanos: to rebuild life. "We must seek to naturalize mind and life, in order to place them back in the nature that has engendered them" but "this naturalization needs a mechanization and an artificialization, as much of nature as of life and mind themselves." "If the ambition of nanotechnologies is to take over from nature and life, it is only after they have previously completely redefined nature and life to their image" (Dupuy, 2004, p.1321. [Translated by the author.]).

The issue of the links between nanotechnology and nature

One of the most determining characteristics of nanotechnologies seems then to be the complex relationship they have with nature. The question, however, is whether this relationship is fundamentally new compared to other sciences or technologies.

More precisely, the opinions differ as to whether the nanos, which take place at a scale which is also that of biological "constructions", (a) reinvent nature, (b) copy it, or (c) continue to differ from it. As we have seen, the first position is Dupuy's, for whom "the expression 'artificial nature' is no longer an oxymoron" (Dupuy, 2004, p.1321). Nevertheless there also exist some authors defending the second position or the third.

Thus, some authors have attempted to establish some criteria allowing the distinction to be made between nanotechnological and natural products. The broader question is of course the definition of what is meant by "natural". In an interesting article, Gregor Schiemann (2006) proposes the following epistemic simple criterion: an object will be said to be "natural" if it is impossible to prove that it was produced by human activity by means of any scientific method available at the time. And he argues that, despite the complexity of the contemporary situations, this criterion remains today good enough to demarcate clearly the nanotechnological productions from the ones existing beforehand in nature (Schiemann, 2006, p.91).

Concerning the more specific issue of the differences between nanotechnological productions and living organisms, Schiemann argues that, in any case, there are still characteristic differences (and pairs of oppositions) between technological and biological systems, particularly on some criteria such as production process, controllability, materials, energy input, environmental sustainability, durability, stability and changeability (Schiemann, 2006, p.89). In particular, the properties of self-replication and self-repair, which are typical of living beings, and the adaptability that a severe natural selection has conferred to them, still remain largely beyond the reach of nanotechnology, so that they can be examples of application of the epistemic criterion above (Schiemann, 2006, p.87). For Schiemann, this phenomenon explains for that matter why nanotechnology often aims at limiting itself to non-living constructions, both in the current research and in the most futuristic discourses (like Drexler's or Rocco and Bainbridge's report).

Nevertheless, the issue of the heuristic role, or of the mimetic function, that nature can play in the development of nanotechnology, seems to us to be a different question. Many authors stress the fertility of observation and copying of nature for the development of nanotechnology. Certainly the history of technology tends rather to show that, until now, human achievements have rarely been made by direct inspiration from nature: for example, the technological efforts of that great observer, Leonardo da Vinci, often remained unsuccessful, while technologies such as the telephone, the steam engine, the internal combustion engine, the aircraft, etc. have been developed only thanks to an emancipation from nature and a dose of invention that are typical of man. But the case of nanotechnologies might still be susceptible to change the situation in this matter. First there exist some pragmatic reasons for this: as Smalley explains it to Drexler during their famous debate, some physical impossibilities can prevent the build-up of nano-mechanisms inspired from macroscopic achievements, so that the imitation of existing biological systems could be the only practicable way. But also, as Ball notes, the descent of engineering to the scale of the cell and of its components deserves in itself an interpretation:

"*There are two ways in which one could respond to this situation. One could regard the coincidence in scale as irrelevant, since engineering's traditional methods and materials have nothing in common with those of the cell [...] The other option is to realize that the cell faces many, if not most, of the same challenges as we do [...] The ideal position lies, as ever, somewhere in between. I feel that the literal down-sizing of mechanical engineering popularized by nanotechnologists such as Eric Drexler [...] fails to acknowledge that there may be better, more inventive ways of engineering at this scale [...] On the other hand, we should remember that the cell's objectives are not necessarily the engineer's."* (Ball, 2002, p.13-16, from Mody 2006, p.112).

Either way, it seems to us that today the most interesting results are provided by a kind of "mixed" method, inspired from already well-known engineering achievements at the macroscopic scale, and replicating them differently at the molecular scale. The famous realization of the "ATP motor" used to spin a small metal bar seems to us to be an example of this (Soong *et al*. 2000, quoted by Mody, 2006). In addition, analysis and pure and simple reproductions of natural "achievements" through the nanos are also becoming full-fledged activities, even if, as Ball remarks, they sometimes run the risk of self-justification (Ball, 2002, p.13). In any case, we wish to note in this respect that, in recent years, a technician and mechanistic vocabulary of description has spread, which compares implicitly the biological entities that one tries to reproduce to engineering achievements. The molecular "structure" involving the movement of the flagellum "propelling" bacteria, for example, is spontaneously described as an "engine" with a "clutch" and a "gearbox" (see e.g. http://www.laas.fr/laas/1-5595-Nano-Moteur.php). This rhetoric seems to us to go beyond the simple framework of the well-known and usual finalism of biological descriptions, and beyond the attempts of physical models (for which one can understand that human achievements play an important heuristic role). And the generalization of this kind of approach of the external reality seems to us to denote a form of conceptual enslavement, not very different from the "redefinition" of nature denounced by Dupuy.

Some "metaphysical effects" of nanotechnology?

Some authors certainly stress how difficult it is to gather nanosciences and nanotechnologies under a single defining paradigm. Indeed the galaxy of "nanos" is still heterogeneous and brings together disciplines with very different methods and projects. Hence the difficulty in attempting to analyse the case of "nanos" and setting it apart from the traditional categories of history and philosophy of science and technology. In particular, as Klein, Grinbaum and Bontems (2007, p.13) remark, neither of the two paradigms which the contemporary nanos inherit but which are also incompatible – Drexler's based on the application of macroscopic methods, and Smalley's, extended by Jones (2004) and based on the capacity for self-assembly – really guides researchers as a "normal paradigm", in Kuhn's meaning, would be expected to do. Nevertheless, we think it possible to pay attention, as suggested by Dupuy (2004), to the "philosophical effects" that an extreme development of the tendencies inscribed in "nanos" – taken as a whole – could imply: "ontological effects" in the sense that, if nature itself is rebuilt, the very notion of transgression will lose its meaning, "epistemic effects" in the sense that the very notion of an external reality to discover will disappear, "ethical effects" in the sense that if conscience is modified the very notion of human conscience on which to found an ethics will disappear, "metaphysical effects" in the sense that some fundamental distinctions may disappear, such as the one between the natural inanimate, the living and the artefact (Dupuy, 2004, pp.1320-1321), etc.

Let us finish by remembering the beautiful novel by André Vercors (1952), *Les animaux dénaturés*. Following the discovery of the "missing link" between animals and humans, there was a quest for a definition of man. The definition which received the greatest consensus was more or less the following: man is the only creature who has an ambivalent link to nature. Let us understand that, if Dupuy is right concerning the "effects" of nanos, such a definition will also need to be re-examined.

Nanotechnology: an Ethical Exception?

A number of questions

It is well known that the emergence of nanotechnology raises a multitude of ethical questions. The creation of a typology of these questions is a problem in its own right, with an important theoretical dimension. While renouncing the ambition of a comprehensive review, let us follow, for example, the method proposed by the Commission on the Ethics of Science and Technology of Quebec in a report devoted to nanotechnology (Commission de l'éthique de la science et de la technologie, 2006). The Commission distinguishes between ethical concerns associated with nanotechnology-based products, and ethical concerns not exclusive to nanotechnology.

In the first category, the report mentions (A) the effects of the development of nanotechnologies on human health and the environment, first with the problems of toxicity and/or dangerousness of nanoparticles (carbon nanotubes, nanoparticles issued from cosmetics, from household products, scattering of fragments of nanomaterials used in construction, etc.), and issues relating to the protection of workers and the population. This also includes all issues on the use of nanotechnologies in the field of medicine: possible harmful effects of products used in the human body, problems related to the early diagnosis of diseases – what to tell and what not to tell a patient, what to reveal in the case of incurable therapies, how to maintain secrecy in relation to insurance companies or credit agencies, risks of eugenics, and so on. It finally covers issues related to the preservation of the environment, including the environmental consequences of a possible mass diffusion of nanoparticles (for example used for cleaning up).

The first category also includes (B) issues related to the use of nanotechnology in terms of national defence and civil security, with all the classical ethical problems of military development (development of sophisticated machines designed to kill for the benefit of protection, etc.), the geopolitical risk of the major competitive edge – accompanied by a notable disruption of the "balance of fear" – that nanotechnological weapons could provide to some states, questions regarding the "improvement of the soldier" through technological means – all kinds of implants, changes in the biochemistry of the human body, etc. – or even the instrumentalization of mammals or insects fitted with electrodes for surveillance purposes, the eternal question of transparency or secrecy in the military field, and all the problems of miniaturization and proliferation of devices used for the surveillance of the civil society.

Finally, this first category includes (C) all matters related to the possibilities of using nanotechnology for purposes of modification of man or of Nature, particularly in a context of optimization of the performances (moving boundaries between therapy and "enhancement" of human body, risk of stigmatization of disabled or "non modified" populations, profound change of human identity and of the link of man with nature, etc.).

In the second category, the Commission classifies some "ethical" concerns that could be common to other areas of technology, but which nanotechnology contributes to, to a greater or lesser extent. There are questions related to governance: what about the legitimacy and transparency of decision-making processes regarding nanotechnology? Then there are questions related to the economic activity, whether related to nanotechnology or more general. In particular, does the possession of nanotechnology provide the already richest countries with an economic advantage? What would their responsibility be towards developing countries, for which nanotechnology could be very useful to solve their most recurring problems? How to organize intellectual property and the management of patents in nanotechnological matters? There is also the very important problem of the participation of nanotechnology (in convergence with information technology) in developing widespread mechanisms of surveillance or filing of data on consumers and/or citizens (e.g. for marketing and/or control), with all the violations of privacy entailed, including through the RFID or biometric chips.

One could add to the risks or ethical concerns described above those that Louis Laurent and Jean-Claude Petit (Laurent & Petit, 2006) propose to subsume more or less together, but also to distinguish under the three following categories: "loss of control", "misuse of discovery" and "transgression" (which also cover some of the problems described above). We find among them the famous risk of "gray goo" extensively discussed a few years ago, the risk of diversion of nanos for the purposes of terrorism, risks related to the use of nanotechnologies to create clones or chimeras, etc.

The debates on nanoethics

The approach to all these problems varies significantly according to the different authors. In all cases, it is remarkable that, after the unfortunate experience of GMOs, even the most ardent promoters of nanotechnology recognize the need for a reflection on the ethical and societal aspects. But while the opponents are inclined to use ethical justifications to try to impose constraints upon the development of nanotechnologies (or even to prevent it completely through a moratorium), the supporters seek to prepare society to an acceptance of nanos through the anticipation of the ethical, societal and legal issues that they will not fail to raise. Some American institutions, e.g. the National Nanotechnological Initiative (NNI), have such a disposition. This difference of understanding has the unfortunate corollary that a partition begins to develop between a "pro-ethics" and a "contra-ethics" of nanotechnology according to the tacit preferences of their authors, while "ethics" should be a place, some would hold, of objectivity and impartiality.

Van de Poel (2008, p.29-30) rightly notes that most speeches on the ethics of nanotechnology, whether they come from one side or the other, suffer today from major common defects. On the one hand, they tend to deny the complexity and the ambiguity of barely emerging technologies, by conveying the idea that the effects of nanotechnologies on society are already predictable and known today (regardless of how one interprets them). On the other hand, they have a very narrow conception of ethics, ignoring its possibility to influence the *direction* of technological development, and confining it to the role of a brake or a motor of a movement that remains rather autonomous. For us, it is in a certain way a defect that one can link to the usual deterministic presupposition concerning the nanos.

However nowadays "nano-ethics" is emerging as an ethics of the issues of nanotechnologies, just as there already exists a proven and successful "bioethics". As Tsjalling Swierstra and Arie Rip (2007, p.3) point out, the journal *Nanoethics* is, however, cautious in its subtitles: *Ethics of technologies that converge at the nanoscale*. More generally, the discussions and public debates about nanotechnologies tend to update such general considerations, so that there is nowadays a real debate on whether an ethics specific to nanotechnology could exist, and whether it is desirable. Thus for example for Swierstra and Rip (2007), the ethical considerations around nanotechnology generally reproduce the concepts and the pattern of any discussion around "New and Emerging Science and Technology (NEST)", a field on which they provide a detailed analysis.

Van de Poel (2008, p.31) rightly analyses that this debate can be understood at two levels: 1) One question is whether nanotechnology raises really new ethical issues which are not already covered by other fields of applied ethics. Thus it may be argued that the problems of sustainable development, risk assessment, human-machine interfaces and so on posed by nanotechnologies are already covered, for example, by bio-ethics, and as such do not need any specific review. Many authors argue, however, that the "convergence" opens the door to problems peculiar to the nanos: just as different scientific disciplines converge at the scale of nanos and traditional boundaries fade away, different ethical issues emerging from different traditions meet and actually create new problems. For example, as remarked by Tsjalling Swierstra and Arie Rip (2007, p.17), the prospect of the medical use of nano-devices introduced into the body and able to decide autonomously on the attack of detected cancer cells is radically new, and is very different from ethical cases related to autonomous macro-devices (such as those that will probably be raised by the emergence of fully automated vehicles). Similarly, the ethical issues raised by the ambition of the "enhancement" of man through nanotechnology could also seem radically new. 2) Another issue is whether the ethical aspects of nanotechnology as such require the development of new types of normative standards. In this respect, several authors argue that applied ethics has already developed a sufficient battery of tools, methods and concepts that one can apply regarding the nanos – for example the concepts of medical ethics can be applied unchanged to the dilemmas encountered in nanomedicine. But van de Poel (2008, p.32) points out that this view is inspired by "deductive ethics", and that, as such, some classical arguments can be opposed to it. On the one hand, it can be illusory to seek a basic reference framework allowing an absolute consensus. Thus in the case of nanos, one can deduce from different ethical traditions some moral judgments that are contradictory to each other. (For example it is well-known that the right to the "enhancement" of a person by technological means can be justified by certain systems of ethics and denied by others.) On the other hand, the search for a normative and theoretical framework beyond any concrete consideration could also be illusory. For example, a distinction such as that between the treatment of a disease and the "enhancement" of a person can be *a priori* theoretically relevant, but can be blurred in the concrete situations caused by the use of nanotechnology. In line with these criticisms, van de Poel (2008, p.33) also seeks to demonstrate that the usual attempts to subsume some areas of ethics of nanotechnologies (such as the risks of nanoparticles) under pre-existent ethical categories, for the definition of which one can try to provide some formal criteria, remain to date unconvincing.

The need for new methods

In the end, we can recognize with Ibo van de Poel the need for an ethics of nanotechnologies that is able 1) to discern the ethical issues of nanotechnologies in all their complexity while these technologies are still at their early stages of development, 2) to inform, to influence and, to some extent, to orientate this development, and 3) to address issues of nanotechnologies in their real context, rather than as theoretical ethical issues resolvable by the simple application of pre-existing concepts or theories (van de Poel, 2008, p.34).

Certainly, one of the most urgent problems posed by nanotechnology remains the noxiousness of nanoparticles (including carbon nanotubes), to the confirmation of which new data are added daily. Yet the beginning of this awareness comes at a time when many products using more or less nanotechnologies are already on the market. Hence the need, above all, of expanded studies and knowledge in this area, of normalizations that are still lacking, and of appropriate legislation. It is precisely this aspect of nanotechnologies that for the moment crystallizes the social opposition, and public as well as industrial authorities are becoming aware of the necessity to address these concerns to avoid the risk of a systematic obstruction. (It is well known for example that, in June 2008, the Japanese firm Mitsui Chemicals stopped its production of carbon nanotubes as a result of articles proving the toxicity of these products).

However, to build up a long-term public confidence in nanotechnologies, to guide their development in the most interesting directions, and to deal with the many questions they raise, will require much more ambitious approaches to their ethics and their context than a simple and traditional risk analysis. There is a real need, even for "ethics committees" invested with these issues, for proactive methods of thinking and acting adapted to the case of nanos, and which can be translated into concrete plans of assessment and governance. One of the challenges is to recognize that, if the paradigm of the "risk society" (Beck, Jonas) is the framework of our relation to nanotechnologies, they can also upset this paradigm. Thus, Klein, Grinbaum and Bontems (2007, p.44) propose to use the category of "indetermination" rather than that of "risk" to describe the case of nanotechnology – and they distinguish the intermediate categories of "uncertainty", "ambiguity" and "ignorance". "Indetermination" is for them a domain where the precaution principle cannot be applied, due to the fact that the probabilities of the various consequences of a problem depend themselves on the analysis of the problem, and on the future interactions between society, nature and technology.

It will of course be useful to mobilize the already existing ensemble of participative methods, hybrid forums and public debates to meet these challenges. In addition, some proposals for more specific methods already exist. An example is the "network approach" advocated by Ibo van de Poel (2008), based on cooperative thoughts of researchers and engineers; another example is the interesting methodology of "ongoing normative assessment" of Dupuy and Grinbaum. This methodology starts from the premise of the existence of certain cognitive barriers in our relationship to the future: in particular the future is partly determined by the description that one gives of it, and the human psyche is characterized by an aversion to *Not Knowing* which sometimes keeps it away from the most rational decisions for the benefit of the decisions increasing its visibility. This aversion also has the corollary that the human psyche is often inhibited concerning its reactions to unpleasant situations, if these situations are predictable but not yet tangible. The method is therefore 1) to encourage the (collective or individual) development of different visions of our technological future, either a) sufficiently optimistic to be desirable and sufficiently credible to be able to arouse effective actions, or b) sufficiently pessimistic to be repellent and sufficiently credible to be able to arouse effective actions; and 2) to link these visions to a continuous process of "real time" feedback from the results finally obtained and the actual course of events (Dupuy & Grinbaum, 2006, p.304-313). These methods can perhaps find other fields of application, but in any case they seem more suited to the case of nanos than a lot of other methods which have preceded them.

Conclusion

There remains a lot of subjectivity in the ordinary expectations associated with our nanotechnological future. Optimists hope that nanos will bring a major contribution to solving the problems of industrialized societies (exhaustion of resources, environmental damage, growing inequality, etc.). And pessimists argue that the problems they create will be more serious than all those they can solve. One thing seems certain: the world that they will help to implement will be different from our world today. And as always, this change will be either accompanied and chosen, or imposed and endured. In any case, all categories of actors (politicians, businessmen, media, citizens, scientists, engineers, and so on) share the responsibility for the direction that their development will take and none of them, sometimes in spite of their natural tendencies, can deny it – even if another chapter would probably be necessary to demonstrate this point.

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Chapter 16

Sustainable Design – A case study in energy systems

Eugene Coyle & Marek Rebow

Abstract: Since the publication of the United Nations climate report in 2007, most countries now agree that recent climate change has occurred as a result of human intervention and that it will require fast and profound measures to reduce this negative imprint imposed upon nature. Central to this is the need to radically reduce CO_2 emissions by increasing energy efficiency and conservation, advancing alternative energy technologies to fossil fuels and controlling future energy demand. Sustainable energy is now to the fore with government agencies developing strategies and preparing new educational and scholarship research programmes in order to develop new ideas and provide innovative solutions. The terms "sustainable development" and "sustainable design" have become part of our everyday vocabulary, and there is now an active trend towards development of new curricula and degree programmes in sustainable energy. The chapter begins with a broad discussion of the context that frames the rationale and the necessities fuelling the growing importance of sustainable development and sustainable design. We explore an holistic engineering approach incorporating the three stepping stones – Principles, Strategies, and Methods/Tools. In addition, we provide some examples of syllabi and curricula developments in sustainable design with a particular focus on energy systems, and we invoke a spirit of engagement in helping create a sustainable future.

Key words: Sustainable Development, Sustainable Design, Energy Systems, Exergy Analysis, Engineering Education

"Then I say the Earth belongs to each generation during its course, fully and in its right no generation can contract debts greater than may be paid during the course of its existence".

Thomas Jefferson, 1789

Introduction

Is it clear that mankind is working toward achieving a better understanding of his relationship with nature in fulfilling the dream of a "utopia of sufficiency" which spans at least the last five centuries (de Geus, 1999)? Has a new energy era – so called "The Third Industrial Revolution" based on three essential pillars: renewable energy, storage technology, and smart power grids – appeared on the horizon to provide a pathway by way of a number of small steps or indeed one giant leap for mankind towards sustainable social and economic development for this century and beyond? Have we started a trajectory of change or have we already developed unsustainable societies, a "utopia of abundance" with "ecological debt" on a global macro-scale to the micro example of Easter Island (Rapa Nui), facing catastrophic repercussions? The current indicators of global conditions seem to confirm worst-case scenarios and reveal how out of balance and unstable our relationship with the environment has become. Tropical forests are shrinking, new deserts are forming annually owing to land mismanagement, and underground water tables are falling as demand for water rises above aquifer recharge rates, whilst we are facing the greatest extinction of wildlife since the demise of the dinosaurs. There is the ozone hole over the Antarctic and above all it is scientifically proven beyond doubt that the amount of greenhouse gases (GHG)[1] in the atmosphere is increasing at an accelerating rate, and global warming is resulting in thinning of the icecaps and melting of glaciers.

The first industrial revolution, which began in the second half of the eighteenth century, started in response to an energy shortage in Britain (Brinley, 1985). Again today, more than two and one half centuries on, humankind is facing a similar though potentially greater problem, with a need on the one hand to generate ever greater amounts of energy and the opposing necessity to reduce the damage inflicted by industrialization, transportation and existing energy production, storage and supply technologies. To quote Jeremy Rifkin, "the rising cost of energy fuel and the deterioration of the earth's climate and ecology are the driving factors that will condition and constrain all of the economic and political decisions we make in the course of the next half century" (Rifkin, 2007). In addressing these problems should we focus our efforts and resources on development of technology innovations in new energy generation, including fusion, hydrogen and renewable forms of energy, for example

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[1] It was not until the 1860s that an Irish scientist, John Tyndall, identified the radiative properties of water vapour and CO_2 in controlling surface temperatures. "The waves of heat speed from our earth through our atmosphere towards space. These waves dash in their passage against the atoms of oxygen and nitrogen, and against molecules of aqueous vapour. Thinly scattered as these latter are, we might naturally think of them meanly as barriers to the waves of heat".

solar, wind, biomass, hydropower, ocean (waves, tidal[2]), geothermal, and in removing of atmospheric carbon dioxide without harmful effects[3], or should we focus on further development of existing energy and transport systems, including clean coal technologies and nuclear energy with all the associated problems? At the present time there is no consensus on how best to balance future energy demand and supply development, with wide difference in opinion on the necessity of building new nuclear power plants and/or the lifetime prolongation of existing plants (IEA, 2007; Peter and Lehmann, 2008). In truth, development of new energy systems and improvements in both efficiency and ecological cleanliness of existing ones, will contribute to sustainable solutions. Whatever the future balance in energy development scenarios and policies, it is becoming apparent that sustainable design will be central to modern holistic engineering thinking and will be of critical importance in delivery of education to engineers of the twenty-first century (The Engineer of 2020, 2004).

The last twenty years has seen a period of transformation from one of scepticism owing to a lack of knowledge and factual scientific data in respect of global change and environmental damage, to one of enlightened consensus where it is now accepted that sustainable development and design is essential to all engineering endeavours if we are to positively influence a change in direction towards redressing the damage. In Deep Design, David Wann comments that "poor design is responsible for many, if not most, of our environmental problems" and searches for a new way of thinking about design, exploring such issues as renewability, recyclability, and nontoxicity in developing design criteria (Wann, 1996). A fundamental tenet of sustainability in design is that technological developments should not harm the environment, either at the present time or going forward in time. System designs must function primarily within bioregional patterns and scales. They must maintain biological diversity and environmental integrity, contributing to the health of air, water, and soil. Designs

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[2] "Blow winds and crack your cheeks.." In King Lear, the bard of Stratford-upon-Avon casts the desolate King, invoking the power of the elements to rage in his despair. Wind and water energy have been both friend and foe to humankind for time immemorial. As friend, technological developments in recent decades have again placed wind energy to the fore of renewable energy generation. Flowing water, one of the cleanest and longest serving forms on energy, is likewise on the cusp of rejuvenation as a highly significant energy source. Following success of traditional hydro generation, innovations in the harnessing of wave and tidal energy are yielding encouraging results with prototype generators connecting to national grids.

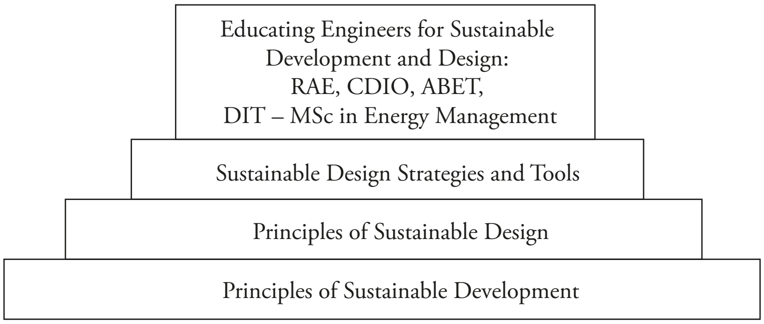
[3] Sir Richard Branson and Al Gore have set up a new global science and technology prize – *The Virgin Earth Challenge* – which will award $25 million to the individual or group who are able to demonstrate a commercially viable design which will remove at least 1 billion tons of atmospheric carbon dioxide per year for at least ten years without harmful effects. The removal must have long term effects and contribute to the stability of the Earth's climate.

should incorporate features that reflect bioregional conditions, with reduction of the footprint of human impact. In tandem with the undoubted benefits technological development has brought to mankind, has been the negative imprint of over urbanization, pollutant waste product creation, societal stress and damage to the natural environment. It is our view that ethical considerations to social and environmental impact need to be addressed at all stages in the sustainable design process. Such considerations must apply both within the educational environment and in the professional workplace and should be informed by and be sympathetic to the social, technical, environmental and economic needs of all social stakeholders. Only by this means can truly sustainable indices be agreed upon, feeding into the design process, whether in design of renewable energy systems or in managing waste products in a safe and environmentally acceptable manner.

Owing to the multidimensional nature of sustainability, based on complex social, economic, and ecological theories, policies and practice, the concept of sustainable development and design can be difficult for students and engineering professionals to fully comprehend and understand, and these topics will require critical analysis by academic leaders, teaching and learning pedagogues and university lecturers and teachers. Koïchiro Matsuura, Director General of UNESCO, postulates that sustainable development should receive a leading place in education at all levels (UNESCO, 2004): "Education – in all its forms and all its levels – is not only an end in itself, but is also one of the most powerful instruments we have for bringing about the changes required to achieve sustainable development." Is it possible to educate 21st Century engineers as "leaders-in-service" capable of dealing with dilemmas of complex societal settings and empowering them to internalize and implement sustainable design principles in their profession at all stages in their professional careers, so that they may consider and take account of the interactions between local (regional and community) stakeholders as well as global (economic, climate, and ecosystems of the Earth) factors? Lucena and Schneider (2008) argue that sustainable development "has significant limitations, particularly when it does not include theoretical and practical considerations of community" and they "would like to see the community made central in 'sustainable community development' (SCD)."

As outlined in Figure 16.1, in this chapter we offer some commentary and attempt to answer some of the above questions by exploring the principles of sustainable development and sustainable design, in the context of engineering education and with particular emphasis on sustainable strategies and tools for energy systems. We offer by way of example an overview of syllabi and curricula development in sustainable design, commencing with an overview of the Royal Academy of Engineering guiding principles, followed by commentary on the important CDIO (Conceive-Design-Implement-Operate) concept. Finally, we present an overview of a recently developed Master of Science degree in Energy Management at Dublin Institute of Technology (DIT) (with a brief of one module, titled Sustainable Building Design).

Figure 16.1: Steps towards engineering education for sustainable development and design



The Principles of Sustainable Development and Design

In discussing engineering education for sustainable development and sustainable design we must initially offer clarity in definition and understanding of these concepts. In the literature there is no universal definition of sustainable development. Perhaps the reason for a plethora of definitions in sustainability is that it is a rich and complex concept. It is therefore essential that engineers and other professionals gain a deeper understanding of sustainable development so that they can recognise it as a guiding principle in the fulfilment of their creative professional endeavours. In order to nurture the planet back to good health, and to create a more stable eco-environment for all, it will be essential that national representatives, individuals and practitioners across the professions work in tandem to develop infrastructural frameworks that will meet agreed sustainable and non-harmful criteria, and be adopted globally. This is not a new concept, a great deal of excellent cooperative venture is already (and indeed has been) taking place, not least through the IEA (International Energy Agency), UNESCO, IPCC (Intergovernmental Panel on Climate Change), WCRE (World Council for Renewable Energy), and by implementation of legislation at the national level and through academic and scholarly endeavour via peer review publication and cooperative research engagement. The issue today is that the stakes are higher than ever before. Not only are we now capable of inflicting untold damage upon the planet, but we are now able to accurately measure and study the effects of this negative impact. It is therefore in the global collective interest that a one-hundred fold increase in effort be made to begin to create systems, standards, frameworks and agreements that will facilitate a return to a sustainable ecosystem with the regulating capability for survival in the short term and, perhaps even more importantly, into the long term future.

An appropriate starting definition might be with the Universal Declaration of Human Rights – the principle of inter-generational equity (UN OHCHR, 1948): "Development which meets the responsible needs, i.e. the Human & Social Rights, of this generation – without stealing the life and living resources from future generations, especially our children.... and their children." In 1987, the World Commission on Environment and Development (Brundtland Commission) put forward a definition of sustainability and called for the development of new ways to measure and assess progress toward sustainable development (Our Common Future, 1987): "Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." Unfortunately, this definition does not provide unambiguous meaning of the term "needs" and does not specify the ethical roles required of humanity in achieving sustainable goals. Nor does it directly incorporate the value of all other constituents participating in the global ecosystem. The concept of *Sustainability* is gradually gaining more applicability and acceptance, depicting the ability of a system to operate indefinitely and complying with the so called "triple bottom line" conditions-- environmental protection (maintaining ecosystem integrity, function, and structure), economic prosperity, and social equity (meeting basic needs with inter- and intra- generational equity)–which, when taken simultaneously, should create a truly sustainable system (Elkington, 1999; Hediger, 1999).

An important contribution in the Bellagio Principles endeavours to "assess sustainable development in practice" (IISD, 1997). These principles

> *"deal with four aspects of assessing progress toward sustainable development. Principle 1 deals with the starting point of any assessment – establishing a vision of sustainable development and clear goals that provide a practical definition of that vision in terms that are meaningful for the decision-making unit in question. Principles 2 through 5 deal with the content of any assessment and the need to merge a sense of the overall system with a practical focus on current priority issues. Principles 6 through 8 deal with key issues of the process of assessment, while Principles 9 and 10 deal with the necessity for establishing a continuing capacity for assessment."*

The ten principles are: 1. Guiding vision and goal, 2. Holistic perspective, 3. Essential elements, 4. Adequate scope, 5. Practical focus, 6. Openness, 7. Effective communication, 8. Broad participation, 9. Ongoing assessment, 10. Institutional capacity.

In articulating the concept of *Design*, the ICSID (International Council of Societies of Industrial Design) proposes that: "Design is a creative activity whose aim it is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life-cycles" (ICSID, 2005). On the other hand, Manzini argues and elaborates that "it would be more appropriate to move away from this product-oriented definition to a more solution-oriented one" (Manzini, 2006). Sustainable design must use an alternative approach to traditional design that incorporates these changes in mind-set articulated by Manzini. One must identify the potential impact of every design choice on the natural and cultural resources of the local, regional, and global environment.

A model of the design principles necessary for sustainability was presented at EXPO 2000 in Hannover by William McDonough Architects in their "Bill of Rights for the Planet" (also known as the "Hannover Principles") (McDonough & Partners, 1992). The McDonough principles purport "the right of humanity and nature to co-exist in a healthy, supportive, diverse, and sustainable condition, recognising interdependence and" respecting relationships between spirit and matter. Responsible acceptance "for the consequences of design decisions upon human well-being, the viability of natural systems, and their right to co-exist," is a core tenet. A further core value is the reduction, if not elimination of the concept of waste in the design process.

Moreover, the concept of sustainable design should be supported on a global and intra-professional scale with the ultimate goal of becoming more environmentally responsive, more energy efficient, and conserving material and energy resources.

Sustainable Design Strategies and Tools in Energy Systems

Before considering subjective ethical motivations, development of sustainable action plans and choosing appropriate design methods and tools, engineers must consider the objective consequences of their actions, the social and ethical problems created by their technologies; in short they must embrace the notion of "ethics of responsibility". We are in complete agreement with Hans Jonas and Al Gore (in their separate declarations) that there is an imperative for action in finding long-term solutions, warranting human survival and well-being: "Act so that the effects of your action are compatible with the permanence of genuine human life." (Jonas, 1979).

> *"We must take bold and unequivocal action: we must make the rescue of the environment the central organizing principle for civilization . . . we are now engaged in an epic battle to right the balance of our earth; the tide of this battle will turn only when the majority of people become sufficiently aroused by a shared sense of urgent danger to join an all-out effort. It is time to come to terms with exactly how this can be accomplished."* (Gore, 2000)

Today's engineering design process requires engagement by many participants, including engineers, politicians, governmental agencies, managers, clients, anticipated customers and the general public (a detailed account is provided by Cañavate *et al*. in chapter 15). Defining and measuring the qualities in engineering designs that need to be preserved is a major challenge if we are to fully embrace and understand sustainability. How can engineers measure the quality of engineering systems, taking on broad goals, requirements and constraints of all concerned parties, and at the same time ensuring minimal negative effect on the environment? It is important to be guided by a set of sustainable indices, including technological, ethical, environmental, economic and social. To achieve the highest possible sustainable environmental index, engineers could learn from the strategies proposed by Mulder's "Life Design Strategies (LiDS)". LiDS comprise a set of rules that a design engineer can adapt to create an environmental profile of a product. In applying the strategies, one should "choose materials with low environmental impact, reduce material requirement, select environmentally efficient production techniques, select an environmentally sound distribution system, reduce environmental impact while in use, optimize the life span, and optimize end-of-life system" (Mulder, 2006).

To implement these strategies an engineer requires analytical methods and tools. Available tools include for example, Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Ecological Footprints, Sustainable Process Index (SPI), Material Flux Analysis (MFA), Risk Assessment, Exergy Analysis and Ecological CumulativeExergy Consumption (ECEC). In particular when considering design in energy systems, LCA and exergy analysis are worthy of particular appraisal.

LCA evaluates the environmental burdens of each product, process, and activity of a business. It quantifies materials and energy used, waste produced, and environmental impact. It goes from "cradle-to-grave" or indeed "cradle-to-cradle" when recycling and re-use are included as part of the process. LCA comprises four stages: i) goal definition and scoping (the system boundaries and validation of data), ii) inventory analysis, iii) impact assessment, and iv) improvement. An out-growth of the modelling pioneered by the "Limits to Growth" report written at MIT in the early nineteen seventies, LCA invites an optimization approach to design, seeking solutions rather than merely pointing out the problems. The Society for Environmental Toxicology and Chemistry states that

> *"life-cycle assessment is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material uses and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life-cycle of the product, process, or activity, encompassing extracting and processing of raw materials, manufacturing, transportation, and distribution, use/re-use/maintenance, recycling, and final disposal."* (McDonough, 1992)

A commentary on sustainable design concerning energy systems would not be complete without reference to the relatively new term (but old concept) in thermodynamics – *exergy*. Exergy is a measure of the usefulness or quality of an energy form and is defined as the maximum shaft work that can be done by the system or a flow of matter or energy as it comes to equilibrium with a reference environment (Szargut, 1980). Exergy provides a scientifically rigorous way of comparing the combined streams of material and energy. Unlike energy, exergy is not conserved (except ideal processes) but is destroyed or effectively consumed due to irreversibilities associated with processes. The exergy analysis method is more useful than energy analysis for improving processes efficiency, in particular energy generation systems (Hammond and Stapleton, 2001), by quantifying the types, locations and magnitudes of wastes and losses. Consequently, an engineer can identify the limit to a design of more efficient energy and other systems with the aim to increase exergy efficiency and reduce exergy losses, both internal exergy consumptions and waste exergy transfers (Szargut *et al.* 1988).

The exergy concept applies not only to the principles of energy systems but to the interdisciplinary associations in professional practice in sustainability; a link exists between exergy and environmental impact and has become a common quantifier of sustainability, indeed a new sustainability index (for real sustainable development, the loss of exergy should be minimal). It can be shown that the most efficient pathway for exergy consumption available will automatically be chosen. Exergy applies also to economics, with concepts of weak and strong sustainability and in respect of policy making in energy. Dincer and Rosen propose that, in addition to other objectives and constraints, exergy analysis should be more widely utilized, clearly stating: "we feel in general that a strong need exists to improve the "exergy literacy" of engineers and scientists" (Dincer and Rosen, 2007).

Excellent overviews of exergy analysis of Renewable Energy Systems (RES), including solar energy, wind power, geothermal energy, and energy from fuel cells, are provided by (Koroneos *et al.* 2003) and (Dincer and Rosen, 2007). A critical point in favour of RES is that they are inexhaustible and have much less adverse impact on the environment than fossil fuels. With exergy analysis, a comparison of energy efficiency in renewable and non-renewable energy sources can be achieved.

Examples of Sustainable Design Curricula

Perhaps one of the dilemmas of today is the quantity and speed of information flow in all walks of life, not least in education. Two important objectives in education should be to help students understand their physical and social environments and the changes taking place in those environments, and to create free space to think individually and collectively about common authentic values and principles.

Students must be tutored in the use of multi-, inter-, and trans-disciplinary approaches and encouraged to work together in teams comprising people from different disciplinary, social, and cultural backgrounds. The education process should focus on identifying competencies and developing appropriate learning environments and processes. (The important Programme outcomes relating to the social development of the engineer, as required by ABET, EUR-ACE and under the Bologna Declaration, are thoroughly reviewed in chapter 5).

The importance of educating future engineers for sustainable development is envisioned and strongly advocated by the National Academy of Engineering in The Engineer of 2020: Visions of Engineering in the New Century (The Engineer of 2020, 2004).

"It is our aspiration that engineers will continue to be leaders in the movement toward use of wise, informed, and economical sustainable development. This should begin in our educational institutions and founded in the basic tenets of the engineering profession and its actions"

and

"We aspire to a future where engineers are prepared to adapt to changes in global forces and trends and to ethically assist the world in creating a balance in the standard of living for developing and developed countries alike".

In his forward to the Royal Academy of Engineering "Engineering for Sustainable Development: Guiding Principles" document (Dodds and Venables, 2005) President Lord Broers comments that "Sustainable development has become an increasingly important theme in local, national and world politics, and increasingly a central theme for the engineering professions around the world".

And: "The sustainable development concept requires of all of us – as engineers and citizens – to consider much more widely than before the impact of our own lives and of the infrastructure and products we produce, both geographically and temporally".

In (Crawley *et al.*, 2007) *Rethinking Engineering*, a detailed explanation and overview of the CDIO concept, Conceive-Design-Implement-Operate, developed in response to a perceived critical need in meeting the desired attributes of the modern engineer, is presented. Initiated at four universities; Chalmers University of Technology (Goteborg), the Royal Institute of Technology (Stockholm), Linkoping University (Linkoping), and Massachusetts Institute of Technology, the number of programmes collaborating has expanded upwards to 30 universities worldwide. The CDIO approach builds on stakeholder input to identify the learning needs of students in a programme, and constructs a sequence of integrated learning experiences to meet these needs. A "best-practice" framework, proffers a CDIO syllabus supported by a set of underpinning standards. Crawley explains:

> *"Modern engineers lead or are involved in all phases of a product, process, or system life-cycle. That is, they Conceive, Design, Implement, Operate. The Conceive stage includes defining customer needs; considering technology, enterprise strategy, and regulations; and developing conceptual, technical and business plans. The second stage, Design, focuses on creating the design, that is, the plans, drawings, and algorithms that describe what product, process or system will be implemented. The Implement stage refers the transformation of the design into the product, including hardware manufacture, software coding, testing, and validation. The final stage, Operate, uses the implemented product, process, or system to deliver the intended value, including maintaining, evolving, recycling, and retiring the system."*

The CDIO concept with potential application to sustainability and sustainable development is briefly addressed in (Crawley *et al.*, 2007), with parallels and correspondence drawn to the guide for teaching of engineering for sustainable development by the Royal Academy of Engineering in the United Kingdom (Dodds and Venables, 2005).

Whilst many academic programme team developers and research and development strategists reach their product goal without reference to or knowledge of the CDIO guidelines and concepts, there is benefit in comparing end products to those of CDIO and assessing how a programme may be adjusted and fine tuned by taking into account the focused principles defined in CDIO. By way of example a recently developed MSc in Energy Management, developed at the Dublin Institute of Technology, is described and offered for comparison.

Sustainable Energy Ireland, the Irish national government agency with responsibility for implementation of regulation and policy in energy, and with particular focus on sustainability, had identified a need for a programme that would educate students specifically for the role of Energy Manager. The programme was planned in response to this need.

The intent in developing the programme was to enhance the present and future effectiveness of managers, engineers and scientists by providing an opportunity to study the theory and practice of seminal developments, laws, standards, and technologies, together with management, economics and finance, associated with European energy and the environment. The main objective is that graduates of the programme will be effective managers of environmental technology with critical awareness of resource management, conditional to financial and environmental constraints. Although primarily designed for engineers, the programme will also be of interest to scientists, managers and multi-disciplinary professionals such as environmental health officers, architects and planning officers.

In proposing the programme to the Institute's Academic Council and the Quality Assurance Committee, and in preparation of the required documentation, a case was presented for the provision of education on the integrated themes of energy, the environment and management. A brief statement on the core programme themes follows:

- *Energy*

The lifestyle currently enjoyed by people in the western world is fast being replicated in developing countries. This is already beginning to place a strain on current fossil fuel production as existing supply systems strain to keep up with demand. It is obvious to all that the dwindling fossil fuel resources cannot supply enough energy on a sustainable basis to meet the aspirations of all nations. A new system for the production of energy needs to be devised that seeks to maximise the useful energy output of fossil fuels as well as developing and utilising alternative renewable energy sources.

- *Environmental*

The environmental damage caused by the current production/consumption cycle of fossil fuels is causing irreparable damage to the environment and its full effect will be felt by future generations. The protection of the environment is recognised as a major international issue that has prompted new environmental legislation from the International Standards Organisation (ISO 14001). Many industrial and commercial organisations are experiencing political, social, and economic pressure and will be obliged to accept their share of the responsibility and adopt and conform to new legislation for the protection of the environment.

- *Management*

A reliable energy supply is seen as vital to the economic and political stability of a country. It is vital for a nation to produce and efficiently manage sufficient supplies of affordable safe energy and raw materials. It is the responsibility of Governments, industrialists, commercial organizations and departments in the public sector to develop a systematic management of energy consuming activities. The objective of this programme is for the participants to develop the ability to assess the current legislation, economic pressures and social obligations and apply them to their respective professional working environments.

The programme objectives are to:

1. Develop appropriate energy policies for a variety of commercial and industrial energy users

2. Identify and evaluate present and future issues facing the Energy Supply Industry
3. Compare alternative energy sources such as Sustainable and Renewable energy technologies
4. Conduct feasibility studies on and evaluate the use of energy efficient technologies
5. Interpret the requirements of the *EU Directive on Energy Performance of Buildings*
6. Advise on implementing *Sustainable Energy Design* in new and used buildings.
7. Advise, assess and evaluate the implications of relevant European legislation and regulation in the Energy Sector
8. Implement and manage a complex energy strategy in a Commercial /Industrial facility
9. Evaluate the environmental issues surrounding energy supply and use
10. Discuss the impact of International Protocols on Energy Usage and the Environment

Following a detailed consultation process with academic, industrial and student stakeholders, a programme plan was approved with a structure (delivered on a part-time basis over 2 or 3 years) as follows. To successfully complete the programme students must earn 90 European Credit Transfer points; Module credits generally have a 5 ECTS weighting. Six core modules (*Business Organisation for energy sector, Business Law, Financial Decision Making – with case exemplars, Energy Supply, Energy Conversion and Use, Energy Management*) are taken in year 1, followed by 6 optional modules in year 2 (selected from a list including *Strategic Management, Energy & Environment Law and Policy, Decision Making & Corporate Finance, Wind Energy for Electricity Supply, Advanced Energy Systems, Sustainable Building Design, Embedded Generation – Wind generation; Co-Generation – CHP, Renewable Energy Technologies – Solar/Wave/Tidal/Biomass, Energy Market Economics, Sustainable Energy Physics (e.g. LCA, Exergy), Biomass Technology/Biofuels for Transport, Transport Energy Economics and Management*). Having completed 12 modules, following consultation with the programme committee each student is assigned a project title with a topic relevant to their particular work environment in sustainable energy. As an exemplar the description of one module in Sustainable Building Design is presented in Table 16.1 (next page).

Table 16.1: Description of module in Sustainable Building Design

Module Title: **Sustainable Building Design**

ECTS Credits 5 Module Code EN1702

Module Aim:

This module aims to examine how both buildings and services can be designed in an integrated way to minimize energy use. This will become an increasingly important aspect of the work of engineers who will work in ever closer consulta-tion with the architect, structural engineer and design team in the years ahead.

Learning Outcomes:

On successful completion of this module students will be able to:

1. Appraise building form, façade, orientation and construction for energy use, indoor air quality and comfort. This is to enable the successful participant to make recommendations to the design team with regard to solar shading, window design, glass selection, blinds, daylight, etc.
2. Evaluate the role that simulation modelling of buildings has to play in ensur-ing that the new design concept of using building thermal mass, building foot-plate and façade design to ensure sustainable building design is achieved.
3. Integrate building design parameters with mechanical and electrical services in design to ensure that the services are not oversized and are run efficiently throughout the year.
4. Work in a group to develop an appropriate assignment.
5. Make oral presentations to a peer group

Learning and Teaching Methods:

Formal lectures and e-learning will underpin an action centred learning ap-proach. Active learning using assignments, case studies, live projects (where possible), simulations, group work and presentations will all form part of the learning methodology. WebCourses will be used as a student resource and asyn-chronous communication medium. Guest lecturers will be invited to present some sections of the programme and will be selected on the basis of expertise and experience. Course work assignments should be designed to reinforce the module learning outcomes. Case studies involving energy related issues should be used where possible. Site visits will be also used.

Module content:

Comfort in Buildings: – Thermal indices, – Ventilation, – Humidity, – Aural, – Visual.
Effects of modern building techniques on comfort: – Adaptive comfort princi-ples, – Indoor air quality, – Sick building syndrome.
Sustainable building design: - Building form, façade, and orientation, – Energy usage and environmental impact of buildings,- Solar shading, natural ventila-tion, thermal mass, window and glazing design, – Passive cooling, heating and other cooling strategies (e.g. night cooling), – Embodied energy of building materials in building design, – Life cycle analysis.
Integration of fabric and services against building form, orientation, glazing etc: – Ventilation & air-conditioning, – Cooling, – Heating, – Lighting.
Building performance: – Energy use, – Operation, – Maintenance, – Control and monitoring, – Building load calculations and design margins.
Simulation in building design: – Building models, – Solar tracking, dynamic airflow and thermal analysis, – Building Energy Management Systems (BEMS)

This programme has been running for two years and there has been an enthusiastic take up by students, with enrolment numbers in excess of intended intake. In particular there has been a great interest shown by professionals in the workplace with responsibility for energy management.

Led by members of the MSc Energy Management Programme Committee, The Faculty of Engineering at Dublin Institute of Technology has recently joined the CDIO initiative. The intent is to contribute to CDIO with programmes embracing sustainable design concepts, both in energy systems and in a wider array of engineering disciplines.

Conclusion

Nassim Taleb in his famous book, The Black Swan, argues in line with Karl Popper that we can not predict future historical events, but we have to be prepared for their consequences. Embracing sustainable development will both facilitate action in implementing corrective measures and prepare us for the unforeseen and damaging consequences resulting from climate change. Sustainable design of energy systems, including renewable energy systems, will play a crucial role in fulfilment of mankind's dream of a "utopia of sufficiency" – the well-being and coexistence of all species on the Earth.

To educate engineers to be "leaders-in-service" of sustainability, we must develop a conceptual framework. We have explored a holistic engineering approach incorporating the three stepping stones – Principles, Strategies, and Methods. These steps provide the platforms for the three main objectives of sustainable engineering education: creating awareness of sustainability and the awakening of a spirit of ethics of responsibility, explaining the concepts of sustainable energy systems and providing best design practice in sustainable energy systems.

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Section 4

Engineers, Workplaces, Institutions

Introduction

Martin Meganck

When trying to define an object, a group or a person, the attention is often centered on the aspects which make this definiendum different from other (often very similar) things. That is what defining means: making sure that the object of our definition is adequately circumscribed, and cannot be confounded with other objects. One of the drawbacks of this approach is that, while focusing on the differences, many other important qualities may be overlooked: qualities without which the object would not be what it is, but which are also shared by other instances. The search for an identity can then result in an over-emphasis of what, when looking at the whole of the picture, may appear as mere details. However, when confronted with others, or when one of these aspects is questioned or threatened, it is just these specific aspects which are experienced to be at the core of the identity. For humans, very typical examples of these dividing qualities which can make us forget what we have in common may be our national or religious belonging, or gender and sexual orientation. But there are certainly many more relevant examples.

This general mechanism, described by the Lebanese author Amin Maalouf in his book "In the name of identity" (1998), is also recognisable when thinking about what and who engineers are. The intended polyvalence of their training, and the multitude of functions and situations in which they work "as engineers", make them difficult to frame. The answer to the question "what is an engineer" will largely depend on the context from wherein the question is asked, and the surrounding backgrounds against which one wants a vision of engineers and engineering. Does one want to understand engineers when compared to scientists, to artists? Compared to entrepreneurs or to employees? Compared to generalists, or to hyperspecialised experts?

In this book, we deliberately wanted to have a multidisciplinary approach, thus hoping that the multifaceted image of engineers and engineering would show up well. In the other sections, the contributors try to draw images of engineers from the angle of their education (Section 2), their work as designers (Section 3), and their insertion in the larger civil society (Section 5). This fourth section offers a closer look at the rather immediate circumstances within which engineers work, which serve for them as normative environments, and from which they derive part of their identity. Some of these aspects may not be typical or exclusive for engineers. Yet so many engineers are confronted with them that thinking about engineers without highlighting these aspects would be incomplete. And maybe (at least some) engineers live these contexts in a particular way just because of their feeling about themselves as engineers.

Bernard Delahousse (Chapter 17) reconsiders a classical theme in organisational ethics (and related fields like business ethics and professional ethics): how to articulate individual and collective responsibility in an organisational context – here considered especially from the angle of business corporations. Being a member of such an organisation, one cannot deny one's causal co-responsibility, especially when one's tasks or role demand one's collaboration. The problem of articulating the responsibility rises when one has the impression of lacking the capacity of really influencing the decisions or the actions, and when the individual responsibility is either diluted in the responsibilities of so many others, or gets depersonalized and is devolved upon something anonymous like "the system" or "the structures". Taking three concrete examples as a starting point, Delahousse considers four values (work, wealth, trust and time) as values which are between professionals and organisations, but which attract at the same time tensions between them. He further presents a series of models for framing the discussion about responsibilities in an organisation, and holds a plea for breaching the asymmetry which is often felt when the word "loyalty" is used in an employer-employee-relationship.

There were times when engineering associations took professional orders, like medical doctors or lawyers, as examples for their self-understanding and professional profiling. And nowadays too, the discussion about the status of engineering compared to traditional recognised "professions" still figures in the background of many discussions, e.g. concerning the existence of something like "engineering ethics". The relevance of this discussion is felt differently in different countries (e.g. depending on the way education and practice of engineering work are regulated by law or by other mechanisms). Some of the characteristics of professionalism as studied in the sociology of professions can (descriptively and prescriptively) certainly be recognised in engineering. For other indicators of professionalism, attempts to apply them to engineering may seem (but there again, depending on the context) rather forced. Martin Meganck (chapter 18) sees, however, a new kind of professionalism (with some characteristics very similar to old-fashioned, almost elitist mechanisms of professionalism) appear in formal structures which are meant to guarantee the quality of work (like some forms of quality management systems). They often end in a logic of procedurealisation or bureaucratisation which is at odds with the ideal of individual professional independence as a recognition of one's competences – a situation which is recognised by many engineers…

The themes of professionalism and bureaucratisation also emerge in the results of an empirical study on work-related stress among knowledge workers, described by Anders Buch in chapter 19. They are – together with "reification" – among the frameworks which substantiate and stabilise self-identity, also for engineers. Reification here refers to the pride and satisfaction taken from knowing that one has contributed to the production of a concrete, tangible artefact which is appreciated by end-users. The stabilising effect of the frameworks of professionalism, bureaucratisation and reification is undermined when demands from the profession, the organisation and society collide, and "flexibility" or compromises offer no realistic solution.

The section ends with considerations on two more specific contexts for employment for engineers: research laboratories, and the military. Erik Fisher and Clark Miller (chapter 20) report from their experience with having "embedded humanists" in engineering laboratories. Like fish who are unaware of the water, engineers would often be trained to exclude broader contextual considerations from their view. The authors hold a plea for working with embedded outside participant-observers in the workplace which appears as a unique and effective method to facilitate the broadening of the perspectives of the professionals (i.e. the engineers). An alternative reappearance of Socrates' *maieutics*?

It is known that Archimedes and Leonardo da Vinci – often seen as forbears of engineers – exercised part of their activity in a military context. And the history of the engineering profession cannot be complete without paying attention to the corps of highly trained technicians (engineers?) in the army from the 17th Century. Even when not working within the military structures themselves, many engineers and researchers today work directly or indirectly for military-linked products and services – sometimes even without knowing it themselves. In chapter 21, Christopher Papadopoulos and Andrew T. Hable extend on the military as a context for engineering, with mainly the situation in the US as an example. They excerpted a series of studies on the proportion of military and defence presence in research and engineering. Inevitably, the ethical question about working for the military is raised: is it credible to say that its mission is to be an instrument in the defence of freedom and democracy? Does it imply the inherent acceptance of the possibility of the use of violence? And what about the problem of the legitimation (in some cases at least, doubtful) of military deployment? They end with a plea for redirecting efforts to humanitarian causes and for giving priority to social needs of the poorest societies.

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Chapter 17

Engineers in Organizations: Loyalty and Responsibility

Bernard Delahousse

Abstract: The engineer's dilemma between corporate loyalty and social as well as ethical responsibility is a classic issue in the field of philosophy of engineering. This chapter aims to discuss engineering practice in the context of today's globalizing organizations. It begins with a brief presentation of three legal actions in which engineers have been involved in recent years: the first two cases show engineers involved in the consequences of industrial hazards in which their responsibility was or should have been engaged, whereas, in the third one, the engineer acted as a plaintiff against his own company for unfair dismissal linked to deontological divergences. The second part will expand from these examples to discuss the relations – some of them conflictual – between organizational values and professional values, between industry's requirements and the engineer's stance. In a third part, we shall focus on the issues of organizational loyalty and responsibility in the light of the new economy, in which the new horizontal structures of companies have an impact on the engineer's role and ethics. Finally, we will stress the necessity for developing reflective skills in engineering education in order to help engineers face such dilemmas.

Key words: Engineering Practice, Ethics, Globalization, Loyalty, Organizations, Reflective Skills, Responsibility, Values

Introduction

The literature on the engineer's loyalty-responsibility dilemma has been abundant over the last thirty years, as organizations are getting increasingly complex and engineering roles are being redefined. The hierarchical and pyramidal structure of the Taylorian firm is giving way to the virtual networking mode of the global organization. Pierre Veltz (2008) uses the concept of *"modèle cellulaire en réseau"* (the networking cellular model) to characterize this organizational mode based on three phenomena: market-oriented decentralization, the contractual form of inter- and intra-business relations and the pluri-functionality of the network's units. This entails radical changes in the internal role distribution within the enterprise, particularly for the engineer who still represents a central human resource, but whose responsibility is more and more at stake and whose status has lost some of its former prestige. The first part of this chapter is a short presentation of three legal cases in which engineers were involved either as defendants or as plaintiffs in industrial hazards. In the second part, we shall put into perspective the engineer's responsibility with the values they share with the organizations that employ them.

Most surveys show that approximately 90% of engineers are employees either in public or private organizations; they collaborate in project teams with other engineers, technicians, managers, marketeers, therefore they are no longer the sole decision-makers in their organizational context. This shared responsibility, also known as "the problem of many hands", is thus summarized by Mark Bovens (1998, p.46): "As the responsibility for any given instance of conduct is scattered across more people, the discrete responsibility of every individual diminishes proportionately". Besides, owing to down-sizing, new professional opportunities or career re-orientation, the mobility rate of engineers, as indeed in most professions, has substantially increased. As a result, the close link they used to have with their company through their corporate culture, their motivation or their top position, is considerably loosened; hence, loyalty to the organization has become a conflictual issue, even more so when it applies to such a diffuse entity as the virtual networking enterprise. The third part of this chapter will then focus on the emerging tensions between new organizational values and the engineer's work ethic. In the fourth section, in the light of these values and of the initial exemplars, the tightly linked notions of responsibility and loyalty will be discussed. The conclusion will open out onto the necessity of developing reflective skills in engineering education to help future engineers cope with such dilemmas.

Three Legal Cases as Exemplars

The legal cases that are shortly described hereafter have deliberately been chosen as exemplars of industrial accidents or hazards resulting from current engineering practice. We deem them more relevant to this study than the more spectacular – yet somewhat exceptional – cases, e.g. the Challenger explosion in the USA or the Bhopal disaster in India, insofar as they illustrate commonplace situations employers and engineers have to cope with all too frequently.

The first case (Beder, 1998, p.284-5) is about the collapse of a railway embankment in the town of Coledale, New South Wales, Australia, in 1988; as a result, huge masses of mud and water swept down a hill, destroying a house and killing its two occupants. The ensuing enquiry brought the evidence that the area where the embankment had been built was unsteady and that the construction design had not properly taken this geotechnical factor into account. Four people, including two engineers, were charged with endangering people's lives on account of insufficient risk assessment. Even though neither engineer was convicted in the end, Australian engineering representatives, supporting their colleagues, contended that responsibility should not lie with these individual engineers. The chairman of the Australian Institution of Engineers' Standing Committee on Legal Liability, Peter Miller, argued that: "Engineers usually work in teams in which an individual engineer cannot totally exercise his or her judgment. Particularly in large organisations, engineers are part of complex networks of experience, knowledge and interests which all interact." (Beder, 1998). This "problem of many hands", which is often invoked by engineers as a line of defence, has been discussed by a number of authors, e.g. Mark Bovens (1998) who points out that organizations act successfully through the collective conduct of their individual employees, "so every member of the organisation, simply by virtue of his or her membership of that collectivity, is in equal measure liable to be held responsible for the conduct of the organisation." Thus the Coledale accident raises the central issue of who should be held responsible when a failure or an accident occurs: the company which, from a legal point of view, is regarded in most countries as accountable and indeed is generally sentenced to pay for the damages? or the individual engineer or manager who, through negligence, lack of control or competence, has contributed to the disaster? Bovens (1998, p.73) refers to a middle way, when he notes that "... most western democracies, at least in legal and political regard, and for the most part in moral regard too, recognise one or the other form of responsibility of natural persons alongside the responsibility of complex organisations."

The second case will take us one step further into this study. In March 2008, a Criminal Court in the north of France, convicted a power-generator company located near Lille, Alstom Power Boilers (APB), and a former plant manager for exposing their workers to asbestos, the notorious carcinogenic heat-resistant fiber, from 1998 to 2001. Seven people had died from mesothelioma or other forms of cancer over that period, and 30% of the personnel had been contaminated. During the trial, evidence was brought that the amount of fibers released in the course of the manufacturing process had exceeded the legal norms by nearly a hundred times; besides, the manager was accused of breaching the 1996 law on the information and protection of the staff: employees denounced the lack of relevant information, warning boards or training sessions on the risks related to asbestos, and pointed out to the lack of protective equipment. Even if a number of similar cases have been brought to court in the last ten years in France, this is the first ruling in which a firm has been found criminally guilty of endangering its employees' lives. APB had to pay a fine of 75,000 euros on top of the 1.5-million-euro damages they had already contributed for the contaminated workers. The plant manager was sentenced to three months' deferred imprisonment and got a fine of 3,000 euros. This second story backs up Bovens' above-mentioned argument that "corporate responsibility" does not exclude individual accountability. But what is highly noticeable in this instance is that no APB engineer was even charged, at least with negligence, nor was any occupational doctor or factory inspector for that matter. Yet these professionals necessarily *knew* about the risks related to asbestos as well as the working conditions in the factory, as a number of workers reported to the court during the trial. However, according to French legislation, these three categories of people could not be held to account personally for their negligent conduct within the collective they were part of; but for most APB employees it was clear that their moral responsibility was as much engaged as the plant manager's. Besides, in consideration of their professional ethics, the company's engineers could at least have blown the whistle internally as a first step, which they had apparently done, but then, as it yielded no result, they should have gone public about the health risks, which they did not.

Whistleblowing can, of course, entail serious consequences for an engineer and thus deter him/her from giving public warnings about product hazards. The Mangan case (Pae, 2005) is a typical example. Joseph Mangan was chief engineer for a Viennese company which manufactures the computer chips and software used to control the cabin-pressurization of the European Airbus A380, an airliner that can carry up to 800 passengers. In 2004, he warned European aviation authorities against some flaws in a microprocessor which could cause the cabin pressure valves to open accidentally, thus letting air leak out so quickly that all people on board, including the crew, would lose consciousness in a few seconds and the flight would then end up in a terrible crash. The former chief engineer paid a high price for this disclosure: not only was he fired, but his firm filed a civil and criminal suit against him for revealing proprietary documents he was not entitled to divulge. He then decided to sue them in return for unfair dismissal, claiming that his sole preoccupation had been to voice legitimate safety concerns on the reliability of the pressurization system. Unfortunately for Mangan, Austrian laws do not offer whistleblowers much protection from corporate reprisals, as U.S. ones do, and a judge ordered him to stop publicizing the affair. Undeterred, he continued to give details on the deficient system in his own Internet blog, so that he ended up being sentenced to something like a 200,000-euro fine for violating the court's injunction. Eventually, J. Mangan and his family left Austria for the United States, still faced with a legal battle to fight and almost ruined.

This third case highlights the plight of whistleblowers who often face dramatic consequences not only in their career, e.g. dismissal, loss of promotion or harassment, but also in their family life, such as loss of income or social ostracism. It also epitomizes how intertwined individual loyalty and employee responsibility are in such situations: personal responsibility stems from loyalty to one's own conscience, loyalty to one's environment leads to social responsibility, loyalty to the organization depends on professional responsibility, etc. This intricate relationship between loyalty and responsibility is to be viewed in the light of organizational contexts, whereby an engineer's professional values are confronted with his company's corporate values. The loyalty-responsibility issue "depends on the structure, the environment, and the culture of an organisation, along which lines responsibility inside the organisation is regulated" (Bovens, 1998), as well as, according to us, on the engineer's status, motivation and culture.

Professional Values Meet Organizational Values

Engineers have generally adopted business values and integrated them into their engineering activities, since it was thanks to industrialists and their capital that they could earn a good living and, what is more, they were able to make use of their skills to create elaborate works. We shall focus hereafter on four main organizational values which engineers have traditionally incorporated in their practice; then we shall study how these values hold out in the face of the values which have emerged from the new global economy, generating tensions between management and engineers.

Work is obviously the fundamental value engineers have in common with their employers: not only hard work as a virtue advocated by early Protestant leaders like Calvin and Luther, and later by the Puritans, in the service of God and the community to ultimately attain personal fulfilment, but also good work, i.e. efficient and fine, to serve the market and the client-king as well as the pursuit of one's own interests. Good work implies that the products that are marketed are good quality, safe, not too costly, environment-friendly and ... aesthetic. In this respect, work is necessarily related to technological innovation, which is a requirement shared by both engineers and their employers. This is corroborated by the findings of the German sociologist, Eva Senghaas-Knobloch (quoted by C. Didier, 2008) who surveyed engineers on their practice: her study highlights the aspiration of engineers to design "*la belle technologie*" and to carry out technological innovation.

As a corollary of the value of work, *wealth* comes as a natural reward both for the organization and the individual engineer. For the company, it generally means profits that can be re-invested in research, new equipment or new manufacturing plants, etc. all of which contribute to the durability of the enterprise and thus allow the recruitment of new employees, or at least secure employment. In this perspective, profit is considered as a factor of collective welfare and success. As regards the engineer, wealth obtained through hard and good work is a means to strengthen one's social status or even to achieve social mobility, hence the myth of the "self-made man". "Success was defined in terms of doing business well and making lots of money". This quote fom S. Beder (2000, p.43) applies to engineers as well as entrepreneurs, and is best exemplified by people like Henry Ford or Andrew Carnegie. Wealth and success are then another set of traditional values that engineers share with employers, and even though their perspective may be slightly different, they strive to attain the common goal: the prosperity of the enterprise which guarantees secure jobs as well as collective and individual welfare.

As highlighted by S. Beder (2000, p.119), *trust* is an essential value that both organizations and their engineering staff rely on:

> *"Studies of engineers in their workplace have found that trust is an important element in the relationship between engineers and their employers. Engineers are promoted when they have proved their dependability and responsibility, and shown they can be trusted by their employers. In return the engineers receive a considerable amount of freedom to exercise discretion, that is, 'responsible autonomy'."*

This mutual trust is all the easier to foster as engineers and employers share the same work value, and engineers tend to identify their welfare with that of their enterprise. This attitude of identification and loyalty is usually reinforced by the various benefits and facilities offered by the organization, e.g. company cars, pension schemes, recreational facilities. Besides, in the present-day context of networking cellular organizations, the trust value is even more indispensable in the relations between partners within the network or the project team, but often located on distant sites.

The value of *time* is central to F.W. Taylor's theory of scientific management, in that the operational time is simultaneously a technical and an economic measurement unit: reducing production time amounts to cutting costs down (Veltz, 2008). Taylor's analysis of operational times in relation to the motions of human workers and the use of machines resulted, in Veltz' words, in a "homogeneous industrial time standard as a universal technico-economic measurement unit" which was at the heart of the division of labour. This time control was enthusiastically accepted by engineers because they perceived it as a rationalized system to plan production and to time workers' operations on the assembly line. Another facet of the time value is that most higher-level employees, like managers and engineers, are expected, and indeed often willing, to work outside working hours as a sign of commitment to their work and loyalty to the enterprise. These two categories of professionals are under constant pressure to work longer hours, even at weekends, without necessarily getting extra pay.

Tensions between Professional and Organizational Values

In the context of the global networking organization, the four values mentioned above, i.e. work, wealth, trust and time, have been subjected to significant changes while new values have emerged, creating tensions in the enterprise. To start with, work remains a deep-rooted value among employees. S. Beder (2000, p.125) refers to a number of surveys from the 1970s to the present, e.g. one conducted by David Cherrington on the attitudes and values of American workers in the eighties, which show that a vast majority wanted to continue to work even if they had enough money to live comfortably for the rest of their lives. She quotes: "The value of work for the modern worker goes far beyond the pay cheque. It has become in large part the basis for the individual's own sense of place, identity, self-respect and self-worth". This statement equally applies to the engineer, in that is it part of his/her professional ethics to work for the common good, which does not exclude the pursuit of his/her personal interests and welfare.

The value of wealth and success, on the contrary, has been substantially impaired as new management methods have moved away from the rational and standardized modes of Taylor's work organization to more flexible and individualized ones, e.g. lean production, insistence on performances and profit. P. Veltz (2008), alongside a number of authors, points out that today the profit produced by large organizations is in the hands of financiers who have very little to do with corporate activities, yet whose power is so decisive for the future of companies. This oligarchy of shareholders and stockbrokers is not concerned with public welfare, they seek the highest possible profits in the shortest possible time. They influence the decisions of Boards of Directors or speculate in Stock Exchanges, irrespective of the consequences for organizations and their personnel. For instance, Veltz deplores the perverse coupling that is often noticed between a decision of downsizing made by a company and the simultaneous valorization of the stocks and shares of the same enterprise. In the same vein, the "golden parachutes" served to CEOs, particularly when they have led their firms to bankruptcies, run counter to the traditional values of work and wealth, hence to the engineer's ethics. In this new configuration, the "value" of profit for profit's sake creates tensions with the engineer whose sense of values is then de-stabilized, and whose status is devalued: decisions are made irrespective of his/her expert advice, as in the Mangan case described above; moreover, like most employees, engineers are confronted with lay-offs when their enterprise is relocated in low-salary countries, or when technical activities are outsourced to smaller expert businesses. As a consequence, the lack of corporate commitment widens the gap between employers and engineers. "As corporations downsize and demonstrate their lack of loyalty to their employees, some employees feel a declining sense of loyalty in return" (Beder, 2000). Even when the engineer is not personally concerned by the lay-off, he/she is bound to feel threatened as a member of the collective, which deeply alters the trust he/she may have had in the organization.

Another trend that can create tensions between engineers and their organizations is the value assigned by employers to the *client-king*. The consumer's demands in terms of a wider range of products, delivery times, after-sales services, higher quality, increased safety, protection of the environment, etc. has entailed a higher complexity of the operations the engineer is in charge of, both at the design and the production levels. According to P. Veltz (2008, p.109-10), this complexity stems from the conjunction of five phenomena: the extended scale of operations through globalization, the variety of products, production contexts and regulations, the variability of the quantities ordered, the diversity of performance and management criteria, and the tightening of the time constraints. As a result, a higher level of specialization is required in each field, so that firms have to outsource a number of operations to specialized industrial units. But in doing so, they dispossess their engineering staff of their competencies, responsibility and prestige, thus creating frustration and reinforcing their mistrust toward the organization.

The time-value discussed above is also the object of tensions in the organizational sphere, it conflicts with the time constraint. The pressure exerted on employees to work longer hours is a direct consequence of the "just-in-time" system. As discussed above, engineers usually have no objection to work extra hours and are used to flexible working time, which are easily accepted provided there is some compensation. With the deterioration of work conditions, e.g. downsizing, increased complexity of operations, profit-only policy, etc. engineers tend to feel less committed to their organization and privilege extra-professional activities, as they do not identify as closely with it as before.

Linked to the time value, as much as to the work and trust values, is the professional value of *autonomy*, which suits both engineers and employers. Beder (1998, 2000) shows that the former consider it a value as they prefer to be free to do interesting work within regular constraints, but in their own way and at their own pace. As for the latter group, they tend to think that autonomy is "the most efficient mode of deployment of skilled workers", since the responsibility then lies with the engineer to decide how he or she will do the task, how much time will be necessary, etc. Similarly, Bovens (1998) contends that autonomy is an important value for "modern, highly educated employees", in that it enhances their self-respect and self-fulfilment. However, Veltz (2008) underlines the limits of autonomy as a potential source of conflicts: in networking cellular organizations, autonomous project teams tend to draw away from the other teams or departments, thus reducing corporate synergies.

The Engineer's Loyalty and Responsibility

In this section, we will make use of the legal cases and the set of values described above to discuss the concepts of loyalty and responsibility in an organizational context. Accurate definitions of these concepts can be found in a host of books on professional ethics, philosophy of engineering, philosophy of law, sociology of professions, etc. We will use as a working basis the definitions put forward by M. Bovens in his book "The Quest for Responsibility" (1998), and based on H.L.A. Hart's classification (1968): responsibility as cause, as accountability, as capacity, as task and as virtue. In the context of organizations, Bovens considers that, even though these five forms are related to each other and therefore can be relevant, two of them are central: *accountability*, which refers to moral, political or legal liability for the results of an action, and *virtue*, in that it constitutes a value judgment and implies a sense of responsibility on the agent's part. In the first form, which he calls "passive responsibility", the central question is: who bears, or not, the responsibility for the consequences of an event or an accident? This is illustrated by the Coledale case (see above), in which two engineers were called to account after the collapse of an embankment. In the second form, called "active responsibility", the emphasis is on acting responsibly and taking responsibility so as to prevent unwanted events, as in the Mangan case of whistleblowing. It is on this basis that Hans Jonas has formulated his imperative of responsibility: "Act so that the effects of your action are compatible with the permanence of genuine human life." As pointed out by C. Didier (2008), this concept of responsibility towards future generations has been translated nowadays into the political issue of "sustainable development", whereby the satisfaction of today's needs must not hamper those of the next generations.

As far as organizations are concerned, they are autonomous "corporate actors", in Bovens' words, that can be addressed in law alongside human actors. They are generally held to account for the damages they cause to public and private property and to human health: in both the Coledale and Alstom Power Boilers (APB) cases, they had to pay compensation to the victims and were sentenced to a fine for causing the damage, either for transgression of a norm – technical at Coledale, safety at APB (asbestos) – or negligence and lack of control. These legal cases address the concept of *passive responsibility*. However there is a debate among philosophers on whether corporate responsibility should be limited to this legal dimension or should extend to a moral one. Bovens stresses that there is no consensus on this issue: on the one hand, he refers to John Ladd who insists that morality has to be excluded as irrelevant in organizational decision-making, on the other hand he immediately counterbalances this posture using Peter French's concept of "moral personhood", whereby organizations can be considered as "full-fledged members of the moral community". Bovens takes up a middle course: "The organisation as such, as well as certain individuals within it, can simultaneously be held responsible for the actions of the organisation. The responsibility of the one need not exclude or cancel the responsibility of the other (or others), for the actions of complex organisations are always bound up with the actions of individuals." (Bovens, 1998, p.3). The ruling of the French Criminal Court in the asbestos case, pronouncing the company APB "criminally guilty" of endangering its employees' lives, backs up this argument. Besides the simultaneous condemnation of the plant manager points to another form of passive responsibility: the hierarchical model, in which the individuals at the top of the organization, e.g. CEOs, members of the Board of directors, etc., can also be held accountable as they are *the* decision-makers within the company.

As regards the engineer, both passive and active responsibilities apply. In the Coledale case, two engineers were indeed charged with endangering passengers' lives, on account of insufficient risk assessment or lack of control. However neither was convicted. As in the APB case, where no engineer was incriminated for not giving a warning at least to the workers, against the health hazards due to asbestos, the limits of the law as to the individual's passive responsibility are blatant. A former president of the (now defunct) Australian Society for Social Responsibility in Engineering, quoted by Beder (1998), argued that: "if engineers were concerned about being personally liable for accidents and failures, they would be less inclined to follow instructions from clients and employers who were primarily concerned with profits and who might not understand the implications of cost-cutting measures".

Active responsibility, briefly defined above as "acting responsibly" in a given situation, hence having a sense of responsibility, is central to the individual engineer's ethics. Here again, we will use Bovens' five conceptions of individual responsibility (1998) which, he admits, are not so easy to distinguish in practice, and are not exhaustive. However, by establishing condensed and simplified links between the concepts of loyalty and responsibility, he comes out with clear models which are of use in this discussion. These five conceptions are:

- the hierarchical model, which implies strict loyalty to one's own company and one's superiors;
- the personal model, which refers to loyalty to one's conscience and personal ethics;
- the social model, which means loyalty to one's peers and social norms;
- the professional model, which focuses on loyalty to one's profession and to professional ethics;
- the civic model, which lays the emphasis on citizens and civic values.

Hierarchical responsibility is best exemplified in the APB case, where no engineer blew the whistle about the asbestos hazards. One reason, which was also put forward in the Coledale case, is that the division of labour entails a division of responsibility; therefore individual engineers did not feel it was part of their role obligations to voice their concern. Another reason addresses the "trust value" on which the employer/employee relations are based, especially when it concerns higher-level employees such as engineers. Besides, as S. Beder (2000) points out, by being loyal to the company, the individual engineer is also loyal to his own career, since his salary and promotion depend on his hierarchy. But, like Veltz and Bovens, she also notes that this employment contract is increasingly breached as downsizing and relocating develop considerably and employees are used as variables of economic calculation, thus jeopardizing the values of work and welfare. They also stress that the new networking cellular forms of organizations, with their focus on partners' and teams' self-reliance, as well as the recent "job-hopping" trend, contribute to the erosion of this form of responsibility.

Personal responsibility is best illustrated in the Mangan case of whistleblowing, in which the chief engineer gave a public alert on the potential danger of a deficient microprocessor in the pressurization system of Airbus A380. He thus voiced his principled objection to the dubious policy of his company, on conscientious grounds; in this respect, personal loyalty is conflictual with hierarchical responsibility, and can lead to difficult personal and corporate situations, as compromise soon becomes impossible, as was the case here. Therefore, this model of responsibility is a complex issue in an organizational context, as it concerns the engineer's personal integrity: his or her conscientious objection cannot be subject to debate.

Social responsibility applies to loyalty to one's direct environment, i.e. colleagues, subordinates, clients, etc. It has the advantage of allowing a public debate with third parties, although the circle is often limited. This is exactly what was lacking in the APB case: neither the company's engineers nor the factory inspector exercised their loyalty to their peers or subordinates by warning them about the danger of asbestos. Loyalty to the company prevailed in this case. However, this form of loyalty which addresses the values of trust, welfare and good work for team members certainly applies to networking cellular units whose horizontal structures require sharing tasks around a common project as well as reliable communication.

The three cases of this chapter undoubtedly address *professional responsibility*, insofar as the engineer's codes of ethics were neglected (the Coledale disaster), infringed (the APB asbestos risk), or on the contrary fully observed (the Mangan case). This form of responsibility has been increasing with the emergence of networking organizations, where loyalty to the company is on the decline and needs to be compensated for through loyalty to a professional group, hence the expansion of codes of ethics in western countries over the last decades and of the discipline of engineering ethics first in the United States, then in Australia and Europe. Like most authors in this field, Beder (1998) observes that:

"*Most modern engineering codes of ethics state that engineers should hold paramount the health and safety of the public or, in the words of the Australian engineering codes of ethics, engineers 'shall at all times place their responsibility for the welfare, health and safety of the community before their responsibility to sectional or private interests, or to other members'.*"

Thus, loyalty to the profession and professional ethics can be conflictual with loyalty to the organization, as illustrated in the Mangan case. As chief engineer, Joseph Mangan blew the whistle over the faulty microprocessor of Airbus A380, not only on conscientious grounds but also with respect to his professional responsibility, since he was one of the few people qualified to give a public expert warning.

Civic responsibility is tightly interrelated with professional responsibility, in that it also places public interest over private ones. It goes one step further by laying the emphasis on loyalty to democratic institutions and laws, i.e. preservation of the environment, respect of labour laws, etc. Thus, by putting his warning in his Internet blog, J. Mangan transcended his personal and professional loyalties into loyalty to his fellow citizens. As noted by Bovens (1998), it is "explicitly a political conception" and, as such, can be discussed by citizens in public debates. He also remarks that it is far more demanding, as it requires the employee-engineer "to be fully up to the demands of citizenship and to disregard the much more concrete personal, professional, or organizational interests. In practice, there is often the danger of social, of ridicule, and of retaliation". As described above, this applies to the situation of J. Mangan who lost his job, had to leave his home country, was sentenced to pay fines, and was almost ruined.

This brief discussion on these central conceptions of responsibility shows that they constitute forces which have an impact on individual engineers. Hierarchical and social forms of loyalty tend to focus the engineer on his organization, whereas personal, professional and civic forms concentrate on external entities and values. As a consequence, engineers are bound to be subject to corporate or personal conflicts between these five models of loyalty. With the development of networking cellular organizations, the engineer is expected to develop more autonomy and initiative as well as more commitment to the enterprise and to citizenship, hence the importance of preparing him or her to cope with these dilemmas.

Conclusion

The evolution of organizations from large well-structured companies to smaller networking cellular units, has created a new precarious equilibrium, shifting the burden of economic uncertainty from corporations towards the workforce (Veltz, 2008). Within this configuration, the engineer experiences deep changes in his or her relationships with his work, his employers, his peers, his profession, etc. P. Veltz emphasizes the risk of a "radical asymmetry" between what the organization requires from individual employees and what it actually gives them in return. As regards engineers, Christensen and Ernø-Kjølhede (2006) emphasize the necessity for "reflective critique and wider societal aspects of engineering" as central to the education of the "reflective practitioner", who should possess good judgment, self-evaluation skills and a greater autonomy. This argument is supported by Didier (2008) who insists that, in his/her daily practice, the engineer must be able to exercise his/her "critical reflection" and to broaden his/her analytical framework, so as to adopt a responsible conduct. Alongside other authors, she thinks that, due to their position as experts, engineers have higher obligations than other actors of technological development and, as such, have a role to play in ethical debates. To conclude, we support Beder's insistence on the "need to provide young engineers with an understanding of the social context within which they will work, together with skills in critical analysis and ethical judgement, and an ability to assess the long-term consequences of their work." (1998, p.310).

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Chapter 18

Engineering between Professionalisms

Martin Meganck

Abstract: Are all professions conspiracies against laity, like George Bernard Shaw indicated in his *The Doctor's Dilemma* (1911)? Professions are given authority to put their knowledge and skills to the service of the community: knowledge and skills that are supposed to be exclusive to the profession, and necessary for public well-being. Good professional practice must rely on trust, as a way to bridge the asymmetry which results from the difference in knowledge and power. The discussion of whether engineering should be considered as a profession has had a large impact on the development of the engineering ethics discipline. The difficulty of defining what engineering exactly is, makes it difficult to apply to it the indicators of professionalism which function well elsewhere. Finally, a new kind of professionalism seems to emerge in the development of formalised procedures for improving and guaranteeing the quality of professional services. On the one hand, these procedures seem to infringe on professional autonomy, which would be specifically visible in circumstances of uncertainty (and hence: difficult to seize in procedures). On the other hand, keeping up with these procedures requires a level of specialisation comparable with how traditional professions work.

Key words: Professionalism, Codes of Ethics, Engineering Associations, Quality Management Systems

Professionalism as a Theme in the Development of Engineering Ethics

On Professionalism

One of the recurring themes in Anglo-Saxon literature on engineering ethics is the discussion about if, how, and to what extent engineering should be seen as a "profession". Professionalism and ethics seem to be closely linked, either because some kind of ethical profiling (e.g., through a code of ethics) functions as a basis for being accepted as a profession, or (in the opposite sense) because the ethical profile is a consequence of professionalism. For continental European readers, this discussion appears somewhat strange, if not irrelevant. The idea of "profession" for them often means hardly anything more than "what one does to earn one's living". Yet the professionalism discussion has functioned as a kind of catalyst in the development of the discipline of engineering ethics, and should at least therefore be taken into consideration when looking at the contexts of engineering.

The words "profession", "professional", and "professionalism" evoke a spectrum of meanings. Inspired by Kole's analysis (Kole, 2007a), one could distinguish a first "thin" significance in which a profession is just what one does to earn one's living. This does not necessarily have any implications for the quality of the work. Some amateur photographers or gardeners do excellent work; and sometimes you pay for services which, in retrospect, were rather low quality, if not mere bungling.

A second layer of significances adds a normative or qualitative implication. Professional work is work responding to high quality standards. The locus of this quality lies as well in the final product, as in the process leading to that product. In order to deliver such high quality work, an advanced form of specialisation will be needed, based on skills, training and experience. One could expect or even demand such specialisation from people who exert this kind of activity to earn their living (the first meaning of "professional"), but again, it is not excluded that other practitioners acquire this degree of performance. In order to maintain and improve the quality, the actor must endeavor for "professionalization", which may imply further theoretical or practical training, and keeping up with organisational and legal evolutions in which the actor's activity is embedded.

It is the third, stronger meaning of professionalism that is at stake in the professionalism debate surrounding engineering ethics. One then thinks of (according to Kole, 2007a and b; Greenwood, 1957; Kennedy, 2001; Van Liedekerke, 2005; and Didier, 2008):

- Practitioners whose field of activity is seen as being of great importance for the public interest, and they are supposed to exert their skills in a spirit of service to the community.
- Their activity necessitates an extensive, systematic training.
- Their knowledge and skills are exclusive. People not belonging to the profession are supposed to be incapable of assessing a situation belonging to the field of the profession. This asymmetry of information, judgment and possibilities to act, confers on them a professional authority and autonomy.
- The professionals belong to an organised group which is officially or factually recognised as the corps of exclusive or privileged experts in the field.

- This group establishes norms of quality and/or behaviour (e.g., through a code of ethical conduct), and exerts control over the members' compliance to them.
- A series of other group-specific elements of a "professional culture": titles, forms of address, rituals, distinctive signs (logo's, specific instruments, garments, etc.), jargon, and narratives by which professionals recognise each other and can be recognised by outsiders.

Corollaries of these elements may be the ideal that the professionals' services are not subject to mere economic criteria (e.g., through the practice of a honorarium which is not based on market mechanisms like the price of commercially delivered goods; limitations on publicity), and the idea of universality: the services should be delivered to anyone needing them (regardless of the identity, qualifications or other qualities of the persons asking for the service).

Experience shows that attempts to use this (or similar) sets of elements as "criteria of professionalism" are not very fruitful, and lead more to controversy than to decisive agreement. They can however be used as indicators, signals, and symptoms, leading to a more/less judgment rather than to a binary yes/no judgment.

On Professionalism and Engineering

Traditionally, medical doctors and lawyers are seen as typical exemplars of real professions (in this third, stronger sense). For engineering, the situation is not so clear. Some of the indicators of professionalism are certainly recognisable in the training, practice and organisation of engineering; the applicability of others may vary according to local or historical circumstances or depending on the actual working conditions of the holder of an engineering degree.

The title of engineer is usually conferred after a *training* of at least four or five years in specific universities or faculties of other institutions of higher education. Most of the educators are themselves engineers. In the initial years of training, courses of fundamental sciences taught by, for example, mathematicians or chemists (non-engineers) may constitute an important part of the curriculum, but in the final years, the majority of the courses tend to be taught by engineers who, at that stage, assess whether the student meets the competences required for a beginning engineer. For this indicator, the applicability to engineering poses no major problems.

The *exclusivity of the knowledge and competences* of engineers is more difficult to establish. The exercise of some specific functions may be de facto or de jure reserved to engineers: design or production tasks, serving as expert witnesses in court, etc. Engineers eligible for these tasks or functions may have to be members of specific organisations. For these kinds of functions and organisations, the indicators of professionalism are almost fully applicable, including professional autonomy and the presence of a specific code of ethics.

There is, however, a wide variation in actual functions and circumstances in which people with an engineering degree work. They find employment in education and research, in production and in commercial functions, in design and waste treatment, in banks and municipalities, and so on. Many of them will have mathematicians, chemists, or economists as their immediate colleagues, doing essentially the same jobs. And their number is far too high to consider them as being atypical, as if they had gone astray from real engineering work. On the contrary, engineering education often deliberately aims to be multidisciplinary, preparing students for a multitude of possible employment opportunities. For them, little remains of the alleged exclusivity of knowledge and skills; at the best, they can exhibit a peculiar mastery of a combination of skills. It is then this multidisciplinarity which may be called "typical for engineers", not the mastery of the individual skills at such. Given that a majority of engineers are employed by either private companies or public authorities, and that in many situations they will have to make decisions in concert or in negotiation with others (be it colleagues, clients, or other stakeholders which may in their turn be represented by engineers), the idea of professional authority (with the resulting asymmetry of power) that is at the background of most theories of professionalism, vanishes rapidly.

These considerations of the difficult demarcation (on a descriptive level) of what would be the typical engineer's activities, may be linked to the difficulties one often has in defining engineering on a conceptual level. Mitcham (2008), elaborating on an analysis by Michael Davis, remarks that in definitions of "engineers" or "engineering" the definiens often includes some form of the definiendum (e.g., when one says that engineers can be recognised by the fact that they are holders of an engineering degree, or that they are members of engineering societies, or that they are employed in functions which include engineering work, or variants or combinations thereof). These definitions therefore often remain either vague or inadequate, up to the point that it may be better not to try to formulate a precise definition, and just fall back upon circumscriptions like "... a set of living practitioners who – by discipline, occupation, and profession – undoubtedly are engineers, constitutes the profession" (Davis, as quoted by Mitcham (2008)).

Mitcham is further struck by another peculiarity in attempts to define engineering (compared to the traditionally recognised professions like law and medicine). The public service goal of medicine lies in human health, the public service goal of law lies in justice, and one may expect doctors and lawyers to have a sound conception and to be good assessors of what health (or justice) mean. In fact, the understanding of health and justice are part of the training and inculturation programme of young doctors and lawyers. The public service goal of engineering, however, is more difficult to grasp in a definition. Some definitions mention "the use and convenience of man"; recent codes of ethics aim at protecting or promoting “safety, health and welfare” (or well-being). But should engineers therefore be considered as the experts in judging what safety, health and well-being are, and how they can best be protected or realised? Even if there may at some moments be discussions in society about how health and justice should be conceived and pursued, the relationship between engineering and safety, health and welfare will be far more often and more fundamentally questioned than the medicine/health and the law/justice relationships. More than health (in a medical sense) and justice (in a legal sense), the safety and well-being which should be the aim of engineering work, is subject to on-going social construction, in which members of society (as customers, as citizens) co-determine the evolution and outcome.

The status and function of *engineering associations* may be very different depending on local situations and historical traditions. In many cases, membership of a professional association is not obligatory for engineers to use the title of engineer or to do engineering work. Engineering associations may then provide initiatives for continuous education, development of technical standards in industry, activities for networking and socialising for their members, legal and career advice, lobbying…. In other cases, the right to use specific engineering titles or admission to certain functions may be subject to registration at an authoritative body of “chartered engineers”, “licensed engineers”, “professional engineers” or the like. Admission to these groups may require, after obtaining an undergraduate or graduate degree, a certain number of years of peer reviewed professional experience, and succeeding in additional interviews or exams. Efforts are being made to harmonise accreditation requirements for engineering (e.g., through the Washington Accord for some Asian and Anglo-Saxon countries or regions, and the EUR ING title conferred by FEANI in Europe), but they have to confront a “variety of local standards, [...] a divergence in educational models for engineers and conceptual differences in the terminology” (Luegenbiehl, 2004, p.58).

The discussion about the status and function of the engineering associations in different situations has drawn so much attention also because it is these engineering associations (often in the context of their striving for a professional status) who develop or adopt *codes of ethics*. And these codes of ethics are (together with the insertion of ethics courses in academic curricula) the most clearly identifiable locus of development of the engineering ethics discipline. The disciplinary power of codes of ethics will largely depend on either the reputation or on the regulatory status of the association. In cases where membership of the association is an asset or a necessity for engineers to exert their functions, abiding with the rules or norms of the code may be de facto compulsory; deviation from the rules may become less serious to the extent that the legal or moral authority of the organisation decreases. A lot of literature exists on the reasons and backgrounds, sense and criticisms around codes of ethics (e.g. Johnson, 1992, pp.93-154; Meganck, 2003; Kaptein, 2008). This theme is not further developed here.

On Autonomy, Power and Trust

Kennedy (2001, p.3) suggests that the discussion of professionalism should not be concentrated on the nature of professions, but on what it means to be a professional. Professionals are, according to him, characterised by "the ability to exercise sound and reasonable judgment about important matters in conditions of uncertainty". In order to do this, they need specialised knowledge, must commit themselves to service to the community, and be allowed autonomy in decision making. Philosophically, the general ideal of autonomy of individuals in modernity could be a first basis for the autonomy of professionals, but more than that, the special skills and knowledge, the competences and capacities of the professionals is invoked as a basis. This is confronted with the (supposed? alleged?) ignorance or incompetence of outsiders, be it the client who would not be capable of identifying his own problem, or other parties who would have to make judgments about the performance of a professional.

The asymmetry in the relation between the professional and her client may be inevitable, yet it is not without problems. It may be due to unequal knowledge at the beginning of the transaction, or to the practical impossibility to control the other, or to unequal access to information (Van Liedekerke, 2005). Even if the professional provides full and correct information, the client is mostly incapable of evaluating the correctness, and of judging whether the rendered services sufficiently meet her needs. Therefore, a moment of surrender, or trust or faith, will be necessary from the client's side – if not a mere gamble. The need for trust will increase to the extent that the informational gap increases, or the stakes of the transaction become more important. It may furthermore make a difference whether it is a repeated transaction, or a once-only event (the latter requiring a more pronounced leap of trust). Trust will be more easily given when the general context supports it ("trust by default"); conversely, cultural tendencies or specific events may make the "default setting" switch towards distrust (like in the aftermath of scandals or crises). The same may happen when one has the impression that either an individual professional or the profession as a group or organisation makes abuse of the informational asymmetry, or does not succeed in communicating transparently about the reasons behind certain choices and circumstances. A particular case of the latter may occur when the public perceives professional organisations as trade unions defending the interests of their members, rather than as guardians of the public interest. A switch from trust towards distrust may lead to a reinterpretation of previous events, reintegrating them into a total vision of a series of situations (Van Liedekerke, 2005, p.31-32). But can one really speak of trust when one of the parties is completely dependent on the other, and has little or no other choice but to surrender?

An other element of asymmetry may lie in the different conceptions about what the "good" the client pursues should actually mean. The standards and expectations of the professional may well be different from what a lay person may expect or be used to. In some cases, the professional will not be able to deliver the services the client expects – maybe due to unrealistic expectations of the client. But sometimes the professional will deliver a level of quality which is well above the client's demand or expectations, to the extent that the client may feel uneasy about it, or be reluctant to pay for services the scope of which he could not foresee. In the best case, this may be due to the pride of the professional wanting to deliver services of "professional" quality, or to a form of well-intended paternalism. In the background, there may be the effect of the value-ladenness of the scientific paradigm in which the professional was trained, which may lead him/her to find self-evident the internal norms and standards of the profession without confronting them with public perception. In the case of engineering, these "mismatches" between the engineer's and the client's (or other stakeholders') expectations may typically concern the acceptability of risks, the number of options and possibilities which may be incorporated in a device, or the redaction of instruction manuals. On a broader scale, it may concern the general optimism of engineers about the calling and the possibility of technology to serve the public interest. One may here again refer to Mitcham's question about whether engineers are good assessors of what the public interest may be (see above).

Real abuse of the professional's autonomy and authority should be prevented by the code of ethics of the profession, if there is such a code. Another way of protecting the clients is to implement an informed-consent-like procedure. The idea is then that partners in a transaction be (1) adequately informed, (2) competent enough to take responsibility, (3) fully free, and (4) give explicit permission for the action. In the opposite sense, some ethical warning signal starts blinking when it seems that one of the parties has taken profit of the (1) ignorance, (2) incompetencies, (3) lack of freedom or (4) absence of explicit approval or disapproval of the other party. This procedure is well-documented and has a long tradition in medical ethics. Martin and Schinzinger (1989) suggest that – as engineering has many similarities with experiments and treatments in medicine – some form of informed consent can also be used to prepare an ethical judgment of engineering work. This procedure highlights the risk of abuse of the informational asymmetry and the differences in competence and freedom, but it does not solve the problem. It may, however, impose an obligation on the professional to be aware of the asymmetry and to bridge the informational gap as far as that is possible. Yet the problem remains that, if a highly complex matter is at stake for the understanding of which an advanced and systematic body of knowledge is necessary, like as may be expected from professionals, the informational gap and the ensuing disparity of power may never be fully bridged. Finally, the informed consent concept – whereas originally meant to protect the weaker party in a transaction – may also be used to share responsibilities, or even to shift responsibility to the originally weaker party, especially when legal liabilities may be high.

Ruling Uncertainty?

The second meaning of "professionalism", described in the beginning of this chapter, imposes on professionals the obligation to deliver services of the highest quality. In order to maintain and improve their level of performance, the practitioner will have to work on her professionalisation. One of the instruments to improve and to recognise professional work can be the development and use of procedures and standards for frequently occurring situations (Kole, 2007a, p.24). These procedures function as a way of transmitting forms of knowledge and skills within the profession. They allow faster recognition and handling of the problem. They facilitate communication between professionals, and may be used for measurement and evaluation of the professional's performance. They should increase the client's trust in the profession and the professional (Mackor, 2005). Yet Mackor warns of a possibly paradoxical effect of procedure development in professions, when these procedures are imposed or accepted as the only way of behaving and deciding professionally. The practitioners may then lose the liberty to follow their own experience-based heuristics, and to decide according to their interpretation of a situation. Procedures meant to improve the "professional quality" of work, could then result in an infringement on the autonomy of professionals, which is mostly seen as one of the key characteristics of professionalism (Kole, 2007a).

The problem with this situation is manifold. A first problem may lay in the difficulty in catching the correct way of recognising a situation and handling a problem (cfr. the difficulties in establishing heuristics in artificial intelligence, when one tries to extract the expert's expertise to integrate it into devices for decision making (or at least: for assistance in decision making). There may be blind spots in the acceptance of the basic elements constituting the problem and its landscape, and some intuitive interpretations and reactions may be difficult to formalise. In Kennedy's conception of professionals, their tasks principally involve "conditions of uncertainty", and also other analysts find it typical for professionals that their work needs some kind of creativity, or that it is difficult to catch in formalisms (Kennedy, 2001; Van Liedekerke, 2005). From this approach, there seems to be an inherent tension between the ideal of professional autonomy and the attempts to improve quality by proceduralisation.

Moreover, especially in contexts where legal liabilities may interfere, rules and protocols may function as legalistic minima. Meeting the standards or following the rules may then become an end in itself, instead of being a means aimed at solving the problem in the best possible way. Or they may impose on the practitioner an amount of supplementary actions surrounding the proper actions of solving the problem itself, like registration and reporting at different moments of the process, or precautionary measures. Many of these measures are meant to anticipate possible accidents, other interfering situations, or post factum discussions. Yet many practitioners do not feel the sense or the necessity of these procedures, perhaps because the issue at stake is rather small, or because the probability that the events for which these measures are meant really occur is expected to be extremely low. This feeling often occurs when using highly formalised quality management systems, if the means/ends relationship is perceived as being disproportionate. And sometimes an awkward style of formalisation, even if meant to promote transparency and trust, may be interpreted as a symptom of systematic distrust – which is, of course, the contrary of what a professional-client-relationship should be based on.

A last observation is that this proceduralisation, although it is sometimes at odds with the ideal of professional autonomy, may in turn become an element of professionalism in itself. Professionals are supposed to be acquainted with the rules and habits surrounding their activity; they are supposed to master the jargon, the formal and informal communication systems functioning inside the profession, and also ad extra with, for example, regulatory authorities. Having to keep up with regulation and administration may be too complicated an effort for amateurs to continue an activity for which this formalisation is required. In this sense, this may become de facto an alternative threshold for outsiders and newcomers to start or continue an activity, even for activities the admission to which is not (like in the traditional views on professions) governed by either extensive systematic training or membership of specific organisations. This may be a good thing if it succeeds in preventing clients from being victims of charlatans; here the similarity with the assigned role of organised professions is striking. But it also inherits of the possible criticisms against professions, in that it may lead to protectionism and corporatism. Finally, many forms of certification, accreditation and licensing function on the basis of such formalised schemes to examine whether a candidate complies with the requirements. And these certifying organisms on their turn must also obey such systems. But "quis custodiet ipsos custodes"?[1]

Conclusion

Many engineers will see no relevance in the discussion of whether engineering is or is not a profession, especially in situations where engineering organisations have hardly any official authority. Yet they often behave like professionals, in their pride of deliv-

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[1] "Who will guard the guardians?" (Juvenal, Satire VI, 347-348)

ering top quality work, and in the mutual recognition of engineers and their work. But even in cases where the formal rules of professionalism would not apply to engineers, a new type of professionalism appears in the form of highly formalised quality management systems, having essentially similar effects as organised professions often have. Is this a new professionalism in disguise?

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Chapter 19

Stabilizing Self-Identities in Engineering

Anders Buch

Abstract: Increasingly, engineering work – and other types of knowledge work – is performed in ambiguous contexts. Although key performance indicators are used to set standards for excellence in engineering work, the character of knowledge work is still flexible and open to interpretation. Engineers constantly have to make sense of their work in order to reproduce their social identities. Organizational contexts – as well as engineering work itself – have become still more ambiguous – always in need of justification. Thus engineers are being held accountable for their actions and their roles as professionals. This puts a lot of pressure and strain on their (professional) identities. In reaction to the strain the engineers are constantly engaged in a process of finding viable subject positions that can help stabilize their self-identities. The subject positions are negotiated in an ongoing dialogue in the workplace and in relation to other significant contexts. Discursive resources and story lines are mobilized in order to make sense of the category "engineer" as a defining characteristic of identities. Empirical findings from an ongoing research project on work-related stress among knowledge workers reveal three frameworks of sense-making among engineers: 1) The archaic professional framework, 2) The framework of bureaucracy, and 3) The framework of reification. The chapter discusses these frameworks of sense-making within engineering work and shows that the frameworks themselves in fact are ambiguous. The frameworks do – *prima facie* – stabilize the professional identities, but they are in fact also a potential source of work-related stress when professionals are faced with demands for flexibility and the frameworks collide.

Key words: Identity, Work-Related Stress, Engineering Profession, Institutions

Introduction

Increasingly, it is reported that engineers and other well-educated knowledge workers suffer from serious work-related stress. Surveys conducted by professional societies, e.g. The Danish Society of Engineers, show that work-related stress has become a serious problem for many engineers. The engineers claim that they are affected by heavy workloads and an increasing pace in work that result in classical symptoms of stress. On the other hand, engineers often regard their work as privileged and stimulating. Due to the nature of their work, engineers often have a high degree of influence on how their work is performed and structured. "Self management" is a predominant form of management when it comes to intellectual, creative, open-ended and complex work. Generally, the engineers have the expertise, skills and (tacit) knowledge that are crucial for success. In addition they are dedicated to – and often very enthusiastic about – their work. Given this background, it is often left to the engineers themselves to determine their methods of work and to plan their work. Engineers will come out with a high score when it comes to influence and job control and should therefore – according to leading theories of work-related stress (e.g. Karasek & Theorell, 1990) – not be stressed due to working conditions. On the contrary, knowledge work is typically characterized by high decision latitude and classified as an active job. This apparent paradox suggests that we are in need of a new and more reflective perspective on job-related stress in order to understand the phenomenon. The limitations of traditional stress conceptions when it comes to understanding knowledge work have been argued elsewhere (e.g. Grönlund (2007), Sørensen *et al.* (2007), Buch & Andersen (2007)). In this chapter, however, I will give an outline of a contextual framework of analysis that attempts to understand stress among knowledge workers in terms of a delicate balance between strain and enthusiasm. The discussion will be informed by empirical data derived from case studies of six Danish knowledge intensive firms – two of which are engineering consultancy firms. I will conclude this chapter by presenting three strategies of sense-making that engineers mobilize in order to alleviate stressful conditions in their work.

The Ambiguity of Knowledge Work

"You don't always have the feeling that your job is straight to the point. Actually, you can have your doubts: Say, did I get it right this time? If you're working on something that's part of somebody's assignment. You've been given some vague constraints for the solution of the task and you get back with your output. And you don't get any response on your work. You get kind of troubled. That's how I feel and I think: Gee – did I get the perspective on the problem right? For example when I do risk assessments. Such things can be done within 1½ page. [But] it can easily stretch over 7 pages depending on how thoroughly you deal with the assignment. In situations like this I feel I'm in need of feedback – that's what I think." (From an interview with Nina – an experienced engineer working in an engineering consultancy firm.)

Nina's remarks remind us that engineering work and performance are susceptible to interpretations. Although much engineering work is regulated by the laws of nature, rigorously audited quality standards and strict company procedures, there is still considerable room for personal judgment. This interpretative flexibility and open-endedness have been argued strongly by theoretical and empirical studies in science and technology. Bucciarelli and Kuhn (1997, p.213) make the point in relation to engineering design when they write:

> *"It is not difficult to lay out performance specifications at the beginning of the design process; indeed, it is standard practice. What is difficult – probably impossible – is retaining those specifications without an ongoing process of modification, clarification, negotiation and joint meaning-making. Specifications that seem clear at the outset are stretched and challenged by the design process itself; ambiguities, incompletenesses, and contradictions are uncovered as part of the process of discovery that is design."*

Thus, contrary to common-sense perceptions, there are no clear and predetermined standards for what makes engineering work – and other kinds of complex knowledge work – successful. The very successfulness (or unsuccessfulness) of the work is established in a complex work context where various goals, interests and perspectives are mediated, altered, mangled and negotiated. The work context is heterogeneously populated by various actors (the customer, the manager, the colleagues, etc.) and actants (quality systems, technical equipment, etc.) that give "voice" to (conflicting) interpretations of what constitutes successful engineering work. Although local routines, standards and conventions guide the day-to-day work and make "going on" possible, these routines can be interrupted and questioned. The increasing complexity of knowledge work makes it likely that the work routines are in fact frequently interrupted. Restructurings, organizational changes, new managerial philosophies and techniques count among the more spectacular interruptions of everyday work routines, but local work routines can also be questioned by colleagues from other departments in the company, colleagues with other professional backgrounds, etc. All in all, engineering work and other kinds of knowledge work are inherently ambiguous. The work is characterized by a high level of ambiguity in input, process, and output. Although traditional engineering knowledge about "how things work" (the physics and instrumental process) might seem to be fairly stable, the work context of engineering is in fact highly unstable, ambiguous and subject to interpretation.

Identity and Stress

These characteristics of engineering work seem to have implications for the way engineers make sense of their work and their own identities. In a general theory of the psychological make-up of individuals, Giddens (1991) describes how identity work has developed as a social, reflexive and subjective project in late modernity. Giddens uses the term "self-identity" to describe the individual's ongoing reflective attempts to make sense and coherence of its experiences and to stabilize the self. Normally the self is stabilized through unproblematic routine actions of the practical consciousness. These routine actions are fundamental for our ability to carry out ordinary social interactions and tasks and they provide a basic cognitive and emotional platform for the development of the self – the ontological security of our existence. However: "On the other side of what might appear to be quite trivial aspects of day-to-day actions and discourse, chaos lurks. And this chaos is not just disorganisation, but the loss of a sense of the very reality of things and of other persons." (Giddens, 1991, p.36).

In other words, the individual must continuously engage in a sense-making endeavour in order to secure the ontological security of the identity. The continuous reproduction of the self-identity is needed in order not to lose sense of reality and face existential anxiety. The reflective construction of self-identity is based on social and cultural resources: language, symbols, meanings, values, etc. These elements are the fundamental bricks of identity work and with these elements the individual constructs and stabilizes the identity. The identity work of knowledge workers is interwoven with their professional training and career background. With an academic training and a professional career in engineering the individual typically identifies with the profession's values and adopts a certain way of seeing and approaching the world. This professional outlook typically will constitute the basis of the individual's appraisal of the work and lay out a horizon of expectations in relation to fulfilment, self-realization, job satisfaction, etc. In this way, the construction of self-identity becomes the yardstick for the individual's sense-making and, *a fortiori,* for the individual's sense of strain or enthusiasm in relation to work. Work-related stress is developed as strains accumulate over a longer period of time. This might of course be due to heavy workloads and other stressors defined by traditional theories of work-related stress. But in the case of many knowledge workers it can also be caused by work-related conflicts, unfulfilled ambitions, professional intimidations, etc. – strains that put pressure on the professional self-identity and threaten the individual's ontological security. For knowledge workers, work will become stressful when their expectations and professional aspirations are not met. When the self-identity adopts a professional codex or ethos it will be stressful to experience conflicts that intimidate or sidestep the values of the profession. It will be difficult for the professional identity to make sense of these violations. They will be perceived not only as unreasonable actions but also as a personal assault, degrading or senseless.

Strain and Enthusiasm in Engineering Work

The ambiguity involved in engineering work – and knowledge work in general – becomes a potential strain on the identity construction of the employees engaged in knowledge work *and* a potential source of enthusiasm and self-fulfilment. Due to the incessant discussion and negotiation of their performances and roles, the engineers are constantly faced with doubts and insecurities about the relevance, use and meaning of their work, yet, these negotiations also hold the prospect of receiving acknowledgement of their importance in developing and executing special assignments. The engineers constantly have to reflect on their contribution to and their entitlement in the organisations, in society in general and not least in relation to personal expectations to career development and work life. The nature of their work requires them continuously (and often openly) to define and substantiate themselves. This makes their work a field of intense and ongoing identity construction and development. When the challenges of the job are successfully overcome, feelings of enthusiasm are evoked, but when they are not, the result may lead to anxiety and doubt. Due to the ambiguous character of knowledge work the identity development and construction of the engineers are under pressure.

In a series of qualitative focus group interviews with knowledge workers and their managers in six Danish knowledge intensive firms, efforts have been made to map the "enthusing" and "straining" factors. Some of the findings derived from interviews in two engineering consultancy firms will be mentioned here[1]. One theme in the interviews deals with professionalism:

- The interviews point to the importance of professional development as a prerequisite for the feeling of enthusiasm. The engineers stress that they thrive on opportunities to struggle with challenging assignments that give room for contemplation of technical problems. One of the engineers sees technical contemplation as the "fuel" that keeps him going on and another one expresses his wish for room to do "nerdish" work. It is obvious that the term "nerd" has a very positive meaning among some engineers and is closely associated with the engineering ethos.

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[1] I want to thank my colleagues at The Technical University of Denmark, Vibeke Andersen and Mette Mogensen, and Ole H. Sørensen from The National Research Centre for the Working Environment, for contributing to produce the empirical material and analyses discussed in this chapter.

- It is also very important for the engineers to be recognized as accomplished and competent professionals by their colleagues, superiors, customers and fellow professionals.
- The engineers do not see their professionalism as something that is given once and for all. On the contrary, professionalism is a thing that needs to be established and proven on a regularly basis. The striving towards personal fulfilment and development is tightly interwoven with a striving towards overcoming and solving technically challenging problems.

Another theme in the interviews addresses the need to produce "results" or manifest products:

- The engineers consider it very important that their work actually adds value to someone or that the work actually results in the fabrication of a concrete (and tangible) product. One engineer tells a story about how proud he was to point to a bridge when driving on the freeway with his son and say: "Dad built that bridge". Others make the point in other words: "I want my work to make a difference [to my fellow citizens]".
- The ambition to make a difference is closely related to the engineers' feeling of pride in their jobs and the products they produce. It is mandatory that the engineers can answer for their products and that the quality of their deliverances is impeccable. If the engineers are forced to deliver a service or a product half-done they feel bad about the situation and feel that their professionalism is being compromised.

This last point about the quality of the products of their work is further developed in discussions about the fragmentation of their workdays.

- Working on several different assignments during a workday is very stressful for the engineers. They feel that their working hours get fragmented when they have to attend to a lot of different assignments during the day. They feel the lack of continuity very unsatisfying because it deprives the engineers of contemplating the technical problems of their work – which can eventually result in unacceptable quality standards.
- Even though the problems are solved on an acceptable basis according to the company's quality standards, the engineers often feel that the fragmented workday does not leave room to solve the problems in ways that are acceptable to their own professional standards of quality. In effect, the engineers work longer hours in order to raise the quality level of the products – even though the budgets do

not give room for this. Typically, the engineers take the extra time to deliver high quality and omit to invoice the extra time spent.

Finally, the engineers are very concerned with questions about management and feedback.

- The engineers appreciate autonomy in their work. Self-management is the dominant form of management when it comes to giving shape and structure to the assignments and the working days. Allowing the engineers professional judgements and individual preferences to structure work is seen as the most effective and satisfying way to get the job done – both managers and employees agree on this point. However, the engineers often feel that the autonomy comes at a price. They often feel that they are left in a vacuum where they have to make decisions and perform without any clear guidelines. Nina's remarks – quoted earlier – exemplify this point. The engineers cry out for feedback – from colleagues, managers, customers, etc. The ambiguity of the engineers' work calls for feedback to let the engineers know they are on the right track.

In summary, the enthusing factors identified in the interviews in all of the six Danish knowledge intensive firms concern:

- professionalism
- development prospects – professionally and personally
- delivering the results (achieving results)
- identification, pride and meaning
- autonomy
- recognition and feedback
- social support from colleagues
- clear framework and "good management"

The themes regarding elements in the work that produce strain decidedly mirror those listed as leading to enthusiasm. Thus, they address the following issues:

- too much work
- too diversified tasks
- interruptions
- not delivering results
- ambiguous demands, vague framework – "bad management"
- unpredictability/insecurity
- rivalry between colleagues

Besides being interesting per se, to find out what precisely the engineers perceive as respectively enthusing and straining factors, what is really striking in the findings are the complexities and ambivalences in engineering work. It appears that factors that enthuse the engineers – professionalism, developing products of high quality, autonomy, etc. – are the very same that cause strain in the work of the engineers. This entails that the very elements that feed the employees' sense of enthusiasm in their work and provide them with fuel to go on, are the same that in the end tip them over the edge and become a strain. When the professional ambitions and values are compromised, their enthusiasm translates into strains and frustrations. It is another interesting point that many of the factors that lead to enthusiasm and strain in the engineers' jobs are produced in the clash between the engineers' subjective ambitions and professional aspirations on the one hand, and the objective reality of the organization on the other hand.

Stabilizing Frameworks in Engineering Work

Looking at the empirical results from the interviews in the six Danish knowledge intensive firms, it appears that there are various coping strategies that the knowledge workers and engineers can choose to apply in order to address the pressures on their identities brought on by the ambiguous character of knowledge work. Various resources and frameworks of sense-making are available for the engineers in their efforts to cope with conflicting demands, extreme complexity and heterogeneity. These frameworks deliver cultural resources, stories, metaphors, discursive material, etc. that can be applied in order for the individuals to establish their subject positions within the dynamic field of the work place and substantiate their self-identity. W. Richard Scott, one of the founders of neo-institutional theory, argues that: "…the insight that professional authority is based on the ability to create and apply a set of cultural-cognitive, normative and/or regulatory elements that provide frameworks for dealing with various types of uncertainty is at the core of the institutional perspective. […] In our own time, the professions are the primary societal institutional agents." (Scott, 2008a, p.227).

In accordance with this institutional perspective, professions can be seen as regimes of competence that give authority and legitimacy to activities, relations and resources. Scott identifies the elements of institutional hegemony in the rules, norms and beliefs of the professionals. Institutions – and professional hegemony – are comprised of three pillars (Scott 2008a; Scott 2008b, chap.3):

- the regulatory pillar, which stresses rule-setting, monitoring and sanctioning activities, both formal and informal;

- the normative pillar, which introduces a prescriptive, evaluative, and obligatory dimension into social life, stressing "appropriate" behaviour – given the demands of the situation and the actor's role within it – vs. "instrumental" behaviour, in which attention is focused on the actor's preference and pursuit of self-interest; and
- the cultural-cognitive pillar, which emphasizes the centrality of symbolic systems: the use of common schemas, frames and other shared symbolic representations that guide behaviour.

Thus the three institutional pillars enhance and restrict behaviour by enforcing professional standards of compliance. Scott's neo-institutional perspective provides a framework to identify sense-making strategies among engineers.[2]

The Archaic Professional Framework

One strategy is to identify with the engineering profession or the engineering ethos (and/or one's academic education). This strategy draws heavily on the cultural-cognitive pillar of the professional institution of engineering. Bucciarelli (1994) and Bucciarelli & Kuhn (1997) have described the cosmology of the engineering profession in terms of work within object worlds. An object world is a domain of thoughts, actions and values that guides the engineers in their work and way of seeing the world – close to Wittgenstein's concept of a form of life. Work within the framework of object worlds stresses precision, closure, stability, rigidity, unambiguousness, consistency, truth, determinism, rationality, mechanic models, reductionism, duality of abstraction/concreteness, conservation, hierarchy, value freedom, results, individual achievement, etc. – ideals borrowed from science and reproduced in basic engineering education. Bucciarelli and others have effectively shown that, although these schemas, ideas and standards are held in high esteem by the engineers themselves, they do not reflect engineering work as performed in real life. Engineering is immersed in social processes that do not live up to ideals of the object world. Ambiguity and social interests are part and parcel of engineering practice. This is why I call the framework archaic: it reflects a vision of engineering inherited from old ideals about the engineering profession that is in fact at odds with present-day engineering practice.

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[2] I realize that the term "strategy" can give rise to some individualistic and voluntaristic connotations. These connotations are, however, not intended. I see the three identified frameworks of sense-making as resources for the professional. It is not the case that the professional arbitrarily chooses from them. On the contrary, the individual will mobilize the resources in accordance with his or her position within the social setting. (Harré & Slocum, 2003)

The archaic professional framework can give comfort and stability in the turbulent world of ambiguities. Belonging to a profession provides an opportunity to enter a frame of reference where it is possible to understand oneself and one's work in terms of a number of conceptual schemas, codes and concepts of values. Life within the object world guards against ambivalence and anxiety. In this way the profession – understood broadly as a particular set of "mindset", internalized for instance through long university educations – can act as a critical reference point to the engineers, making it possible to keep informed and find one's bearings in the complexity of their work; especially when the identity is under pressure.

At the same time, however, it is clear that especially this strategy, emphasizing the cultural and cognitive standards of the engineering profession, may fall short when it encounters the aims and frameworks of the work which exist in the organization. The archaic "mindset" of the engineering culture can turn out to be an absolute impediment. Far from dealing with the ambiguities involved in engineering work, clinging to the archaic professional framework is close to a state of denial: the troublesome complexity of the work is shunned away and seen, instead, in terms of the object world. This state of denial is of course counterproductive in the long term.

The Framework of Bureaucracy

This strategy did not prevail in our interviews with the knowledge workers, but it has been reported elsewhere (Kärremann *et al.*, 2002). We did, however, learn that the engineers express a need for clearer frameworks, more structure and more guidelines in their work. Hence, an alternative or supplementary strategy for the professional could be to seek stability and continuity in work by adopting routines, established procedures, standards and other bureaucratic regulations (Scott's regulatory intuitional pillar). Due to the technical development which makes standardization of more and more areas of work possible by integrating them in various IT-based systems, engineering work and other types of knowledge work in the recent years have become increasingly more bureaucratic (Broadbent *et al.*, 1997; Andersen & Nielsen, 2008). The bureaucratization of engineering work can be interpreted both as a strain (conflict with the engineer's demand for autonomy and professional integrity) and as a potential relief when it comes to the pressures on identity construction. Kärremann *et al.* (op.cit.) report that bureaucratic standards can in fact provide symbolic value and shared meanings in professional settings that help to establish codes that allow organizational members (from diverse professions and backgrounds) to communicate with each other about their respective tasks. They argue that bureaucracy provides a sense of closure, control, and predictability in organizations and work relations, and thus makes them more manageable. "Selective" bureaucratization of engineering work (i.e. bureaucratization that only indirectly and marginally affects core work, while administrative and planning matters are tightened up to a stronger degree) may contribute significantly to minimize the ambiguous nature of the work; for instance by introducing quality systems, that provide guidelines for how the work should be carried out and, not least, what the quality demands for the "products" are at a given time and place: in other words context needs to be considered.

However, if the quality standards are set arbitrarily or in accordance with criteria that do not accommodate the professionals" own standards of quality, the engineers feel that their work gets stressful. In a recent stress-survey among Danish engineers (Andersen & Nielsen, 2008), it is reported that large portions of engineering work are regulated by bureaucratic procedures and management concepts (e.g. lean-production, TQM, BPR). The engineers feel unsatisfied with their work situation if the bureaucratic procedures are "imposed" without local adjustments that take the specifics of their work into account. On the other hand, they are not opposed to quality systems or regular monitoring of their work as long as the criteria of evaluation are designed "intelligently" (i.e. the criteria do not conflict with their professional criteria of quality).

The Framework of Reification

The third coping strategy found in the study relates to broader contexts of justification. Scott mentions that institutions also rest on a normative pillar that draws on a broader normative basis of social obligation, appropriateness and morality that, in the end, rests on affective feelings of shame or honor. It concerns the feelings of pride and satisfaction when the work of the professionals leads to the production of a specific product and/or result. Several employees emphasise the importance they attach to the fact that what they do results in something concrete and tangible; something appreciated by the end-users (e.g. the bridge that eases the traffic congestions on the roads). Thus, the framework of reification refers to very specific and everyday criteria for success, to a large extent taken from a wider societal and/or material context. All the same, the framework of reification may also refer to criteria for success and "good results" laid down by the company and/or the profession. What characterises the framework is that the engineers, so to speak, materialise themselves in unambiguous categories. The abstract and intangible nature of knowledge work (e.g. calculations, risk assessments), combined with the lack of clarity (e.g. negotiations with the contractors, environmental groups, public authorities), seems to be – at least temporarily – reduced via referring to an independent authority: the concrete artefact (i.e. the bridge) or a positive verdict by the end-user.

Conclusion

The findings from the interviews with engineers working in knowledge intensive firms reveal the complexities and ambivalences in engineering work. The interviews identify that the engineers perceive the same factors as respectively being enthusing and straining. Professionalism, developing products of high quality, autonomy, etc. become factors in engineering work that can either enrich work life or result in serious work-related stress. The factors can contribute either to stabilize or to de-stabilize the self-identity of the engineers. In order to cope with the ambiguities of knowledge work the engineers find stability in one or more of the three identified institutional frameworks: self-identity is substantiated and stabilized by drawing resources from ideals about professionalism, bureaucratic standards and/or other reifications ("products" or "results"). The stabilizing frameworks draw their discursive resources from different domains. The archaic professional framework sustains the engineers' self-identity by borrowing discursive resources and ideals reproduced in science and engineering education. The bureaucratic framework legitimizes closure and seeks to eliminate ambiguity through company regulations and conventions. Whereas the framework of reification brings stability by referring to a wider societal context, here stability comes through social, unanimously held ideas about beneficial "results" and a shared reality of objects. The frameworks do – prima facie – stabilize the professional identities, but they are in fact also a potential source of work-related stress when professionals are faced with demands for flexibility. There are no guarantees that the ideals, rules, codes of conduct and values reproduced within either the profession, the company or in the broader societal domain can be brought into harmony. As a result, the engineers must engage in an ongoing sense-making endeavour where professional standards, corporate procedures and social obligations are negotiated and mediated. When mediation is not achieved, work becomes strained and can in the worst case result in work-related stress.

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Chapter 20

Collaborative Practices for Contextualizing the Engineering Laboratory

Erik Fisher & Clark Miller

Abstract: The effort to think about engineers and engineering in the broader social, ethical, and political contexts they inhabit is often linked to the normative objective of producing more socially robust and responsible technologies. In this chapter, we suggest one approach to building collaborative practices for contextualizing engineering work and the engineering laboratory – the embedding of participant-observers from the humanities and the social sciences in engineering activities – with the long-term goal of assisting engineers to become more reflexively aware of the contexts within which their work takes place. Of course, the desire to create more socially robust and responsible technologies implicates a vast array of social and institutional work, and engineers are thus only one of many contributing social groups whose ideas and practices shape the development and use of technologies. Nonetheless, engineers and engineering practices deserve special attention, for two reasons: (1) engineers play critical and instrumental roles in modulating the performance of innovation systems; and (2) engineers are often unaware of, and sometimes even trained to explicitly ignore, the broader contexts of their work. This challenge, however, can also be converted into a potential opportunity for practitioners and embedded humanists and social scientists to jointly reflect on engineering ideas and practices, so as to create greater awareness of the broader contexts of engineering work, to better prepare engineers to render those contexts more visible in their future work, and thus, ideally, to better position engineers to contribute to more socially robust and responsible outcomes.

Key words: Embedded Humanist, Embedded Scholar, Ethical Reflection, Ethnography, Laboratory Engagement Study, Participant-Observation

Introduction

Thinking about and reflecting upon the roles of engineers and the nature of engineering activities in their broader social, ethical, institutional, environmental, and political contexts, is a task that is often seen as a means for advancing the normative objective of producing – indeed, engineering – more socially robust and responsible technologies and innovation systems. The use of the phrase "engineering in context," which is the title of the book in which this chapter appears, implies that it is both possible and desirable to conduct engineering activities with more systematic care and attention to these broader contexts, as technologies and socio-technical systems are proposed, developed, deployed, and diffused over time and place. In fact, the ethical duty "*plus respicere*" ("to take more into account"), which has been applied by Carl Mitcham as a moral injunction for engineering design researchers to expand the considerations that they take into account during their research (Mitcham, 1994), could be considered to be a more general form of the moral imperative expressed in the phrase, to "engineer in context."

This injunction, to "engineer in context," raises a more practical question: given that engineers are not trained to analyze or engage many of the contextual dimensions of their work, how can engineers be aided in the task of contextualizing their practices in both meaningful and instrumentally effective ways? In this chapter, we suggest an answer based on fashioning collaborative relationships between engineers and participant-observers in engineering work – what we term embedded humanists and social scientists or embedded scholars. Such individuals, we suggest, bring unique education and skills to the laboratory that enable them to ask questions that stimulate reflection on the broader contexts of engineering work and, ideally, to help train engineers to contextualize their own work more rigorously and diligently.

We begin with several general introductory remarks about the instrumental challenge surrounding this normative project of contextualizing engineering as it occurs in real-time. The first remark is that, while engineers are no doubt important and influential actors in the production and use of socio-technical knowledge, artifacts, systems, and arrangements, they are hardly the only actors that matter. Citizens, consumers, professional users, research sponsors, investors, regulators, activists, entrepreneurs, marketing departments, instrument suppliers, educators, and a host of other people and groups also contribute to and help shape socio-technical outcomes. Thus, a key aspect of engineering in context will be to recognize, in the first place, that engineering work already takes place within a broad array of social contexts. Engineering is, as Miller and Pfatteicher (2008) suggest, always and inevitably "social engineering" in that it both shapes and is shaped by social dynamics at all stages in the innovation process. Put another way, engineering simply is, all of the time, engineering in context.

The second remark is that, regardless of how rich, comprehensive, and accurate the reflections of humanists, social scientists, and other scholars are in excavating, describing, and analyzing engineering contexts, if such insights are meant to be integrated into engineering practice then at some point engineers themselves will need to identify, assess, and take them into account (Fisher *et al.*, 2006). Hence, it is not enough for engineers to be told by other experts what to do or to be given rules and guidelines that substitute for creative responses to complex situations. Rather, it is important for engineers to develop specific skills, dispositions, and habits that support this objective (Miller & Pfatteicher, 2008).

This brings us to our third introductory remark. On a practical and a conceptual level, efforts to prepare engineers to more explicitly "engineer in context" will, to be effective, need to be adapted to the particular and unique social arrangements and institutional settings within which any given engineer is working. Engineers who are being asked to alter their practices in order to put them in context are already enabled and constrained by countless social and institutional factors. These contextual interactions are often invisible to the very engineers who operate within them, and who are trained to exclude broader contextual considerations from their educational and hence professional activities (Bucciarelli, 1994). Nonetheless, these contextual interactions operate and can, in principle, be rendered more visible. Accordingly, the same ethical, social, and political dimensions that may be invisible to engineers can, in turn, be invoked to enhance the ability of engineers to function with more reflexive awareness of broader contexts.

Thus, a central challenge that this chapter focuses on is that of rendering unperceived contexts more visible to the engineering practitioners who occupy and inhabit them, and in a hands-on manner. This challenge, when taken on simultaneously as a subject of study and of deliberation, can be synergistically converted into an opportunity for engineering practitioners to reflect on what they are already doing – including how they relate to and interact with other actors and groups. Such reflexive awareness has been argued to be a prerequisite for the learning necessary to contribute to goal-directed changes in routine practices and behaviors (Fisher *et al.*, 2006), and there is empirical evidence that supports this claim (Fisher, 2007).

Taking the engineering laboratory as a case in point, we begin, in the next section, with a brief descriptive analysis of the social and political ecologies – the multifaceted and overlapping social and institutional contexts – within which work inside the engineering laboratory takes place. We then suggest, in the subsequent section, that humanists and social scientists are well positioned to aid engineers in making more visible these social contexts, and helping engineers to learn how to perform such contextual work on their own. For this to happen, we argue, engineers should have first-hand experience in integrating insights generated from self-critical reflection into their actual engineering practices. A unique and effective method to facilitate this experience, and one that contributes to the goals of engineering practice and education, is that of embedding outsiders as collaborative participant-observers within engineering laboratories. Accordingly, we describe the role of the embedded humanist or social scientist, who contributes both to traditional pedagogical and to broader normative objectives by opening spaces of reflection that occur in close proximity to laboratory work. The purpose of these collaborations is for engineers to develop the facility to conceptualize their practices as they occur and with the aim of enhancing their responsiveness to the concerns, values, and priorities that arise from such real-time contextualization (cf. Guston and Sarewitz, 2002).

Contextual Dimensions of the Engineering Laboratory

Before describing the role of the embedded scholar, we enumerate several instrumentally important social and institutional contexts within which engineering work takes place, many of which receive much more in-depth treatment in other chapters of this book. We do so, primarily, to illustrate the diversity and overlapping nature of these contexts, as well as to aid in identifying relevant contexts for consideration in any given engineering laboratory (or, more generally, engineering research, development, or implementation sites). Of course, this list is not meant to be an exhaustive treatment of the social and institutional contexts of engineering, nor do we intend to exclude alternative conceptions of what constitutes an engineering context from consideration. This list is simply meant to provide concrete and intuitively obvious starting points for thinking about engineering in context.

Immediate institutional contexts: The immediate institutional setting in which the laboratory is housed constitutes an obvious contextual domain. Here can be found the structures that manage and administer laboratory employees and research projects. Such structures can play a key role in shaping the overall research orientation of laboratories, for instance whether their work is seen as supporting the continuous improvement of existing technologies, catalyzing the creation of new products and systems, or enabling the exploration of new frontiers of knowledge, etc. Such structures frequently define the social organization of research groups and departments, and they help determine, mediate, and reinforce the role that the acquisition and use of research funding and resources play in the case of individuals and departments. The immediate institutional setting can be instrumental in articulating and codifying the social reward structures that shape career advancement and, in turn, their relationship to research. One of the most studied settings of the laboratories that educate and train future engineers is the university. For example, numerous studies have observed recently the impact of growing commercialization (Slaughter and Rhoades, 2004; Slaughter and Leslie, 1977) and interdisciplinarity (Nowotny, Scott and Gibbons, 2006) of the university on changes in the institutional structures that support and reward science and engineering research. Other immediate institutional settings include government laboratory administrations as well as those of private firms.

Clients and potential users: Clients and potential users of the knowledge, systems, and technologies that are conceptualized, packaged, or produced by the laboratory, whether these are professional users or end-users, constitute another well-known context of engineering work (Oudshoorn and Pinch, 2005). Models of user needs and desires – constructed via *ad hoc* imagination, market research, or direct user interaction – are often used to shape engineering design decisions. User decisions, whether to buy or not to buy a product or how to use a technology, can also feedback into later engineering decisions (see, e.g., Kline and Pinch, 1996).

Resource allocation and regulation: Traditional forms of governing science and engineering take the form of "upstream" resource authorization and allocation through funding agencies, and "downstream" rules and guidelines promulgated by regulatory agencies (see, e.g., Dickson, 1984). Despite being analytically distinct, funding and rule-making can often coincide; for instance, in the case of educational requirements to combine teaching and research, to articulate the broader impact of research projects, or to develop and implement a specific public works project. Certain regulatory rules, however, such as material or inspection requirements by government agencies, may constrain all projects carried out of a certain type within a given region or country.

Public discourses and values: Less frequently acknowledged are the less tangible and often diverse discourses in the public sphere that can give voice to public values, concerns, and priorities (e.g., civic epistemologies; see Jasanoff, 2005). Widely shared and promulgated discourses and imaginaries may filter into engineering practice and design through the negotiation of project requirements with funding or regulatory actors (e.g., agency administrators) who are ultimately responsible, at some level, to the general public. Or, they may become direct inputs into projects when publics become aroused, such as protests that broke out during the development of the Boston Big Dig project (NTSB, 2007), when key neighborhoods opposed the siting of bridge terminuses in their communities.

Professional associations and standards: Professional associations and standards setting bodies constitute somewhat more fluid organizations that can be directly or indirectly involved in the professional decisions of individual engineers and the routine material practices surrounding specific devices, materials, and procedures (Schmidt and Werle, 1998). They can also, more broadly, shape the relationships between engineers and others in society, such as public and business officials (Layton, 1986).

Material, labor, and moral economies: Still other dimensional categories would include the political economy of the instruments and materials in which the laboratory deals (see, e.g., Kohler, 1994), as well as its products, the labor market in skilled personnel necessary for laboratory work (see, e.g., Zucker, Darby, and Brewer, 2003), and the moral economy and credibility of the epistemology and knowledge claims associated with the laboratory's work and products (Shapin, 1996).

The Study of the Laboratory and its Context

It should be obvious that engineering laboratories exist within this wide array of social contexts, yet the day-to-day routines of engineering work, as well as aspects of engineering training and culture, can often obscure the visibility of such contexts to laboratory practitioners. We propose, therefore, that engineers develop collaborative relationships with humanists and social scientists who work closely within the laboratory to inquire into, stir up, and seek to render more visible the social contexts of engineering work. Such collaborations can constitute extensions of more traditional forms of pedagogy and training, or they can be conceived in terms of broader participation in engineering research and design. In either case, the immediate objective is to assist engineers to become more reflexively aware of how contextual elements can both shape and be shaped by engineering.

Humanists and social scientists bring valuable skills to this endeavor. Using ethnographic and participant-observation methods, studies of scientific and engineering laboratories have provided a great deal of insight into the internal sociology and material practices of laboratory work. Beginning in the 1970s, laboratory ethnographies have documented the cultural practices and social processes observed to constitute scientific and engineering work (Sismondo, 2003). The early work in this area of Karin Knorr-Cetina (1999, 1981), Bruno Latour and Steve Woolgar (1986 [1979]), Michael Lynch (1985), and Sharon Traweek (1988) revealed the contingent and negotiated nature of experimental results and research decisions. In so doing, these works helped lay the foundation for the field of science and technology studies (STS). Since then, countless ethnographic studies have described scientists and engineers at work and within work places, highlighting the social context of the laboratory itself and its immediate institutional confines.

Historical and sociological studies have also examined the social and institutional relationships that exist between laboratories and their contexts. Such works include Robert Kohler's *Lords of the Fly* (1994), which studies the material and human resource exchanges between and among laboratories; Kohler's *Partners in Science* (1991), which examines the institutional sponsorship of laboratories by philanthropists, such as Carnegie and Mellon; Daniel Kleinman's *Impure Cultures* (2003), which studies the laboratory's relationship to its diverse funding sources in government and industry; and Michael Crow and Barry Bozeman's *Limited by Design*, which surveys the system of roughly 16,000 U.S. laboratories from the standpoint of research policy (Crow & Bozeman, 1998).

Historical studies have also delved into a number of social and institutional contexts that surround and condition the work and nature of scientists and engineers, the research and implementation sites where they are educated and work, and the ultimate reorganization of major aspects of society around novel engineering innovations. Thomas Hughes' *Networks of Power* (1983) and Bruno Latour's *Pasteurization of France* (1988), for instance, explore relationships between the laboratories of Edison and Pasteur and the sites and behavioral contexts that their work influenced and shaped in transforming energy systems and public health practices, respectively, in the 19th centuries. Michael Dennis (1994) chronicles the differences that exist between two military laboratories in how they relate to the development and production pathways of a device after it leaves the laboratory. The different orientations of the labs and the intensity of their ongoing involvement are largely seen as the result of the personal relationships and unique imaginaries of their directors.

Significantly, studies like those of Hughes, Latour, and Dennis do as much to show us the laboratory director's entrepreneurial understanding of the sites and institutions that their laboratories could potentially interact with, as it does those sites and institutions themselves – a point to which we will return momentarily when we consider contextual awareness.

Humanists and social scientists are thus well positioned, in terms of both conceptual frameworks and analytic skills, to excavate and illuminate the social and institutional contexts within which engineers operate. When embedded in the laboratory, we suggest below, they can also collaborate with engineers in order to cultivate the practices of probing and exploring the invisible and latent role of these and other contextual dimensions through appropriate educational and research strategies.

The Role of Contextual Awareness

As stated above, historical studies of the laboratory often focus on the enterprising individuals who found and direct laboratories – and by extension (whether explicitly or implicitly) on the particular ability of these people to envision the social, political, institutional, and even cultural contexts of their laboratories' services and outputs. In short, the cognitive ability on the part of engineers to conceptualize, imagine, and anticipate contextual categories is itself an important contextualizing factor that can help shape how engineering work contributes to the production of both scientific knowledge and social arrangements.

Ironically, while contextual dimensions may be highly (if often only partially) visible to some entrepreneurial laboratory directors who have advanced beyond the day-to-day work that goes on at the laboratory bench, they are at the same time largely out of sight for those who labor more exclusively within the confines of the laboratory. Admittedly, the degree to which junior level engineering laboratory members, and especially engineering students, are introduced to and encouraged to think about the contextual dimensions of their work is largely a function of the specific laboratory in which they find themselves and of the individual management style of the laboratory director. By and large, however, it is fair to say that such engineering laboratory researchers are not only frequently unaware of the broader social contexts of their work, but that there are disincentives for them to think about and to integrate them.

There is a critical need, therefore, if engineering is to be more explicitly conducted in context, to acknowledge the powerful role that cognitive factors play in modulating the flow, output, and contextual interactions of laboratory work. In particular, the expectation, whether on the part of laboratory directors or laboratory practitioners, that day-to-day engineering work will best be performed in isolation of broader contextual considerations clearly works against the injunction to engineer in context in the sense of *plus respicere*. We will return to this point in the next section. Here, we note that reflexive awareness can function as a cognitive bridge between the practice of engineering in isolation from its broader contexts and the explicit integration of contextual dimensions. Reflexive awareness refers to the recognition that one makes choices and that one's behavior is conditioned by material, social, and cognitive considerations (Fisher *et al.*, 2006, Fisher & Mahajan, 2006). The awareness that one's actions are both enabled and constrained by various actors, factors, and arrangements beyond one's immediate control (and can, in turn and over time, enable and constrain them) can encourage engineering practitioners to perceive a broader horizon of social, environmental, and ethical considerations as potentially relevant to their work. Fisher *et al.* (2006) posit reflexive awareness to be a pre-condition for incrementally adjusting the decisions of engineers – and thus modulating the continuous flow of ideas, people, and resources among different sites and stages of technology development.

Following up Fisher's work, Miller and Pfatteicher (2008) suggest that reflexive awareness requires the cultivation of "reflexive habits" that are intended to help engineers "anticipate a range of potential trajectories in the technological forms of life they design" (p. 568). Such habits help student engineers recognize the heterogeneous social, economic, political, cultural, and ethical contexts of engineering. Arguing that all engineering is social engineering, and recognizing that engineers do not act in a vacuum but interact with partners in many different sectors and roles, Miller and Pfatteicher identify eight habits of mind for engineering educators to aspire to develop in "social engineers":

1. Recognize that engineering work is a form of social engineering.
2. Develop a commitment to systematically inquire into the broad impact and import of engineering work.
3. Regularly seek out opportunities to learn new skills to successfully pursue such inquiries.
4. Recognize the obligation of engineers to work in partnership with those who will inhabit the technological worlds the engineers design and build.
5. Recognize that all design decisions involve the need to balance, choose, and evaluate interests, views, and perspectives.
6. Look for ways to make those choices an explicit and integral part of the dialogue that surrounds design decisions.
7. Develop a tolerance and appreciation for dissention, debate, and dialogue.
8. Involve the public more actively as participants in deliberations about the public good as embedded in technological systems (p. 572).

Human and Social Scientists Embedded in Laboratories

One way to provide engineering researchers and practitioners with the kind of hands-on experience that would cultivate these reflexive habits and encourage them to identify and engage more broadly with the social contexts of their work, is to bring in participant-observers from the humanities and social sciences. Such outsiders can tap into the scholarship on and methods for mapping and reflecting on social, political, and ethical contexts to help open up spaces for engineers to inquire more deeply into the broader contexts of engineering work. Some engineering educators already attempt to cultivate such reflexive habits of mind in engineering students in the classroom (Miller and Pfatteicher, 2008). By going beyond the classroom, however, such activities provide direct opportunities for reflexive thinking and experience-based learning that is rooted in the pragmatic, day-to-day activities of engineering work and practice.

As a case in point, Fisher regularly interacted as an “embedded humanist” with practitioners for thirty-three months in an engineering research laboratory. The interdisciplinary collaborations that developed out of this collaboration coincided with documented changes in both discourse and material practices within the laboratory (Fisher, 2007). Importantly, this “laboratory engagement study” did not seek to directly counteract the mental habits of engineering researchers, but to work with them to allow new contextual considerations and previously unperceived options to emerge in engineering thinking and practice. The results included not only measurable increases in reflexive awareness (Fisher & Mahajan, 2006) and the alterations of research decisions (Fisher, 2007) but also reinforcements of the educational objectives of the mechanical engineering department and college of engineering within which the lab was housed (Fisher, 2006). In analyzing the results of applying a "midstream modulation" protocol during the course of day-to-day engineering work, Fisher's engineering counterpart made the decision to substitute one material for another during an experiment. This decision, which held value both for the productivity and the responsibility of the research,

> *"was instrumentally triggered not by the interjection of mandates or prescriptions, but by [the engineer's] own cognitive work of reflection, association, and invention. Rather than introduce social or ethical considerations, the protocol instead allowed [the engineer's] latent concerns to surface. As an intervention, this engagement of research capacity was productive because of the work of the subject – the engagement may have influenced practice, but to do so it required the practitioner's desire to remedy a perceived deficiency. [The engineer's] recognition was, in turn, enabled by [the embedded scholar's] ongoing attentiveness to his unfolding account of social processes and material properties"* (Fisher, 2007).

It is important to note that, while the cognitive role of an engineering practitioner can be central to the nature of his or her engineering work, cognitive orientations and hence decisions and behaviors do not shift at will but are emergent properties of multiple zones of human, social, and material conditions. In other words, the contribution of the embedded humanist or social scientist may actually be counter-productive if it does not respect and work within the self-governing parameters of the laboratory and the perceived context of the practitioners.

We noted earlier that it is not uncommon for laboratory directors and practitioners to consider that day-to-day engineering work is best performed in isolation of broader contextual considerations. Obviously, a necessary condition for embedded interactions between laboratory insiders and outsiders is for the director to be willing to open the doors of his or her facility for such purposes. Once embedded in the lab, however, instead of opposing or seeking to directly counteract such beliefs and expectations, it may be more productive for the outside scholar to seek to enhance the reflexive awareness of engineer practitioners, *in situ*, in real-time, and during key junctures of research conduct, formulation, assessment, and deployment. Such "soft" interventions, which can take the form of sharing observations and raising questions, are more in the spirit of collaboration – although they need not and should not exclude the raising of challenging and probing questions.

The cultural embedment of Fisher and of the techniques that he used – which were co-produced by himself and the engineers he was working with – allowed the routine interactions to function as a feedback mechanism, creating a more self-critical environment for knowledge production and introducing new considerations as well as new technical alternatives. In an attempt to replicate Fisher's laboratory engagement study, a second embedded humanist has confirmed that regular and routine interactions with biotechnology laboratory researchers can indeed stimulate reflection on the ongoing social dimensions of their research processes and can constitute a form of social responsibility in science (Schuurbiers & Fisher 2009).

As observers, embedded humanists and social scientists can understand and describe the unique social and cultural elements internal to a given engineering laboratory – whether the lab is housed in a university, government facility, or private entity, and whether it functions primarily as a research, development, implementation, or hybrid site. As participants, they can interact in various modes with laboratory practitioners in order to open up, sustain, or enhance opportunities for reflection on broader social contexts and the ethical issues which these reflections in turn raise. Once practitioners start to see the more immediate contextual dimensions in which they work, including internal social processes, decision processes, group dynamics, local research practices, etc., these can be linked more and more plausibly to wider concentric contextual dimensions and opportunities for integrating their consideration into individual laboratory decisions can be sought.

Conclusion

This chapter began with the observation that the ethical injunction for engineers to *plus respicere* or "take more into account" can be recast as an injunction to "engineer in context." In order to pursue a program of assisting engineers to perform this activity, we noted that engineering already takes place in multiple contexts, that engineers do not act alone in producing outcomes, and that any attempts to alter or enhance the mental habits of engineers ought to take into account the already reflexive nature not only of engineering but of engineers. After briefly describing a variety of social and institutional contexts that condition the work of engineers within engineering laboratories, we noted that humanists and social scientists are well positioned, in terms of both conceptual frameworks and analytic skills, to excavate these contexts as such.

Given that humanists and social scientists are adept at studying and revealing the social and institutional contexts of engineering sites such as laboratories, we suggested that such scholars could be a valuable aid to engineers in exploring ways to integrate contextual considerations directly into engineering work and in broadening the purview of engineering training and education to take such aspirations and abilities into account. After emphasizing the central role that cognition and contextual awareness play in choices of engineers, the chapter enumerated a set of mental habits and reviewed some of the innovative and promising work that interdisciplinary collaborations between engineers and embedded scholars is beginning to produce in respect to instilling such habits on-site in engineering research laboratories and in a hands-on manner, in keeping with some of the best practices in engineering research and design education. Thus, collaborations between engineers and embedded scholars who work closely within the laboratory can inquire into, stir up, and render more visible the social, institutional, and other contexts that both enshroud and pervade engineering work. Such collaborations can enhance more traditional forms of pedagogy and can open up opportunities for broader participation in engineering activities, which both shape and are shaped by social arrangements.

In closing, we stress that engineering is always done in context, and yet, this very fact is often both invisible to the engineers who practice engineering and taken for granted by the scholars who claim that engineers should be more sensitive to social and ethical considerations. Given the immense challenges posed by the prospect of developing capacities for engineering to be done more explicitly in context, we suggest that synergies can be pursued that leverage what initially appears to be cultural and epistemological barriers and cognitive and institutional blind spots into mutually productive exercises between laboratory insiders and outsiders. These efforts can be aimed at integrating broader contextual considerations more explicitly and deliberately into routine material and engineering practices. Indeed, we believe possibilities exist for extending collaborative practices for contextualizing engineering work well beyond the laboratory into the social and institutional practices of technology development, dissemination, and use. Why not reflect on what we are doing anyway?

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Chapter 21

Engineering as an Enterprise of War and Peace

Christopher Papadopoulos & Andrew T. Hable

Abstract: The profession and practice of engineering have historically evolved in tandem with activities sponsored by military agencies and purposes. Employment and research funding data demonstrate that these ties persist today. Yet these circumstances, and the host of moral and practical issues that follow, have received relatively little attention in engineering education, including in engineering ethics. Certainly engineers will always play an essential role in developing and maintaining systems of national defense, so long as sovereign states assert their rights to self-defense. But in the context of establishing sustainability, peace, and social justice in a world of growing social stresses, and the critical contributions of engineers toward these ends, the preponderance of military and defense-related sponsorship of engineering deserves examination. In addition to posing dilemmas for individual engineers who wish to avoid various types of military or defense work, over-emphasis of defense-sponsored engineering threatens to divert sufficient engineering attention away from crucial humanitarian concerns and fuels the possibility of war as competition for diminishing resources intensifies. New efforts must be undertaken to prioritize humanitarian causes and appropriate technologies that best advance human needs, especially the needs of the poorest societies.

Key Words: Military, Defense, Peace, Humanitarian, Poverty, Development [Engineering]; Appropriate Technology

Introduction

Engineering, as any other profession or field of inquiry, exists in a world in which pressing concerns of unprecedented magnitude and nature are emerging. Although societies throughout history have confronted many challenges that directly bore on their basic quality of life and existence, perhaps for the first time, human society is at a juncture at which the exhaustion of the earth's life-sustaining natural resources is in plain view.

In *The Upside of Down*, Thomas Homer-Dixon (2006) sees this world in terms of five "tectonic stresses" – emerging dynamics in world population, energy supply, environmental integrity, climate change, and global economics – that will conspire to threaten the welfare of human society during the next century. Among other effects, growing economic and population disparities between wealthy and poor countries will increase the likelihood of conflict as competition for basic resources becomes evermore acute. In particular, the projected increase in youth population and unemployment in politically unstable countries – an effect known as the "youth bulge" – is viewed as a breeding ground for violence and terrorism (National Academies of Engineering, 2004).

Alleviating these stresses will require a wide range of approaches, including the focused efforts of engineers to provide development and management of appropriate technologies. Conversely, the urgency of addressing these social issues will place new demands on engineering and engineers.

It is in this global context that the role of engineers as both professionals and citizens must be examined. Traditionally, engineering efforts have been dominated by military and defense-related interests that fail to represent the wants of the poorest or neediest members of society. The chief subject of this paper is to express the view that these traditional venues must be balanced with new alternatives through which engineers can more directly and judiciously focus their expertise toward serving areas of greatest societal need.

In particular, development needs that undergird poverty eradication – clean water and sanitation, irrigation, roads, power generation and transmission, and communications networks – all require engineering expertise. Addressing these needs is a moral imperative and must be a priority in professional, corporate, and governmental policies, including in engineering. What's more, addressing development needs of poor nations is likely to reduce the likelihood of war and violent conflict in these countries (Collier *et al.*, 2003), a result that could benefit wealthier nations that are sometimes the objects of terrorism. Development efforts should therefore be informed by both principles of economic justice and nonviolence in order to maximize their effectiveness and stability.

Such reprioritization to serve the world's neediest communities will require that engineers be broadly educated to understand the ethical and socio-economic circumstances that surround their work, empowering them to make informed choices to consciously engage in or abstain from work in accordance with their understandings. Indeed, notions of "peace engineering" or "humanitarian engineering" are entering the mainstream as students and educators are seeking ways to harness engineering ingenuity to develop appropriate technologies that best advance peace, justice, and the service of the neediest. Engineering institutions, organizations, and employers should actively support engineers in these pursuits through expanding provisions in engineering codes, providing engineers with further resources, and redirecting their strategic objectives.

Military and Defense Influences in Engineering

Historically, technology and the related disciplines of science and engineering have evolved in tandem with military endeavors. Work of even the earliest engineers and scientists, such as Archimedes' catapult (c. 250 BC), was directed toward serving military purposes. Such relationships continued as engineering emerged as a profession in the 17th century (Davis, 1998). Indeed, "the very term 'civil engineer' appeared in the 18th century to name a new kind of practitioner: one who engineered something besides fortifications or weapons" (Hacker, 1993). Yet despite the emergence of the field of civil engineering new complicities between military and civilian projects evolved. For example, from the earliest stage, "roads, bridges, railways, and other state-sponsored civil projects may themselves betray more than a trace of military motive" (Hacker, 1993). Today questions of dual-use technologies remain at the center of many ethical and political issues, such as the relationship between nuclear power and nuclear weapons proliferation.

The military sponsorship of engineering intensified after World War II as organized military research & development programs became dominant and institutionalized. Seely (1993) describes the nearly singular support of the U.S. Department of Defense in funding basic research during the 1950s. Even the National Science Foundation was founded largely on the basis to support militarily-relevant research, as envisioned by its leading proponent Vannevar Bush (1945): "There must be more – and more adequate – military research in peacetime. … This can best be done through a civilian-controlled organization with close liaison with the Army and Navy …".

Military and defense influences in engineering persist today as evidenced by patterns of federally funded research and employment. Between 1950 and 1985, 65%-70% of federal R&D funds were channeled through the Department of Defense, compared with only 1%-3% through the National Science Foundation (Mitcham, 1989). Defense sponsorship accounted for approximately 57% of all federal R&D expenditures during the period 1986-2006 (Koizumi, 2006). And for 2007, based on data provided by the National Science Foundation, about 50% of all federally sponsored research (excluding development) categorized as "engineering" was defense-related, a far greater ratio than that in other disciplines (Papadopoulos & Hable, 2008).

In addition, a relatively large share of engineers are employed in military and defense-related work. Harrison Brown (1978) estimated that during the 1970s, "perhaps 40% of the world's total pool of highly qualified research people [dedicated] their research skills to military projects." Robert Rutman estimated that this relationship persisted into the 1990s as "two-thirds of the scientists and engineers in the United States work for defense contractors or on defense contracts in institutions and universities" (Center for Defense Information, 1992). In an effort to substantiate these estimates, Papadopoulos & Hable (2008) compared derivations of equivalent engineering employment effort necessary to produce goods and services purchased by the U.S. Department of Defense (DoD) with employment statistics provided by the U.S. Bureau of Labor Statistics. By this measure, nearly 10% of all professional engineering employment effort is devoted toward military or defense purposes that are channeled through DoD, a rate that is about three times higher than for the average professional in any discipline. Because this estimate excludes purchases by NASA, the Department of Energy, and the private defense industry (non-DoD), and also because many engineers will devote partial effort to military or defense projects during the course of their employment, much more than 10% of engineers will perform some substantive military or defense-related work, lending credence to the higher estimates claimed above by Brown and Rutman.

In *Engineering and Social Justice*, author Donna Riley (2008) provides additional evidence linking engineers to the defense industry as well as a more general critique of militarism in engineering and the larger military-industrial complex. The great industrialization that grew in the U.S. during World War II created both a capacity and a mindset in which mass, rapid, and uniform production of infrastructure and consumer goods quickly eroded environmental resources, community fabric, and other characteristics vital to an ecologically and socially sustainable society (Maser, 1997).

Given the many military and defense underpinnings of engineering, it is not surprising that engineering education has military roots. For example, the first institution of higher education in the U.S. to grant a degree in engineering was the United States Military Academy at West Point. William Streett (1993) describes how the military culture of regimentation has infused engineering education throughout the 20th century to the exclusion of varied styles of learning. It is worth noting that the vast majority of high profile graduate fellowships advertised by the American Society of Engineering Education are sponsored by defense agencies.

However, engineering curricula do not adequately address the ethical or social implications of strong ties to the military and defense organizations. Systematic efforts to introduce ethics into engineering curricula emerged in the 1970s with the earliest treatments focused on immediate professional concerns, such as relations between engineers and their clients. Broader issues of social responsibility emerged by the 1980s (Manion & Kam, 2000). However, neither of these movements directly addressed questions dealing with weapons development or other military applications. Based on a systematic review of standard textbooks and online resources in engineering ethics, Papadopoulos & Hable (2008) determined that direct treatment of ethical issues regarding military and defense applications of engineering is conspicuously absent, absolutely and in comparison to other coverage of other issues.

At the heart of education, especially ethics education, is preparation to make informed decisions. But as Jonathan Feldman (1989) contends, the preponderance of military and defense applications in engineering biases engineering education: "[m]ilitary dependency determines what kinds of science are taught and what kinds of science are practiced by graduating students. There is a close relationship between science and engineering curriculums and the sponsors of faculty research … ." In order that students can be prepared to make informed decisions about how they wish to apply their engineering skills in future research or employment, engineering education, particularly in ethics, must provide direct and ample attention to the military and defense context of engineering and related ethical and social issues.

Prioritizing Ethical and Social Justice Imperatives

The dominance of military and defense influences in engineering raises both moral and practical questions. A variety of ethical dilemmas exist when an individual engineer is confronted by either tacit or overt participation in military projects, such as weapons development. At the macro-level, further questions are raised due to the reality that the very enterprise of engineering talent, creativity, and expertise is directed toward military or defense functions at the potential exclusion of other necessary functions.

At the individual level, some engineers have principled objections to working on various military projects, ranging from committed adherence to ethics of nonviolence to historical understandings of war-making as primarily a tool of hegemony and imperial power. Such engineers should be afforded not only the right to abstain from such activities, but also ample opportunities for alternative employment. This includes selective objection in which a given engineer might deem, say, the development of a conventional weapon appropriate, but the development, maintenance, or simulation of a nuclear weapon inappropriate. Support for legitimizing and allowing selective objection has been expressed, for example, by Stephen Unger (2000) and the U.S. Catholic Bishops (1983).

Expressing the need to protect this ethical freedom is not simply an academic exercise. Given the preceding analysis, many engineers are likely to encounter the decision of undertaking some form of employment with a military or defense organization or project. Moreover, due to complexities introduced by dual-use technologies and in-direct support for military or defense applications, many engineers might contribute work toward projects that they do not support (Unger, 2000), because such activities are often difficult to avoid (Unger, 1989): "[t]he great majority of [engineers] are not in business for themselves. They are compelled to choose among limited employment opportunities. A high percentage of engineers are employed, directly or indirectly, on military-related projects, but this use of engineering talent is not a result of wholly free choices engineers have made." In addition to or even in the absence of explicit objections to performing military work *per se*, engineers might avoid such work in order to focus on other activities for which there are moral imperatives, such as developing appropriate technologies for poor or developing societies. Sophisticated technologies inspired by military or defense objectives are unlikely to provide solutions for basic human needs, such as clean water, sanitary systems, irrigation, housing, and the like, although some military personnel do work to erect such infrastructure as part of their active duty assignments.

Beyond the level of the engineer's individual moral choices, the appropriateness of military and defense objectives driving engineering trends and priorities must be further questioned in the context of global social priorities. Indeed, conditions of extreme poverty plague about one fourth of the world's population (about 1.4 billion people live on less than $1.25/day; Chen & Ravillion, 2005), whereas the direct beneficiaries of sophisticated military or defense systems reside in smaller, wealthier populations. Reprioritizing the agenda of engineering at the disciplinary level to serve such pressing human needs can be viewed as moral imperative.

In addition to moral and ethical considerations, practical imperatives also suggest the urgency and appropriateness of serving societies that lack basic needs. The risk of war, particularly civil war, is arguably escalated in the presence of poverty. According to a 2003 report of by the World Bank (Collier *et al.*, 2003) the risk of civil war is concentrated in low-income countries (15 times greater than OECD risk) and, to a lesser degree, middle-income countries (4 times greater). Collier argues that "[w] ar retards development, but conversely, development retards war." A model created by Collier and Hoeffler (2002) showed that each percentage point increase in growth rate reduces the risk of civil war by approximately the same. The *State Failure Task Force Report – Phase III* (Goldstone *et al.*, 2000), funded by the CIA's Directorate of Intelligence, found that infant mortality rate is one of the most significant variables associated with an increased risk of state failure, which includes conflict and state collapse.

The damage and ill effects of civil wars are far-reaching. Even high-income countries are affected when civil wars break down rule and order in low-income countries. The problems of trafficking cocaine from Colombia and opium from Afghanistan are two examples well known to adversely affect the U.S. Moreover, international terrorism has been rooted in this type of country, such as Al Qaeda's use of Afghanistan for training.

The double causation relationship between poverty and conflict provides a strong rationale to invest in further development efforts. Not only do these efforts play a direct role of providing all persons with their freedoms and rights, but also the role of preventing conflicts that span states, regions, and the globe. As described in the report of the UN High-level Panel on Threats, Challenges and Change, "development … is the indispensable foundation for a collective security system that takes prevention seriously" (United Nations, 2004). This view has been echoed by former U.S. Secretary of State Colin Powell (Daalder, 2002):

> *"Terrorism really flourishes in areas of poverty, despair and hopelessness, where people see no future. We have to show people who might move in the direction of terrorism that there is a better way. That is why ... the United States of America [is] committed to channeling our noble energies into an effort to encourage development and education and opportunity throughout the world, including the Muslim world."*

None of this is to suggest a categorical rejection of the professional military or related military applications of engineering. Indeed, many engineers will uphold armed warfare as legitimate or even obligatory for purposes of national self-defense, and will therefore choose to actively apply their expertise to advance military requirements. Plenty of non-military engineering applications, moreover, such as emphasis on extraneous consumer luxuries, also distract engineering attention away from core needs of the world's poorest societies.

But on the whole, military and defense efforts are principally oriented around exerting violent force, which intrinsically addresses symptoms but not root causes. At best, resorting to violence can limit existing conflicts or possibly serve as a deterrent. But even military deterrence is premised on posing threats that create fear, not on building common goals that lead to trust and mutual understanding, the true keys of lasting peace and justice. It is in this light that well-funded and explicitly-focused efforts to harness engineering ingenuity toward meeting humanitarian needs, particularly for the world's neediest societies, are advocated.

Peace and Humanitarian Engineering

The tradition of engineers and scientists seeking to direct their efforts away from war-making and toward peace-making dates at least to founding of the Federation of Atomic Scientists (FAS) in 1945 "to both warn the public and policy leaders of potential dangers from scientific and technical advances and to show how good policy could increase the benefits of new scientific knowledge" (Federation of Atomic Scientists, 2008). Somewhat later the Russell-Einstein Manifesto of 1955 warned against the dangers of thermonuclear war and inspired the first Pugwash Conference in 1957 "to bring together, from around the world, influential scholars and public figures concerned with reducing the danger of armed conflict and seeking cooperative solutions for global problems" (Pugwash, 2008). Several other prominent organizations, including the Union of Concerned Scientists (founded in 1969), the Institute for Energy and Environmental Research (founded in 1987), and Scientists for Global Responsibility (founded in 1992) seek to advance the uses of science and engineering to promote peaceful uses of technology.

However, not until somewhat recently have efforts to emphasize peaceful or humanitarian uses of engineering entered the mainstream of engineering education. This movement is marked by the founding of groups such as Engineers Without Borders (EWB) in 2000 and Engineers for a Sustainable World (ESW) in 2004. Some engineers, including the second author, are also applying their engineering expertise after graduation through service in the Peace Corps or USAID. Through these and many other organizations, engineering students engage in projects that directly assist poor and developing communities to establish basic infrastructure.

Within this movement, some programs are emerging that specifically identify goals of engineering to serve peaceful and humanitarian causes. In *Peace Engineering: When Personal Values and Engineering Careers Converge*, Aarne Vesilind (2005) explains "Peace Engineering" as growing from the desire of more and more young engineers to seek applications of engineering beyond the entanglement between military and civilian engineering applications.

Today, new academic programs and curricula are appearing under the umbrella term "humanitarian engineering". A leading program was established in 2003 at the Colorado School of Mines (Muñoz, 2008). The CSM program defines humanitarian engineering as "design under constraints to directly improve the wellbeing of underserved populations" (CSM, 2008). Other programs in humanitarian engineering exist or have been proposed at Valparaiso University (2008) and Queen's University (Miller, 2008). These programs help students focus their studies around serving needy societies, and assist them in identifying career opportunities to continue such work.

More broadly, countless engineering programs now offer or emphasize "ethics", "sustainability", "green", and/or "international" components and concentrations in the curriculum. These programs provide engineers with outlets and opportunities to target their expertise toward solving problems of societal import.

While the emergence of these new programs is promising, they nevertheless appear to be small in scale and organization in comparison to disciplinary efforts as a whole. No data appears readily available to quantify how many engineers work on humanitarian projects that directly benefit developing societies, but consider that the 8,000 members of Engineers Without Borders in the U.S. is quite small in comparison to the 400,000 undergraduates enrolled in U.S. undergraduate engineering programs.

At the professional level, conferences are organizing around the themes of social justice and humanitarian engineering, including *Engineering, Social Justice and Peace*, *Engineering, Social Justice, and Sustainable Community Development* sponsored by the National Academy of Engineering, and *Engineering: Innovation with Social Responsibility* sponsored by the World Federation of Engineering Organizations.

However, few research & development activities seem to be organized for the explicit purpose of developing appropriate technologies for developing societies. Modern R&D activities in wealthy nations emphasize "'cutting edge" research topics [that] exclude many of the issues that affect the largest number of people and have the greatest impact on the environment", relegating appropriate technologies as "mundane" (Kammen & Dove, 1997). One emerging example is the International Development Design Summit organized by MacArthur Fellow Amy Smith at MIT which brings together cross-disciplinary and cross-cultural people from around the globe to brainstorm and create useful technologies for developing communities (International Design Summit, 2009). Several wiki's, including *Appropedia*, are also coming into existence to solicit and exchange ideas for appropriate technologies.

It should be noted that efforts in engineering to promote development and sustainability, even those that explicitly carry words as "peace" or "humanitarian", are not necessarily "non-military". Indeed, many activities that are undertaken within the military, such as building schools and other infrastructure, can be considered "humanitarian". Also, many advances in sustainability, such as in developing efficient uses and generation of energy, are sponsored by research conducted within the military agencies. Many engineers might reason that working through the military to achieve these ends is both morally permissible and strategically efficient.

Yet the question will remain for at least some engineers whether working to achieve humanitarian and sustainability goals under the umbrella of military or defense sponsorship is morally acceptable or most productive. Indeed, as voiced by representatives of non-governmental organizations, military sponsorship poses potential dilemmas of politicization (Bristol, 2006). As a technical remark, although the terms "humanitarian" and "development" are applied in the same vein in the context of engineering approaches, development professionals distinguish "humanitarian" aid and assistance, which is focused on providing immediate relief, from "development", which is understood to work toward longer term goals. In this sense, aid agencies and non-governmental organizations typically view the military role to be as playing a support role for "humanitarian aid", but no role in "development assistance" (Integrated Regional Information Networks, 2008).

Concluding Remarks

While military and defense interests continue to be omnipresent in engineering research, development, and practice, new alternatives are emerging for engineers who seek to avoid such activities on ethical grounds, and/or who seek to devote their efforts directly to addressing societal needs that are not addressed by military or defense initiatives. Eradication of poverty and the corresponding development requisites will crucially depend on the contributions of engineers, who in turn must respond by devoting their energies toward new priorities through new ways of imagining engineering and technology.

The crux of this matter is to engender organized and institutionalized support and incentives for engineers to focus their creativity and expertise toward serving developing societies, in ways that directly involve and listen to the recipient community. In developing communities with limited infrastructure and low levels of education, the rich world's technologies are not always applicable. Technologies that are costly and require knowledge-intensive maintenance, for example, are inappropriate for low-income communities. As the second author has experienced in rural Panama, lack of electricity and road access inhibits the implementation of ideal solutions for water treatment and sanitation problems. Sand filters go unmaintained, creating potential breeding grounds for bacteria; chlorination is difficult to regulate and in the presence of organic materials poses the threat of creating cancer-causing byproducts; and septic tanks and lined latrine pits cannot be emptied and unlined pits potentially contaminate groundwater. Experts in appropriate technologies widely agree that simplicity of design is key to enabling indigenous control and long-term maintenance of any new infrastructure or technology (Smith, 2008; Parsons, 1997).

Many in the grass roots of engineering are already responding to this call. But the full potential of engineering as a discipline will not be realized without substantive changes in priorities and standards at the disciplinary level. George Catalano (2004), for example, has suggested explicit incorporation of paradigms for peace in the ABET criteria that govern engineering curricula in the U.S. The intent is that at least, if trained, students will apply these ideas in the context of otherwise usual jobs in engineering practice. And perhaps if funding agencies and university executive bodies will provide incentives and institutional legitimacy for R&D activities in appropriate technologies for developing communities, greater investments and results by graduate students and research faculty will follow.

Responding to these challenges not only will positively influence the developing world but also the profession of engineering itself. One view of development-related engineering shows that "having to "throw away the book" and go back to "first principles" when addressing a problem in an unfamiliar, resource-poor context" can be both a challenge and a source of pride of engineering creativity (Wilson, 2008). Moreover, a significant body of research in engineering education has demonstrated that the image of engineering as a discipline that is oriented around helping others will attract students who traditionally avoid engineering (National Academy of Engineering, 2005).

In summary, while the efforts of engineers alone will not solve the world's development problems, comprehensive development solutions demand the participation of engineers. In the words of Maurice Strong, Secretary General of the 1992 UN Conference on Environment and Development, "[s]ustainable development will be impossible without the full input by the engineering profession" (Amadei, 2004).

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Section 5

Engineers in Civil Society

Introduction

Joseph C. Pitt

In this section we look at some of the dimensions of considering the engineer in civil society. A number of questions are explored, among them:

- How do various ideologies of engineering affect how engineers understand their roles in society?
- What are the relationships among engineers' political, religious, and ethical beliefs?
- What should be the obligations of engineers with respect to acknowledging the relevance of the knowledge produced by non-engineers to their work?
- How are engineers represented in science fiction ?
- How can we use film in engineering education?
- What are the social risks of engineering?

All professionals tend to live semi-schizoid lives: they are members of society, equipped with values, goals, and background assumptions, who have obligations as wives, husbands, fathers, mothers, consumers, voters, etc., but they also have certain skills as members of a profession with specific obligations, as members of that profession, to use those skills wisely and in accordance with the rules, policies and codes of behavior of that profession. Further, those rules, codes, and policies reflect a certain stance the profession takes toward society that in turn helps mold the image of the professional and eventually informs how we, other members of society, see those professionals. Engineers, in these respects, are like other professionals. But the engineer is also different.

Engineers differ from other professionals by way of the kind of influence they exert in society as shapers and creators of technologies that transform how we live our lives. In an increasingly technological world it becomes increasingly important to understand the social forces that mold engineers and sources of the engineering *ethos*. One such factor is the professional engineering society. These societies play an enormous role in articulating the responsibilities as well as the worldview of their members qua engineers.

In *How Engineers Contextualize themselves,* Matthew Wisnioski explores the sources of some of the ideologies that influence how engineers behave as engineers and some of the conflicts competing ideologies create. Crucial to an engineering ideology is a conception of what ought to be the case, what engineering ought to be paying attention to, what engineers ought to do, both with respect to their employers and as citizen engineers. These ideologies are central to forming in an engineer's mind the image of himself or herself as an engineer. They play defining roles and they can create genuine problems for engineers who find that the demands of the engineering ideology conflict with other values they hold.

Thus, in *Religious and Political Values and the Engineering Ethos,* Christelle Didier explores the impact of religious and political values of engineers on their ethical values. She has conducted an empirical study of engineers in France. Relying on survey data, she explores differences between catholic and non-catholic engineers, including gender differences, socio-economic backgrounds and other variables. Her conclusion, that religious and political values have an impact on the ethical views of engineers, contributes greatly to our understanding microethical issues in engineering.

Joseph Herkert, in *Macroethics in Engineering: The Case of Climate Change,* explores the need for greater attention to macroethical factors in engineering codes of ethics. By this he means questions of collective responsibility. The case he examines is climate change. After noting that there has been a consensus in the scientific world about the fact of global warming, he examines the ethical responsibilities of engineers who ignore that consensus and continue to raise the possibility that there is no real climate change going on. The point of the case study is to focus attention on the need for engineering societies to build into their codes some notion of responsibility that requires engineers to acknowledge the knowledge produced by others and the fact that they are not the only voices that matter when it comes to transforming the world in which we live.

Joseph Pitt and Jen Schneider turn to a different set of concerns involving various literary media. Pitt examines the representation of engineers in science fiction, exploring their portrayal as tools of the commercial world. Schneider takes on the problem of using film in engineering education, noting first that it is very difficult to find commercial films in which engineers are explicitly identified as such. After reviewing some of the difficulties inherent in using film as a pedagogical device, she suggests three approaches, film as history, film as technology, film as ethics, and she ends her discussion with the idea of film as art. Although she doesn't head deeply into this mind field, one quick note should give a sense of the difficulty of the problem. For the most part, engineering students aren't interested in art. And any attempt to get them interested in the technology of film making will quickly be interpreted as some kind of ruse. It is not that much can be conveyed about the social context in which engineers will find themselves through film, it is, rather, that engineering students rarely have a great interest in the social.

The social, however, is very much the concern of Wayne Ambler in *Social Risks of Engineering.* Ambler is not so much concerned with, for example, the unintended consequences of a particular technology as he is with what he calls the "technological way of thinking". In particular, he explores in depth the conflict between the drive for technological innovation and the need for social and political stability. In this sense he is examining the social risks of engineering as a way of life.

The moral to be derived from these essays is that engineering is embedded in our cultures, just as engineers are. The complex of factors influencing how we see and understand engineers and how they understand themselves and their various roles, is complicated and hard to unravel, for it is not clear that there are direct lines of causality between individual, culture and being an engineer. The relationships are complicated and messy, as is the world.

Chapter 22

How Engineers Contextualize Themselves

Matthew H. Wisnioski

Abstract: Engineering is an inherently normative practice dependent on how engineers understand history. Ideology, however, when mentioned in an engineering context typically brings to mind extremist regimes such as Nazi Germany or Stalinist Russia. But all engineers practice with assumptions about how their interventions in the material world will change society. The historian of American engineering Edwin Layton called this set of socio-political beliefs *the ideology of engineering*. Engineers' beliefs, however, have not been uniform across time and geography. Engineers have worked in specific national, international, corporate, and government contexts that have influenced how they see society's past, present, and future. This essay surveys the historical literature on ideologies of engineering and presents a detailed case study of conflicting worldviews in 1960s American engineering to explore how engineers have acted upon differing normative visions. I argue that studying how engineers contextualize their world – particularly during moments of historical crisis – provides a source of inspiration and classroom instruction for those concerned with the current "crisis of engineering" in a global world.

Key words: Contextualization, New Engineer, Ideology, Responsibility, Technological Change, Globalization

The Many Shades of New Engineering

Engineers make their own context. They define what it means to be a professional, to be responsible, to be an American, a Swede, or a global citizen. Not anything goes in this act of contextualizing. The laws of physics and nations apply, budget offices reign, contracts must be honored, social norms obeyed. But like the material world, which a skilled engineer bends to his or her will, who engineers are also is malleable.

In the normal state of affairs, engineers collapse *is* into *ought*, focusing on solutions to problems without incorporating how a problem came to be, what sets its boundaries, and how reconceptualizing its past has the potential to redefine engineering itself (Alder, 1997). This strategy is in part born of necessity. If engineers challenged every aspect of their being, they would not be engineers but rather skeptic philosophers and historians, incapable of resolving their disputations on time and under budget. But it is also a strategy premised on sequestering the social from the technical in constructions of society and self. To question whom or what one serves is to cast doubt on present needs and to challenge the social order.

A minority of engineers, however, dedicate careers trying to make engineering transcend the needs of the day. Not satisfied with engineering in the world as it is, these visionaries seek to articulate and build into reality what it should be. As a consequence of their contextualizing in the United States we currently have the *Engineer of 2020* (National Academy of Engineering, 2004). Forty years ago it was the New Professionalism, before that a mandate for engineer-economists.

At the edges of the profession, questions of who engineers should be can take on an overtly political cast with the intention of provoking change in the mainstream. Organizations from Technocracy, Inc. to Engineers Without Borders have sought to remake engineering to control a failing global economy, to restore human values to autonomous technology, or to bring modernity's fruits to the other ninety percent of humanity.

Those most concerned with recontextualizing engineering often turn to history, literature, or the social sciences to form an ideological basis for implementing change. Assisted by humanist and social scientist mediators, they use these sources not to understand the past on its own terms, but to mine history and culture as sources of meaning in the present and guides to the future, sometimes reaching as far back as the Neolithic Age for a usable past.

The engineer as social theorist in action is a phenomenon hardly unique to the United States. Whether in calls for "Bildung in Engineering" or "new Renaissance engineers," a concerned minority from Denmark to Australia, is turning to local heritages to produce flexible engineers for a global world. Indeed, this volume's organizers have argued in a previous transatlantic collaboration that: "it seems justifiable to speak of a general crisis in engineering education calling for 'a new engineer.'" (Christensen *et al.*, 2007)

By studying how engineers have used ideology to remake their world, this essay seeks both to interrogate and contribute to efforts to design "new engineers." I first highlight tensions raised by the prospect of engineering in a "global context" by surveying engineers' past engagements with nationalist ideologies. I then turn to a detailed study of another engineering crisis – the culture wars of late 1960s America – to show how disputes about the meaning of technology can reshape engineering's dominant images and practices. Finally, I argue that historical accounts of how engineers contextualize their world during periods of conflict offer reformers a more robust usable past than narratives of context.

Ideologies of Engineering

Do engineers across borders share a common perspective that transcends local tradition and national interest? Edwin Layton (1971) asserted the historical emergence of a common engineering ethos when he posited the existence of an *ideology of engineering*. Engineers, he explained, are hybrid agents, borrowing from the worldview of the scientist and the businessman, yet identifiable as neither.

To create a unique social identity, American engineers in the early 20th century propagated a set of beliefs about society and self that drew upon a powerful new rhetoric of *technology* as the wellspring of social progress. In a Machine Age rife with class warfare and alienation, engineers portrayed themselves as heroic servants, harnessing man and nature to build technological systems for the greater good.

As engineers crafted their normative vision, they claimed sole authority over the domain of technology. *The Machine* was neither an autonomous historical force nor a collective cultural achievement; it was the product of the engineer's organized intelligence. This creative agency was fused with prevailing notions of masculinity, middle-class respectability, and, for leading reformers, progressive politics. The *professional* engineer was to apply his *scientific expertise* guided by *moral* virtue. His pursuit of *efficiency* would eradicate waste to bring *profit* to all, *bridging* rifts between Labor and the Captains of Industry.

The ideology of engineering was a resilient set of beliefs despite the fact that its point of origin belied its mythic nature. It cast engineers as autonomous experts, while most were employed in the bureaucratic hierarchy of industrial corporations. But the ideology of engineering maintained its allure even when it failed in practice. Railing against industry's control of professional standards, in the 1910s-1920s a core of reformers drew upon this ideology to challenge the corporate status quo as a first step in remaking society at large. Significantly, however, most of the same forces that led reformers to believe engineers should be at the vanguard of social change via autonomous expertise, proved even more effective in supporting a vision in which the corporation was the necessary agent of social progress. Supporters of this worldview recast rank-and-file service as subordination to the corporation for the greater good, and argued that the rise to top management marked the pinnacle of professionalism (Noble, 1977; Oldenziel, 1999).

A quarter century of historical scholarship has proven Layton's notion of a unitary ideology of engineering to be an Amerocentric perspective, at the same time that it has reinforced the importance of ideology in the lives of engineers. In different national territories engineers have been trained to serve a range of organizational structures and social philosophies that make any single explanation of what it means to be an engineer untenable (Bailes, 1978; Hecht, 1998; Meiksins, 1996). Currently, there at least forty-five distinct paths in Europe alone, from the *Akademiingeniør* to the *Ingénieur technicien* (Lucena *et al*., 2008). Moreover, who engineers should be changes, sometimes dramatically, even within these boundaries. In Germany, for example, engineers who were avid servants of the Nazi project of reactionary modernism became supporters of Communist engineering in the German Democratic Republic (Herf, 1984; Augustine, 2007).

We might identify these distinct political ideologies among engineers of different countries to prove that context matters. No doubt it confirms Ken Alder's (1997) adage that "engineers are designed to serve." On the other hand, we might argue that it tells us something *universal* about the character of engineers, that as C.P. Snow (1954) once wrote: "In nine cases out of ten engineers are acceptant of any regime in which they find themselves."

My claim is that if these historical accounts offer a useable past to engineers, it is the recognition of how embracing or resisting ideology always is an act of contextualization – not only of social goals but also of who engineers are and what they are for. I am primarily interested in the engineers in Snow's remaining tenth, but even the most compliant organization man structures his vision of past, present, and future in such a way as to make resistance seem inconceivable. In both extremes engineers rework their social politics hand-in-hand with the work of defining their uniqueness as engineers.

The somewhat out of fashion concept of ideology best conveys how engineers' visions of society and self structure experience and guide future action. Studying ideology draws attention to the critical role of the minority of engineers who attempt to scale up their societal visions. Ideologies are not rigid sets of values, but rather plastic networks of sometimes contradictory ideas, images, and practices that individuals use to enroll others toward shared goals and a common sense of self.

Still, ideas have consequences and some concepts are more flexible or constraining than others. The failure of progressive reformers in America to make good on their vision at the same moment that their values were espoused in a different register by the businessmen that defeated them, is indicative of ideology's flexibility and limitations. Ideological concepts, moreover, are often powerful on the local or national level but either fail to extend beyond these borders or are translated and modified when exchanged across them. *Bildung* in engineering, for example, may be an effective strategy in Germany; have the potential to be enrolled with the contested but powerful concept of *Europe*; and likely will find little traction across the Atlantic.

Making the Local Universal

Accepting the local character of ideology-making, how then can we account for the obvious similarities among engineering cultures internationally, particularly since what it means to be an engineer appears to be converging as a consequence of transformations in the global economy?

For one, engineers have never lived in hermetic national containers. Whether in frontier expeditions, the development of colonial infrastructures, humanitarian missions, or corporate multinational outsourcing, engineers, their practices, and their devices have been among modernity's most mobile actors. While most engineers have been fiercely protective of local norms and standards, they nonetheless have altered and recontextualized their practices and ideas in this international circulation. The nationalist policymakers who worry about falling behind accelerate this exchange in their desire to know what competitors are doing to define what it means to compete.

At the same time, the expansion of multinational corporations and the globalization of design and manufacturing have brought the role of circulation in engineering to the fore of international consciousness. But employers' visions of what engineers are and whom they serve are sometimes at odds with those of professional societies, national policymakers, and engineering educators. Consequently, one finds both employers and professional organizations expressing fear about autonomous social changes that engineers are failing to master.

Two powerful keywords – *technology* and *globalization* – are at the center of local efforts to contextualize these macroscopic economic, material and social changes. Recognizing how these concepts have come to structure engineering's normative vision is of more than mere academic interest, because "while 'technology' expands its rhetorical reach, that of 'engineering' shrinks" (Williams, 2002). But the hazardous concepts (Marx, 1998) of *technology* and *globalization*, as well as the visions of historical change they support, are not spread by their own volition. They have been and continue to be appropriated, modified, and promoted by individuals and organizations – including engineers – in support of political and material projects.

The historical period I know best, the American 1960s, offers vital insight into the processes by which engineers make coherent their changing world by contextualizing the meaning of technology. In the cultural revolutions of the late 1960s factions within American engineering struggled to enlist the profession's majority in normative visions that challenged dominant narratives of the engineer's societal role. It provides not only a case from which to generalize about ideology in engineering cultures, but also an understanding of the undercurrents behind the current clamor for "new engineers."

Engineering the (Counter)Revolution in 1960s America

In the late 1960s, American engineers' compression of *is* into *ought* exploded in stunning fashion. Confronted with critiques of technology from without and changes in labor and knowledge practices from within, engineers' semantic control over technology threatened to unravel. Decrying an onslaught of "New Luddites," professional society officers beseeched engineers to "look back in history and recognize the frailty of the philosophical foundations upon which our acceptance of technology rests" (Marlowe, 1970). At the same time, radicalized engineers preached "revolutionary engineering" for "countertechnology" (Aquarius Project, 1971).

The heyday of the Cold War scientific state – from roughly 1950 to 1969 – brought about the largest transformation in the engineering profession since the rise of the corporation. Engineering expanded rapidly to maintain domestic, military, and cosmic supremacy. Depending upon who was counting, engineering manpower in the United States increased four-fold from 250,000 after World War II to over 1,000,000 by 1965. The consolidation of America's largest corporations was equally impressive. Nearly 75 percent of the engineering workforce was employed in just 1 percent of all firms. For engineers, however, the most visible change was the expansion of government patronage. When corporate contracts for federal R&D were taken into account, the United States government had become the profession's largest employer, supporting the work of 45 percent of the nation's engineers (National Science Foundation, 1968; Perrucci and Gerstl, 1969).

In the political economy of Cold War, engineers' self-image evolved from system-builders to servants of the system. The cultural ascendancy of the scientist, contract-based work on giant teams, and the compartmentalization mandated by secret research strained the tenability of narratives of autonomous expertise or entrepreneurship for the rank-and-file, prompting disgruntled engineers to describe themselves as "high-class migrant labor" (Wakeman, 1970). The success of a handful of systems-entrepreneurs such as Simon Ramo and engineering-scientists like Vannevar Bush provided templates for new identities, but did little to combat the image of engineers as organization men.

Instead of an America of unbridled technological optimism, engineers found themselves in a hostile intellectual world. The rise of civil rights, environmental, and antiwar movements challenged the authority of the institutions that engineers served at the same time that they reified technology's agency in social change. Technology, which had been the de facto marker of societal achievement, became a specter of out-of-control power. Texts like Lewis Mumford's *Myth of the Machine* (1967, 1970), Jacques Ellul's *Technological Society* (1964), and Herbert Marcuse's *One Dimensional Man* (1964) portrayed society as totalitarian, based on rationalizing, destructive values. According to these intellectuals, unless the existing system was dismantled, there was no hope for a future in which technology enhanced the "human center."

By the late 1960s, engineers of all stripes concluded that the world was in the midst of a crisis of modernity, characterized by men on the moon and children on fire; campus research centers occupied by student dissidents; environmental hazards resistant to linear solutions; an aerospace industry subsidized by the Department of Defense; a creed of individualism and company loyalty in a system that normalized mass layoffs; and a popular culture in which journalists wrote proudly that "There is no stopping the engineering mentality, we can only try and stop the Engineers" (Marine, 1969).

It would be a mistake to recognize these changes inside engineering and trace how the *context* of the late 1960s impacted the profession in one way or another. Rather, given the multitude of challenges, this historical moment offers a rich case of how engineers *contextualize* ideas and events in order to negotiate who they are and what they do. While the proximate causes of the crisis were new demands for pollution control, ecological harmony, and the conversion of techniques of warfare to welfare, above all else engineers experienced it as an existential and intellectual threat. As *technology* expanded its rhetorical reach, engineers feared that they were losing their identity as its masters.

A tiny minority, no more than a few thousand engineers, responded by turning to the growing genre of *Technology & Society* literature, written by American and European intellectuals, in an attempt to retool engineering's normative vision. This literature encompassed a range of beliefs, but two competing positions dominated how partisan intellectuals talked about technology.

The political theorist Langdon Winner (1977) described the first position – advocated in the writings of critics like Ellul and Mumford – as an ideology of *technological politics*. This view had two defining tenets: (i) technical decisions were inherently political, and thus technological systems embodied political philosophies; and (ii) once the dominant system was sufficiently advanced, it would become autonomous. Analysis between society's *is* and its *ought* would drive reasoned action to liberate man from totalitarian rationality. In the absence of blueprints for a human-centered society, one's first task was to become aware of his place in the system.

A small core of engineers – generally professors and disaffected defense industry employees – was catalyzed by an ideology of technological politics. They strove to integrate the lessons of technology's critics into their vision of engineering service. John Boyd (1972), a mechanical engineer at WPI, for example, summarized Ellul in his *Journal of Engineering Education* essay "Science is Dead – Long Live Technology!" He claimed that *technique* rendered even engineers into cogs, concluding that engineers needed "to teach how man can use technology rather than be used by it." Underground corporate newsletters and alternative journals like General Electric's *GE Resis-*

tor and the Committee for Social Responsibility in Engineering's (1971) *Spark* were venues for bringing together those interested in recontextualizing engineers as collaborative partners with the public rather than as servants of the "military-industrial complex."

This worldview did not *require* reading critical texts, but doing so provided engineers with intellectual authority. It appealed because it named the complex in which they worked – its control of the economy, employment patterns, Vietnam – and most of all because it confirmed their alienation and offered a way forward. Nor were these engineers guided solely by the beauty of their ideas. In addition to constructing human technology, they saw their criticism as a means for gaining control over their labor and discrediting their enemies.

An ideology of technological politics thus was an attractive proposition because it created new and successful modes of political engagement for engineers. Reform movements within the professional societies and engineering schools pushed for all engineers to better understand technology's critics. Its converts, however, could become so engaged in recontextualizing their profession's past, present, and future that they could lose sight of the goal of engineering it. Indeed, there were few projects where the principles of technological politics were implemented into actual projects. Nonetheless, from the perspective of these engineers, success seemed just over the horizon.

But talking about a revolution extended beyond dissenters and reformers. Alarmed by the outsized impact of the critical minority, the nation's engineering deans, society officers, and top management also strove to restore progressive meaning to engineering through a new vision of technology. They conceded that technology created real problems, but a culture of protest was no solution. With the help of establishment intellectuals they crafted a robust counter-ideology to technological politics in a worldview I call an *ideology of technological change*.

An ideology of technological change posited that technology was neither good, nor evil; neither was it neutral. Technological change was a semi-autonomous force that was accelerating rapidly, outracing the ability of social institutions could adjust. It produced tremendous opportunities, but also social dislocations, alienation, and the threat of nuclear holocaust. Through rational management, however, technology's negative *unintended consequences* could be *minimized* and its positive capacities *maximized*.

Engineers circulated three variants of this worldview. The first called for a new "socio-technologist" – an engineer that would be equally versed in the natural sciences and socio-humanistic learning. Simon Ramo, then one of the nation's best-known engineers, was a vocal advocate of this strand as a means of restoring the profession's heroic luster. In two monographs and over a hundred articles and speeches, he argued that systems engineering would be the *Cure for Chaos* (1969) in a *Century of Mismatch*

(1970) between technology and society. The second placed the onus for socio-technical decisions on the social science and policy think tanks that gave an ideology of technological change its academic credibility (Harvard University Program on Technology and Society, 1972). The third variant targeted the rank-and-file, arguing that the engineer's primary responsibility was to technological change itself. While elite experts resolved the complicated human problems of technology, the majority of engineers were to keep pace with accelerating change.

Advocates of both an ideology of technological politics and technological change in the late 1960s and early 1970s targeted the nation's engineering schools as the key battleground for reform. That engineering schools were such an important focus of attention comes as no surprise. It was in pedagogy where "new engineers" could be formed before students were disciplined into existing norms. It was also where engineers had greatest access not only to texts in the *technology & society* genre, but in many cases to the authors themselves.

At least since the aftermath of Sputnik, educators had struggled to establish a distinct identity for engineers amid Cold War transformations, particularly the new hegemony of science. Exacerbated by campus unrest, critical theories of technology redirected institutional reform. The same organizations that had pushed to overhaul the nation's curricula to produce engineering-scientists now explored how to use "liberal education" to distinguish the "genuine engineer" from the irresponsible scientist and the menial "technician" as a man who could envision the "system of the future as a whole." (ASEE Humanistic-Social Research Project, 1968) One survey identified over 200 schools revamping their curricula (Knepler, 1973).

Some engineering educators found themselves empowered in the rush for change. The active mediation of humanists and social scientists made pedagogical reform possible. The historian Lynn White (1967), for example, called engineers "the chief revolutionaries of our time" and suggested that humanists and engineers join forces in the creation of a "new humanism" and a "global democratic culture."

Still, educators conceived of what engineers were for differently, and thus read history differently. A handful of faculties and programs sought to use the past to train humility and alternative power relations in technological decisions. Harvey Mudd College, for example, pursued a model in which classic texts were used to recognize that problems of human nature could not simply be engineered out of existence (Waldman, 1971). The great majority of educators, however, cultivated an ideology of technological change. They used historical texts to instruct that the consequences of rapid technological change had been unforeseen, but now that its logic was identified, it could be managed by incorporating history and culture as variables in formal design methodologies (Rosenstein, 1968).

At the center of these differing interpretations were assertions of whether the engineer was a "conscious agent of social change," or a tool to be directed by change's "manipulators" (ASEE Humanistic-Social Research Project, 1968; De Simone, 1968). However, once establishment intellectuals, top management, society officers, and many educators contextualized a vision that both explained technology's ill effects and absolved engineers for the "unintended consequences" of their work, the force of alternative visions dissipated. Re-fusing the divide between *is* and *ought*, American engineers in the early 1970s internalized an ideology of technological change as a self-evident reality rather than a socio-political worldview.

This moment of rupture in American engineering offers two significant insights about engineering formation – one hopeful, the other cautionary:

1. During moments of expressed crisis, engineers – especially engineering educators – are more likely to turn to texts, practices, and human collaborators outside the accepted realm of engineering to recontextualize what engineering is and who (or what) it should serve.

2. Challenged by alternative models of engineering, those vested in the dominant practices of engineering do not simply dismiss technology's critics, they craft *counter-ideologies* that recontextualize the reformers' claims to weaken their impact.

In other words, the story of engineers in the late 1960s ultimately is not about alternative conceptions of whom engineers are for. Rather, it is an account of the contextualization of the hazardous concepts that structure the lives not only of engineers, but of most citizens of the globalized world.

Conclusion: Change without Change?

The historical inquiries into ideological formation presented here offer those concerned with educating "new engineers" in the age of Microsoft and Royal Dutch Shell a pedagogical resource by suggesting that we present history to engineers as more than mere context. Since even the most unrepentant humanist will recognize that anything we teach engineers is likely to perform a normative function, engineering educators should emphasize processes of contextualization to help students make meaning of their world, now and in their future careers. To do so values method over genealogy. This is far less likely to lead to mythology or, worse, strong normative control in the workplace (Kunda, 1992), because it gives students the resources to recognize the ways in which dominant images are constructed.

In this regard, studies of conflicting ideologies in engineering are especially valuable. Cases of contradictory worldviews are pedagogically useful because they make visible the processes that take place implicitly in everyday engineering. Attention to opposing conceptions of what engineering is for emphasizes the mechanisms of authority and the reality of alternatives.

Educators might conclude that introducing nascent engineers to the history of conflict in their own ranks will lead to cynicism. While the perhaps quixotic escapades of radicalized engineers in the 1960s fade into obscurity, the meaning of technology developed in reaction has become the "background ideology of modernity" (Habermas, 1972). Indeed, if anything, the rhetorical structure of *globalization* has further likened engineering service to "keeping pace." To read Thomas Friedman (2005) is to read the ideology of technological change in a new register. This vision is the impetus behind many campaigns for "new engineers," which emphasize making engineers maximally appropriate for accelerating global change. What is to be gained, these skeptics might charge, by showing students that the beat goes on?

Thankfully, Bruno Latour (1996) reminds us that to simply conclude that "plus ça change, plus c'est la même chose" is to practice crude scholarship. Engineers are not preordained to reproduce the status quo, and a particular technological future is not inevitable.

Educators – who are critical mediators for helping new engineers contextualize what it means to be a "new engineer" – might apply the lessons of the 1960s to think not about engineers in the *context* of a global world, but rather how they *contextualize* that world in ways that constrain and afford engineers' service. Before asking what competencies make someone maximally appropriate for the global economy it is worth questioning what one assumes *globalization* to be and what engineers should be doing to make it something else. As engineers become involved in global teams, for example, they might focus on where there is room to learn from other groups and where differences are important. By doing so students can learn how to recognize the limitations of the conceptual framework of *technological change* and *globalization* and how those concepts structure their labor.

At the very least, when student exercises aimed at demonstrating the difference between *context* and *contextualization* become integrated into engineering pedagogy, the majority of engineers who do not dedicate their lives to questioning first principles might come to see that there are assumptions involved in their everyday practices – and that in attempting to solve problems they always recontextualize what is given, and thus what is possible.

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Chapter 23

Religious and Political Values and the Engineering Ethos[1]

Christelle Didier

Abstract: In this chapter, I propose to examine the relationship between engineers' political views (leanings as well as interest) and some of the issues discussed in the field of engineering ethics. I will also examine the relationship between religious commitment (belief and practice) and such issues. This reflection is based on the findings from a study that included 3901 French graduate engineers[2]. Although the survey on "Engineers, Science and Society" (ESS) is more relevant in its national context, it contributes to supporting three ideas that are worth considering outside of France: firstly, engineering ethics is neither independent of political persuasion nor of religious values; secondly, there is a need for a more sociologically informed approach to engineering ethics; thirdly, this may have some implications for the teaching of ethics to engineers.

Key words: Religion, Politics, Values, Engineering Ethics

Introduction

Engineering ethics (as it has developed within professional organisations and in engineering education) has not been discussed a great deal in the field of social science, not even in the field of Science and Technology Studies. It has been mostly discussed, especially in the US where it is developed more, by professionals first, and then by

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[1] A special thanks to Mia Farlane and Jen Schneider for proofreading the last version of this paper.

[2] This survey served as the main field research in the project I conducted to obtain my PhD in sociology. The methodological choices and means used to constitute the pool can be found in Didier (2008b, pp.47-50). Some key sociodemographics describing the respondents of the EES survey and those of the CNISF national survey on engineers conducted at the same time can be found in the appendix.

professionals and philosophers involved in collaborative projects, mainly since the very end of the 1970s.

However, one of the first recognised authorities in engineering ethics, the American philosopher Robert Baum, noticed in the early 1980s that the specific social characteristics of engineers had better be taken into account when designing engineering ethics courses. He described the engineer as male (which is still often the case), ill at ease with expressing feelings, in search of the one best way – even when dealing with moral problems – and perceiving engineering as a male profession (Baum, 1980). Unfortunately, Baum's insights regarding a better understanding of the relationships between social factors such as gender (and also social class) and ethical competences (skill, behaviour and also knowledge) were not put to use; there was no study made concerning the impact of the psychological features of this population on its values and ethical attitudes.

More recently, the American philosopher Michael Davis a specialist in professional ethics, put specific questions to social scientists (Davis 1998, p.172). He would have liked them to draw a line between those who might be considered engineers and those who might not, in the same way as Karl Popper drew a line between sciences, non-sciences and pseudo-sciences (Popper, 1963). Indeed, social scientists could contribute to a better understanding of some issues discussed in the field of engineering ethics, but the specific demarcationist approach proposed by Davis may not be the only way to build bridges between engineering ethics and social sciences.

I have already examined the relationship between gender, age and engineering ethics in another work which is still in process. This chapter will focus on two aspects of the engineers' value system(s): political values and religious values. I will describe the relationship between the political and religious attitudes of the respondents to the Popper survey, and their attitude toward engineering ethics issues.

A large part of literature in engineering ethics focuses on the fact that technology and engineering are not value-neutral sciences. Langdon Winner asked if artefacts had politics (Winner, 1986). The question addressed in this chapter is: do engineers have politics? And, then to take this further, what are the links between engineers' politics and their ethics? Lynn White argued in a famous article, published in *Science* in 1967, that the anthropocentric worldview due to Christianity was the main cause for environmental degradation, a growing topic of interest within engineering ethics. This chapter also deals with the religious attitude of engineers, and questions their influence on the individual engineer's view of ethics in their profession.

A clarification is needed here. What one considers a question "related to engineering ethics issues" may differ from one person to another, or from one scholar to another. I know that there are questions other than those I asked in my survey and topics other than the few I analyse in this chapter that may seem crucial – and therefore missing – to some readers. This chapter does not aim to be conclusive regarding the links between politics, religion, and engineering ethics. Its aim is to pose questions and give a better recognition to the importance of the intersections between religion, politics, and engineering ethics. The idea defended here is that engineering ethics is neither politically value-free and nor free of religious values.

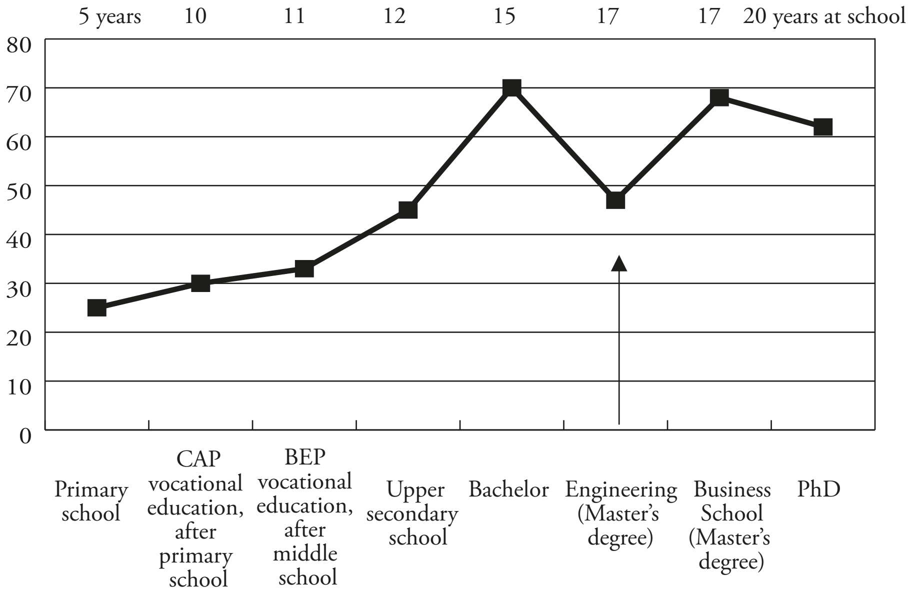
One obvious limitation of this chapter is its purely national focus. Since the 3901 engineers who answered my survey graduated from French engineering schools, the reflection on the engineers' religious attitude focuses solely on Catholicism. The number of respondents belonging to other religions was too low for reliable statistical interpretation. Also, because of the national context of the survey, the political affiliation of the respondent is measured using a left-right one-dimensional scale that is a standard in France. Although this scale is a common way of classifying political positions, it may not mean much in other countries where multi-dimensional spectra are more commonly used in political sciences, such as in the USA.

Engineering Ethics and Politics

The interest of French engineers in politics has already been discussed far from the world of engineering ethicists, in the field of political sciences. One of the main surveys to be quoted dates back to 1979 (Grunberg and Mouriaux, 1979). This survey did not concern only graduate engineers but also other types of managers ("*cadres*" in the French survey). The sample was composed of graduates from business schools, universities, as well as autodidacts. All of them were, at the time of the survey, employed as engineers, managers (middle or upper), or executives in various companies.

In most surveys dealing with political interest, men seem to be more concerned than women. Generally speaking, it also appears that the more people are educated (i.e. the more they have studied), the more they express their interest in politics. All over the world, graduate engineers are mostly male and they are among the most educated in their generation. This was the case in 1979 in France, but surprisingly, in Grunberg and Mouriaux's survey, graduate engineers did not appear to be very concerned with politics. They were less interested than the other *cadres* of the sample, especially those who had a university background (under-graduates as well as graduates and postgraduates). Engineers also expressed less interest in politics than their colleagues who went to business schools. Although this result is not very surprising, it motivated me to investigate further the relationship between politics and engineers.

Table 23.1. Interest in politics in Grunberg and Mouriaux's Survey



Percentage of the respondents "interested in politics", according to their level of education (number of year, and kind of education). Reading : 70% of the *cadres* who hold a bachelor's degree answered that they were *very* interested or *rather* interested in politics.

Political Orientation

One finding of the survey on "engineers, science and society" (ESS) is that graduate engineers rarely occupy extreme positions on the political scale. This scale was composed of seven ranks: 1 for "far left", 7 for "far right". Only 0.7% of the respondents of the ESS sample chose either 1 (0.3%) or 7 (0.4%). The main choice was "5" called here "centre right" (chosen by 33% of them), followed by "4: centre" (24.5%) and then, "3: centre left" (20.7%). Globally speaking, we can see that over one-fourth of the respondents is left wing (1, 2 and 3), one-fourth of them occupy the centre (4) and less than half of them is right wing (5, 6 and 7), most of them holding a "centre right" position (5).

Over the last few decades, political scientists have noted a shift to the left wing of the group called *cadres*[3] in France (Bouffartigue & Gadéa, 2000, p.102). While

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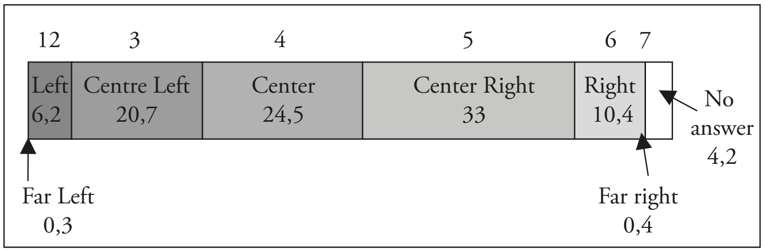
[3] For a better understanding of this social category and of its birth in France, see Boltanski (1987).

its members were traditionally voting for right-wing candidates, they have started voting in the same way as the non-executive employees. Actually, in the ESS survey, the youngest respondents (under 30 years old) are more likely to identify as left-wing than are other engineers. But can a single survey allow us to conclude that this result has to do with the particular age group of the respondents or that it depends on their belonging to a specific generation?

Table 23.2. Engineers's political attitude (ESS sample) on the 7 ranks scale



Two facts may enforce the generational explanation. Firstly, the increasing number of graduate engineers has led them to identify less strongly with the nation's elite. Secondly, the gender and social diversification of the engineering schools' recruitment may also partially explain the shift of the profession towards the left. Actually, engineering schools today are composed of more girls[4] and also more students coming from low-middle class rather than upper-middle class origins. At the same time, the share of the engineers graduated from university programmes, which are less socially selective than the engineering schools, has increased.

Another finding is that the engineers' political orientation depends on their main professional activity. 50% percent of the respondents who work as civil servants and 46% of those who work in the field of education identify as left wing. Conversely, 61% of those who are managing directors, 56% of those are in the field of production, 54% of those who are executives, and 50% of those who work as commercial engineers identify as right wing. Since the share of engineers working for public services and in education is rather low (4% and 3% respectively), their influence on the profession's political view is also negligible. Another influencing factor is the professional sector: the respondents working in the field of construction or agriculture (who operate in small firms based on old technologies) are more likely to be right-wingers.

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[4] Usually women are more likely to be at the right side of the political scales, but this is not the case of most female engineers, especially the younger ones. Engineering is still seen as a male profession, therefore their parents are less likely to be conservative than the males' parents… and political orientation is, for the most part, a question of family socialisation (Didier 2008b, p.109).

Those who work for the state or local government and in the field of communication technologies and computing, (often in large or high-tech companies) are more likely to be left-wingers.

Interest in Politics

The first finding about political interest suggests that engineers are more likely to express their interest in politics than other French people. While 54% of the respondents declare that they are interested in politics ("somewhat" or "very"), this is the case for only 37% of the French people aged 18 and over (Riffault 1994, p.167). This finding is all the less surprising given that the more people are educated – and the older they are – the more likely they are to declare their interest in politics. The French sample used by Hélène Riffault is composed of younger people (from 18 and over, while the younger ESS respondents are 23 years old). It is also composed of many people who are less educated than the in ESS sample, which is composed of graduate engineers only. The French sample is also composed half of women and half of men, whereas only 13% of the ESS respondents are women. And women are usually considered as less engaged in politics than men[5].

We need to go into more detail to understand the relationships between engineers and politics. First we note that the respondents who are most interested in politics belong to two separate groups: the civil servants on the one hand and the top managers and directors, closely followed by the executives, on the other. This result tends to confirm Pierre Bourdieu's thesis that those who express a high interest in politics are those for whom it can be beneficial as individuals (Bourdieu, 2005). Indeed civil servants are more involved in political decision-making than other engineers: they are directly concerned by politics in their work. Also, those who work at the highest levels of management in private companies are very concerned with political decision-making because those decisions may impact on their business.

What about the other engineers? They seem to be more concerned than many less educated people. But, only 13% of those who are employed by a private company declare being "very interested" in politics, while this is the case for 9% of the respondents in the national sample of French men and women over 18. It must also be stressed that to state that one is interested in politics is a highly subjective answer; it has to do with how one sees oneself or wants to be seen. For some people, to state a lack of interest would be embarrassing. Engineers, because they occupy an enviable social position, *have to* be interested in politics. This is even truer for men, because the social pressure is stronger on them than on women.

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[5] In fact, men and women have different ways of thinking about political interest as Debra Horner shows in her researches (Horner, 2008).

Another finding from the ESS survey is that the less the respondent feels free to make decisions at work, the less likely he or she is to say s/he is interested in politics. This feeling is clearly linked to the objective level of responsibility of the respondent. But, as Hélène Riffault has shown, it is even more linked to the degree of satisfaction at work whatever the position on the social and professional ladder (Riffault, 1994, p.101). If male and graduate respondents are very likely to report a higher level of interest in politics, if engineers express a great degree of work satisfaction, as observed in many surveys, that only 13 % of the respondents say they are "very interested" in politics may seems rather low.

Political Attitudes, Business Ethics and Engineering Ethics

A strong majority of ESS survey respondents (74%) believes that "engineers should commit themselves to contributing towards transforming society". The most interested in politics and those who are active in several organizations strongly agree with this statement. The majority of those who disagree are right wing. If we look more closely at the results, we note that those who agree are more numerous among the "centre left wingers", than among "centre right wingers", and than among both extremist groups (rank 1 and rank 7). The three other options come only after.

The answers given by engineers appear paradoxical regarding political commitment and support for unionism. They consider that their profession should be better represented in public debate, but they also declare that being an engineer is not compatible with a political commitment and only 6% declare that they hold a political commitment (at a local, regional or national level). They answer that unionism is not incompatible with being an engineer, but only 7% of them are actually members of a trade-union (or are elected members in order to represent their colleagues and co-workers within their company)[6]. In fact, they declare that to be involved in a trade union is very bad for one's career. Surprisingly or not, this idea of incompatibility is less prevalent among the engineers who are themselves trade-unionists. It is also less prevalent among the youngest respondents. Two hypotheses can be proposed : the first one is that over time the young engineers will come to understand that direct commitment is not possible for them. A more optimistic hypothesis would be that the younger generation is more willing to commit themselves actively than the older generation.

Most business ethics handbooks quote Milton Friedman's famous saying about the *social responsibility* of corporation officials: to make as much money for the stockholders as possible (Friedman 1962, 133). No one will be surprised to learn that the engineers' attitudes towards this position are inextricably linked to their political stand: while 60% of the engineers in position 6 and 7 on the political scale agree with

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[6] For a better understanding of engineers' unionism in France, see Didier (1999).

Friedman, this is true for only 30% of the engineers who are in position 1, 2, or 3. Another statement proposed in the questionnaire was: "do you consider it justifiable for a company to lay off employees when it is making a profit?" Most left-wing engineers disagree (65%) while this is the case for only 32% of the respondents who are at the very right side of the scale (6 and 7). Finally, while only 17% of the left-wingers agree with the idea that "ethics concern solely well-off companies", this is the case for 29% of the right-wingers.

The great majority of the respondents, from the right to the left side of the political scale, appear to be more technophilic than other citizens. It is no surprise that engineers have more faith in technology and in scientific expertise. But their political sensitivities bring some additional nuances to their opinions, especially regarding the relationship between engineering and society. Those who identify as right wing are more optimistic and more likely to think that technology brings more good than harm to society. They are also more likely to trust that technology can solve the problems caused by technology. Those who identify as left wing, express more scepticism regarding the way private companies deliver public information around issues such as risk and safety. They value more than the other engineers the stirring up of public debate on technological problems and controversies, and they are more likely to agree with a greater democratisation of technological decision-making.[7]

Implications for Ethics Education

In 1992, Michael Loui wrote: "from the engineer's point of view, politics is a messy business. (…) Why would an engineer want to participate?" (Loui, 1992). Much earlier, the French historian Bruno Jacomy analysed the early days of the older French engineering professional organization, the *Société centrale des ingénieurs civils*. He stated that its members were clearly avoiding all political discussions and preferred to place emphasis on the scientific and technical vocation of their professional society (Jacomy, 1984). One of the findings of the ESS survey was that the more engineers are involved with technology (rather than management) in their work, the less likely they are to be interested in politics. Yet, many graduate engineers are engaged in mainly technical activities, especially at the beginning of their career, but also until retirement in most cases. Wouldn't it be an ethical problem if we were surrounded by artifacts "with politics" designed by engineers who would believe that their actions on the world is a politically-free, value-free activity?

If the ESS survey does not fully answer the question: "do engineers actually lack an interest in politics?" – no survey could entirely achieve this, in any case – it does

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[7] For more detail on the topics adressed in this last paragraph, see Didier (2008b, pp.126-132). I could explore this last finding in more detail, but it would unfortunately cause this paper to exceed the expected length.

go some way towards discerning some links between the political attitude of the individual engineers and some matters central to the field of engineering ethics. There are most probably various ways of encouraging engineering ethics among professionals and in education, and those various ways are not politically value-free. If the answer to the question "Do engineering ethics have politics?" is yes, we can expect all those who contribute to the engineering ethics forum to be more explicit as concerns the political dimension or implication of their reflexions or proposals. Moreover, if engineering ethics have politics and if engineers are not very interested in politics, engineering ethics education needs, more than ever, to deal with the links between technology and politics.

Engineering Ethics and Engineers' Religious Attitudes

Two main reasons led me to include the topic of religion in my questionnaire. Firstly, when examining the development of engineering ethics education in France, I highlighted two dominant models: one of them was the social catholic one, the other was the "encyclopaedic" or academic one. One of the findings of this research was that questioning religious background helped bring about a better understanding as to why and how engineering ethics courses developed in higher education. Later on, while looking into environmental issues, I came across Lynn White's thesis. According to him, Christianity, more than any other religion and more than atheism, is responsible for the destruction of our natural environment (1967). Although White's work was criticised and contested, it seemed to me that it might be of interest to look at both ethical attitude and religious attitude in my survey.

In my previous research, I found that engineering ethics courses proposed in catholic engineering schools often originated in the heritage of the social teachings of the Catholic Church. At the very end of the nineteenth century, one Jesuit chaplain, in the context of the encyclical *Rerum Novarum,* initiated a reflection on the "social mission of the engineer" (*le rôle social de l'ingénieur*). Soon after, the catholic engineers' social ideology spread widely among the engineering community (beyond the Catholic milieu), and this continued until the middle of the twentieth century. Georges Lamirand wrote a very successful book, republished several times, entitled *le role social de l'ingénieur*. He believed that engineers should serve as mediators between workers and employers and possibly eliminate the conflicts between them. As a consequence of this heritage, the actual courses offered in catholic schools are more often social, business or professional ethics courses than courses based on human and social sciences or linked to the field of Science, Technology and Society.

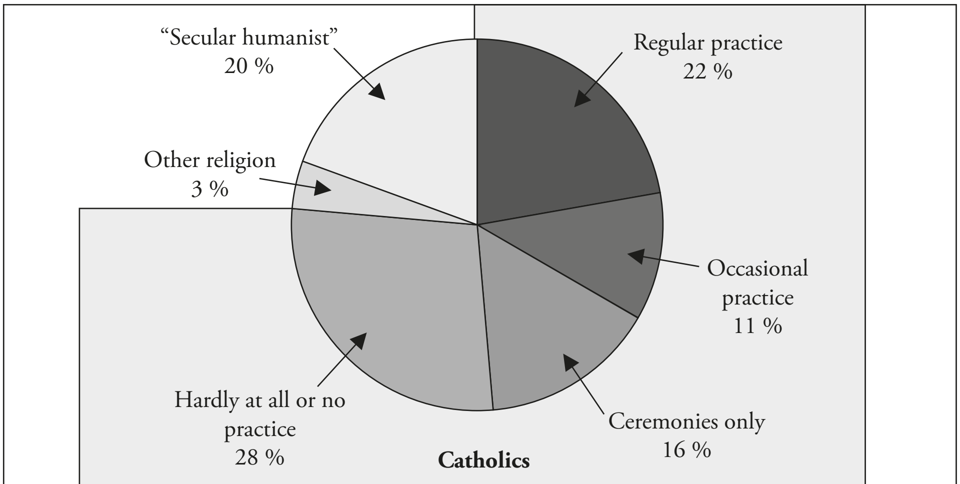
Engineering ethics courses, when offered in public state engineering schools, usually follow another model. They identify with the "encyclopaedic" or academic ideal of the prestigious École Polytechnique, where literature – and more recently philosophy – has always been part of the teaching programme along with sciences since the eighteenth century. Those courses dealing with engineering ethics issues (and they are rarely labelled as such) focus less on the individual duties and obligations of engineers, than on the social complexity of technological decisions. In the schools which follow this model, such courses may include a great deal of epistemology or philosophy of science, and more recently sociology of sciences and technology, as well as sociology of organisations.

If religious background has an influence on the design of courses dealing with engineering ethics, it may also influence the individual engineer's perception and understanding of the ethical issues of engineering. "Are Catholics more socially responsible and less environmentally active because of their ideological heritage?" was one of the questions that I became interested in when analysing the ESS survey.

Engineers' Religious Attitudes Today

Most engineers declare having a religion: 77% of them identify as Catholic, 3% as another religion. This is very similar to what we found in most national survey**s**: in 1995, 75% of the French population declared being close to Catholicism (CEVIPOF, 1995). Some surveys use a filter question. First, the respondents are asked if they consider themselves religious. Only then do they indicate the religion to which they belong. In such surveys, only 62 % of the French respondents declared having a religion in 1990, and 58 % in 1999 (Riffault, 1994; Bréchon, 2000).

Table 23.3. Engineers' religious practice (ESS sample)



Regular practising Catholics represent a rather important proportion of the ESS sample (22%). According to the definition used by French sociologists, a "regular practicing Catholic" is someone who goes to church at least *once a month*. Nowadays, in France, which is one of the less religious countries of Western Europe, those who go to church weekly are too few to be studied separately in a national survey. The great majority of the Catholics in the ESS sample are "more or less" – or even "not at all" – practising, and 20% of the respondents said they had no religion. In comparison, only 12% of the French sample used by Pierre Bréchon declared having a "regular" religious practice (Bréchon, 2000).

Three factors contribute to explaining the difference between the two samples. The first factor is that engineers belong to the upper-middle- and upper class whose members are more likely to be practising than those of the working class. The second notable factor is that the French national sample, as explained earlier in this chapter, is composed of a younger population (people 18 and over), whereas the ESS sample is composed of graduate engineers 23 and over. Since the younger generation is less practising than the older generation, this difference between the samples can go some way towards explaining the difference in the degree of practice. Finally, the ESS sample is composed of engineers who graduated from engineering schools situated in the north of France and the proportion of catholic schools is greater in this region than in all the other French regions. Engineers who are graduates of catholic schools are more likely to be catholic themselves: for instance, 38% of the engineers who come from the *Institut Catholique d'Arts et Métiers* (ICAM, a very old school run by Jesuits) are regular practising Catholics, while this is the case for only 5% of those who come from the École Universitaire D'Ingénieurs de Lille (EUDIL, a public state school which is not very socially elitist).[8]

Demographics of the French Catholic Engineers

What are the differences between practising catholic engineers and the rest of the population, and also what is the difference between those who are regularly practising and non-believers, whom I call in my work, using the term favoured by Yves Lambert

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[8] One factor that does not explain at all the differences between the answers given by the two samples is the gender. Engineers who are mainly male, would be expected to be less religious than a sample of French people composed of half men half women because males are supposed to be less religious than women. In fact, in the ESS survey, this is not the case, and not only because women are younger than men. Even among the respondents who are under 40, men are more religious than women.

(in Riffault (1994, p.133)) and Sylvette Denèfle (1997), the “secular humanist”[9]? First, regularly practising catholic engineers and secular humanists have in common the fact that they come from upper and upper-middle class origins. The hardly at all- or non-practising Catholics come from middle or even working class families and their fathers are less educated than those of the engineers belonging to the two first groups. Also, the largest proportion of families where both parents left school after primary school is among the group of the hardly at all- and non-practising Catholics.

What differentiates the members of the regularly practising Catholics from the secular humanists has to do with the family model: the family of origin as well as the one they create. Secular humanists are more likely to have a mother and a father who studied at university while the most common family model among the regular Catholics is composed of a father who went to university and a mother who is a high school graduate. Another difference worth noting: while 48% of the regularly practising Catholic engineers have a wife (or a husband, though less likely) who does not work outside of the house, this is the case for only 21% of the secular humanist engineers. Regular practising and secular humanists do not come from the same family types, and they also do not build the same kind of families: regular practising Catholics have more children, they are much more often married than the secular humanists, and less often divorced, although engineers are very seldom single (this is true for men only: 98% of them are living in couples).

When defining success in the questionnaire, engineers rank first in order of importance “to have an interesting job” (80%), then “to live a balanced home life” (65%), followed by “to bring up one or several children” (58%). The two next choices are “to earn a lot of money” and “to be active in a cultural, social or political field”: they are both chosen by 19% of the respondents. While regular practising catholic engineers and secular humanists make the same first choice, the order of the two next choices is reversed: for the regular practising Catholics, bringing up children comes before having a balanced home life. Then we can note that “earning a lot of money” is half as likely to be chosen by the practising Catholics as by the secular humanists and “to be active in a cultural, social or political field” is more frequently chosen by the practising Catholics than by the secular humanists. The two last choices are strongly linked to the age of the respondents. The younger respondents declare a preference for the desire to earn money, while the older respondents place greater value on social and political commitment.

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[9] Lambert and Denèfle prefer to talk about the secular humanist rather than the “non”-believers in order to describe people by what they are rather than by what they are not, and because most people who describe themselves as non-believers share what those authors call “secular humanist” values.

Religious Adherence and Moral Attitude

Not only do the members of the two groups rank slightly differently what it is they consider important in life, but also their opinion on how to distinguish between right and wrong, in moral life, is dissimilar. While 36% of the practising Catholics believe that there are clear guidelines that can be followed in any circumstances, this is the opinion of only 14% of the secular humanists. More than half of them believe that discerning right from wrong depends entirely on the circumstances. The proportion of those who consider that neither of the proposals is correct is almost the same in both groups (a little more than one third of both groups).

Some statements proposed in the questionnaire were more accepted by respondents who were Catholics and regularly practicing. This is the case with: "a code of ethics for the engineering profession would help with making decisions in difficult situations". It is also the case with: "pursuing a research project that may violate some moral principles should not be allowed". In another part of the questionnaire, the respondents had to say if they considered it justifiable (by choosing from a 7-rank scale, with 1 for "fully justifiable", and 7 "not at all") to make public confidential information belonging to their company concerning a security problem. The proportion of those who consider this act unjustifiable (ranks 6 and 7) is all the more important as the respondents are Catholics and practising: 40% of the regularly practising chose 6 or 7 on the scale, and only 25 % of the secular humanists (28% of them chose 1 or 2).

But on other matters, the secular humanists and the regularly practising Catholics agree with each other, while their position is dissimilar to that of the hardly at all and non-practicing Catholics. In this category, we can quote "ethics concern solely well-off companies". Even if the proportion of the regularly practicing Catholics who disagree is greater than that of the secular humanists, both are more significant than the proportion of the hardly at all and non-practicing Catholics. Also, the regularly practising Catholics and the secular humanist both disagree much more strongly with the statement which says that the only social responsibility of companies is to make profits, than the other groups. Finally, in both groups, the proportion of those who consider it justifiable (ranks 1 and 2, on the 7-rank scale) for an individual to refuse to take part in one of the projects of the company for personal reasons is more than one third. This proportion is more significant than among the hardly at all and non-practising Catholics. Still, the group for which this proportion is the most significant is from among the regularly practising Catholics who are also members of a religious group. It is even greater among those who also consider that religious authorities should be listened to when deciding which technologies should be developed or not.

What Attitudes Are Specific to Catholic Engineers?

We can conclude from these last figures that on some matters which are very central to engineering ethics – such as the need for professional ethics guidelines for the individual, the ability to refrain from some technological development for moral reasons, and the right to conscientious objection – the engineers' positions are inextricably linked to their religious adherence. We can also note that for some other central topics in engineering ethics – such as defending a wider definition of social responsibility than that of only making profits, such as the need of business ethics guidelines for companies, such as the duty to blow the whistle if needed – regularly practising Catholics have more in common with secular humanists than with hardly at all or non-practising Catholics. It seems that, on those matters, having a clear position regarding religion, whether for or against, is more important than the choice in itself: engineers who have a clear attitude towards religion have in common their sensitivity towards "social ethics". In contrast, the most determinant factor regarding these matters is religious practice: the more engineers are religious (Catholic, here) the more likely they are to place high importance on individual ethics and moral principles.

"Are Catholics too technophilic?": this was one of the questions that motivated me to look at both religion practice and ethical attitude in my research. One finding of the ESS survey is that regularly practising Catholics are not great supporters of environmental organizations, nor do they support activists against nuclear or genetically modified organisms. This type of commitment (political activism) is perhaps not their preferred means of expressing their interest regarding a particular issue. Still, we can note that the strongest influence of the Catholic practice on the rejection of a social movement (in the questionnaire) concerns "environmental movements". To conclude on that topic, engineers are in general quite optimistic about technological development, all the more so when they are Catholic and church-goers. Maybe because they don't share the same understanding of what science is: those who are regularly practising and who are also members of a religious group are twice as likely to define science by "what enables man to have a better life".

Table 23.4. Correlations between the level of religious practice and the political attitude of the respondents (EES sample)

Religion	Catholics				Secular Humanist
Practice	Regular	Occasional	Only Ceremonies	Hardly at all or no	
Left , far left (1,2)	2	3	4	6	18
Center Left (3)	11	15	16	23	37
Centre (4)	25	25	21	30	22
Centre Right (5)	45	42	47	32	18
Right , far right (6,7)	17	14	13	9	6
Total	100	100	100	100	100

Conclusion

Engineering ethics is a young field in the academic world, not yet mature. Many definitions can be given to this concept, from the most prescriptive when focusing on the codes of ethics, to the most descriptive and supposedly "neutral" when focusing on engineering values. In this chapter, I have focused on some aspects of the engineering ethos and tried to show some links between ethical attitudes and two fields of values that are essential to human life in society: politics and religion. My aim is neither to say that a left-wing – or right-wing – engineering ethos is better than the opposite, nor that catholic engineers have a better understanding of ethical issues than secular humanists.

I wish to encourage – especially when thinking about teaching implications – a greater awareness of the fact that the contents and methodologies chosen in the field of engineering ethics are not politically neutral. Ethics and politics are different but they are closely related, especially in engineering because there are so many social consequences. Ethics is not religion-free either, because whether people are religious or not has an influence on the way each person sees ethics in her or his personal as well as professional life. But what is apparent also is that on some matters, the engineers who have a clear position towards Catholicism, whether secular or religious, share similar views, and are opposed to the "cultural Catholics" because of a shared "sense of responsibility" for the world around them. Thus, I would conclude in encouraging educators to develop the students' interest for politics and to invite them to make clear their position towards religion, which can contribute to the students' capacities in the field of engineering ethics.

Appendix: Some sociodemographics of the ESS sample compared to the CNISF national sample (CNISF 2001).

Age	ESS	CNISF
Under 30	18 %	24 %
30-39	37 %	37 %
40-49	22 %	21 %
50-59	16 %	17 %
60 and more	7 %	5 %
Total	100	100

Gender	ESS	CNISF
Male	85 %	83 %
Female	14 %	16 %
Total	100	100

Main activity	ESS	CNISF
Production, manufacturing, construction	12.5 %	10 %
Logistic, quality, security, organisation, environment	15 %	9 %
Research and development	24 %	37 %
Computing, network	16 %	17 %
Sales, technico-commercial	12.5 %	7 %
Admin. : finance, legal, communication or human resources	4 %	3 %
Direction (of a company or a factory)	11%	9 %
Public sector administration	1%	2 %
Teaching, training	3 %	3 %
Other	1 %	3 %
Total	100	100

Activity sector of the company	**ESS**	**CNISF**
Industry, energy	41 %	35 %
Computing (service)	9 %	9 %
Food industry, agriculture	8 %	6 %
Commerce, distribution, transport	7 %	7 %
Telecommunications	7 %	4 %
Research department	6 %	10 %
Civil servant : state, region, hospital	4 %	4 %
Building, public works	4 %	4 %
Finance, bank, insurance	4 %	4 %
Non technical consulting, audit	4 %	8 %
Teaching	2 %	9 %
Other	2 %	9 %
Total	100	100

Size of the company	**ESS**	**CNISF**
No employee	1 %	1 %
Less than 20 employees	8 %	7 %
21 to 499	32 %	27 %
500 to 4 999	25 %	25 %
5000 and more	34 %	40 %
Total	100	100

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Chapter 24

Macroethics in Engineering: The Case of Climate Change

Joseph Herkert

Abstract: Human-induced climate change is one of the most significant policy challenges of the 21st century, and thus of critical interest to engineers and professional engineering groups. Less obvious are the ethical challenges for engineers posed by the climate change issue. Indeed, climate change is one of the most important macroethical challenges of our time, in terms of both intragenerational and intergenerational equity. Engineering as a profession has become more sensitive to environmental issues over the past decades, and some engineers and professional engineering societies have even begun to focus attention on the broader concept of sustainable development. These concerns have begun to be reflected in engineering codes of ethics, albeit with a focus on microethical (individual) responsibilities. More attention on macroethical (collective) responsibilities is required in the codes. While the participation by engineers in public policy discussions of climate change is important, engineers have an ethical responsibility to acknowledge the scientific consensus on the significant role of human activities in causing recent and future climate changes.

Key words: Climate Change, Codes of Ethics, Engineering Ethics, Intergenerational Equity, Macroethics, Sustainability

Introduction

> *"So, let me conclude somewhat provocatively by suggesting that the global community should let the CO_2 rise as it may and spend the money that the populace seems to want to devote to its stabilisation or reduction on research. At this level of expenditure (some \$50 billion/annum), this would assure new ways of finding the energy to enhance standards of living without devouring fossil fuels; it might also provide us with political freedoms that we would appreciate greatly".*
>
> Raymond Spier (2008, p.2)

The preceding quotation concluded a recent editorial comment in the journal *Science and Engineering Ethics* under the headline "Climate – An Item for the Ethics Agenda." That the leading journal in the field of engineering ethics would weigh in at this late date in the debate over climate change and endorse a "do-nothing" strategy is a prime example of the lack of consideration given to the climate change problem in the field of engineering ethics. Indeed, climate change is an example of "macroethical" problems and issues that have until recently been given short shrift in traditional approaches to engineering ethics.

Human-induced climate change is widely recognized as one of the most daunting policy challenges of the 21st century. Less obvious to many, including engineers, are the ethical dimensions of climate change. While (mis)use of technology is arguably responsible for human-induced climate change, few would argue that solutions to the problem can be obtained without further use of technology, whether by reducing carbon emissions with technologies such as wind power and alternative fuels vehicles or deploying technological fixes for the problem such as carbon sequestration and geoengineering. Engineering thus plays a critical role in addressing the problem, as do many other disciplines. While engineering as a profession has become more sensitive to environmental issues over the past several decades, and some engineers and professional engineering societies have even begun to consider social, environmental and economic aspects of sustainable development, there has been little serious discussion to date on the ethical responsibilities of engineers with respect to global climate change.

This chapter attempts to begin to fill this void by considering the following questions:

- What are the individual and collective ethical responsibilities of engineers with respect to human-induced climate change?
- How and to what extent should engineers and professional engineering societies contribute to public policy debates on climate change?
- Do the traditionally recognized (microethical) responsibilities of engineers (as conveyed, for example, in codes of ethics) provide an adequate response to macroethical issues such as climate change?
- Are new tools and institutions necessary for engineering to fulfill its ethical responsibilities concerning issues such as climate change?

Microethics and Macroethics in Engineering

"Ethical responsibility...involves more than leading a decent, honest, truthful life, as important as such lives certainly remain. And it involves something much more than making wise choices when such choices suddenly, unexpectedly present themselves. Our moral obligations must...include a willingness to engage others in the difficult work of defining the crucial choices that confront technological society and how to confront them intelligently".

Langdon Winner (1990, p. 61)

During the past three decades, as engineering ethics has emerged as an academic subfield, several authors, including the ethicist John Ladd (1985), have noted that the content of engineering ethics encompasses multiple domains. The field can be viewed from three frames of reference – individual, professional, and social – that can be divided into "microethics," concerned with ethical decision making by individual engineers and the engineering profession's internal relationships, and "macroethics," referring to the profession's collective social responsibility and to societal decisions about technology (Herkert, 2001). Microethical issues in engineering include such matters as designing safe products and not accepting bribes or participating in kickback schemes. Macroethics in engineering includes the social responsibilities of engineers and the engineering profession concerning societal issues such as sustainable development and the ethics of emerging technologies. This distinction can also be applied to other fields of applied ethics, such as research ethics (see table 24.1 below).

Table 24.1: Some Microethical and Macroethical Issues in Science and Engineering

	Engineering Practice	Scientific Research
Microethics	Health and safety Bribes and gifts	Integrity of data Fair credit
Macroethics	Sustainable development Climate change	Human cloning Stem cell research

Research and teaching related to engineering ethics to date have for the most part focused on microanalysis of individual ethical dilemmas in such areas as health and safety issues in engineering design, conflict of interest, representation of test data, whistle blowing, accountability to clients and customers, quality control, trade secrets, and gift giving (Herkert, 2000) with little attention being paid to macroethics in engineering and still less to attempts at integrating microethical and macroethical approaches to engineering ethics. The melding of ethics and professionalism has significantly contributed to the development of engineering ethics concepts. At the same time, by overemphasizing issues internal to the profession, engineering ethicists have historically tended to neglect macroethical issues (O'Connell and Herkert, 2004).

Recently engineering ethicists and engineering leaders alike have begun to turn their attention to macroethical issues by appealing directly to policy makers and to the engineering profession (National Academy of Engineering, 2003). For example, some professional engineering societies have promoted the concept of sustainable development and the role of engineering in making it a reality. A document prepared by several U.S.-based engineering societies for the Johannesburg Earth Summit 2002 states:

"Creating a sustainable world that provides a safe, secure, healthy life for all peoples is a priority for the US engineering community. It is evident that US engineering must increase its focus on sharing and disseminating information, knowledge and technology that provides access to minerals, materials, energy, water, food and public health while addressing basic human needs. Engineers must deliver solutions that are technically viable, commercially feasible and, environmentally and socially sustainable." (American Association of Engineering Societies *et al*., 2001)

Engineering Initiatives in Response to Climate Change

Consistent with increased interest in sustainable development, engineering organizations worldwide have also begun to show an interest in climate change and engineering's role in addressing its impacts. For example, a project on "Future Climate – Engineering Solutions" from Scandinavian countries and Germany argues (2008): "Overcoming climate changes is the number one engineering challenge of the 21st century. There is a strong need for a reduction of emissions of greenhouse gases (GHG) to a sustainable level. Engineers are involved in every energy systems and we hold valuable knowledge of new sustainable technologies." Professional engineering societies in the United States have also begun to take policy stands on climate change. For example, the American Society for Civil Engineers (ASCE) in 2007 revised their policy on greenhouse gas (GHG) emissions to recommend that: "…Congress should adopt a policy that addresses the emission of greenhouse gases. The policy should lead to significant reductions in national greenhouse gas emissions by:

- Establishing clear and reasonable targets and timeframes for reduction of greenhouse gas emissions.
- Making cost-effective use of existing technologies to improve energy efficiency and reduce greenhouse gas emissions in all sectors, including both stationary and mobile sources.
- Stimulating private investment in greenhouse gas reducing technologies by establishing a market value for greenhouse gas emissions over the long term.
- Incorporating additional incentives for the short term development and implementation of high efficiency and low or zero greenhouse gas emitting technologies and cost-effective carbon capture and storage.
- Providing appropriate assistance to economic sectors, geographic regions and income groups that may be disproportionately impacted by both the effects of climate change and reductions in greenhouse gas emissions.
- Including credit for early action to reduce greenhouse gas emissions.
- Encouraging actions by other countries to reduce their greenhouse gas emissions.
- Encouraging the use of non-greenhouse gas emitting energy-generating sources.
- Exploring the utilization of forests and the ocean as carbon sinks or other mitigation technologies."

Similarly, the ASME (formerly the American Society for Mechanical Engineers) is working on a general position statement on climate change that focuses on reducing carbon emissions.

Though clearly on the radar of the engineering profession, the rationale for action regarding climate change has heretofore been articulated largely in economic and political terms, with little if any discussions of the ethical implications of climate change.

Climate Change and Ethics

Surprisingly, like engineers, philosophers have generally avoided discussion of the ethical issues surrounding climate change. One of the few exceptions is Stephen Gardiner, who in a 2004 review article in *Ethics*, made a strong case to philosophers and other ethicists to embrace the problem.

Gardiner dismisses the issue of scientific uncertainty as grounds for inaction on climate change by noting that "…the really vital issue does not concern the presence of scientific uncertainty, but rather how we decide what to do under such circumstances." (p. 569)

Gardiner then proceeds to outline an array of ethical issues associated with various approaches to and problems posed by climate change including economics (e.g., social discount rate is problematic, some costs and benefits are not accounted for, the ongoing debate over relative costs of adaptation versus abatement); risk management (application of the "Precautionary Principle," especially regarding harm to future generations); responsibility for past emissions and its role in allocating future emissions; and questions of global action (or inaction as the case may be), especially regarding international justice and intergenerational justice.

Codes of Engineering Ethics: Environment and Sustainable Development

More so in the United States than in other countries, codes of engineering ethics express the profession's ethical commitments (Davis, 1988). While none of these codes addresses climate change explicitly, more general provisions regarding the environment and sustainable development began appearing in the codes in the 1990s.

As seen in the following examples from the four major engineering disciplines, all modern engineering ethics codes contain what is known as the "paramountcy clause" which stipulates concern for the public health, safety and welfare as "paramount" among an engineer's ethical responsibilities:

ASME Code of Ethics of Engineers (last revised 2006):
"Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties."

American Institute of Chemical Engineers (AIChE) Code of Ethics (2003):
"Hold paramount the safety, health and welfare of the public and protect the environment in performance of their professional duties."

American Society of Civil Engineers (ASCE) Code of Ethics (2006):
"Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties."

Institute of Electrical and Electronics Engineers (IEEE) Code of Ethics (2006)
"…to accept responsibility in making engineering decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment…"

Beyond the general obligation to uphold the public safety, health, and welfare, the current versions of the codes of the four major societies also acknowledge the importance of the environment and/or the concept of sustainable development. As noted above, the IEEE and the AIChE specifically list environmental protection in their paramountcy clause. In addition to including sustainable development in the paramountcy clause, the ASCE code's first "Fundamental Principle" pledges engineers to "using their knowledge and skill for the enhancement of human welfare and the environment." The ASME Code contains a separate canon providing that "Engineers shall consider environmental impact and sustainable development in the performance of their professional duties."

The question of intergenerational equity, as noted above a key point in ethical deliberations about climate change, is mentioned in two of the codes. The AIChE code provides that its members: "Formally advise their employers or clients (and consider further disclosure, if warranted) if they perceive that a consequence of their duties will adversely affect the present or future health or safety of their colleagues or the public."

A footnote to the ASCE code defines sustainable development as incorporating concern for future generations: "Sustainable Development is the challenge of meeting human needs for natural resources, industrial products, energy, food, transportation, shelter, and effective waste management while conserving and protecting environmental quality and the natural resource base essential for future development." Codes of ethics, then, would seem to lend support to the notion that individual engineers do have ethical responsibilities with respect to climate change in such areas as environmental protection, sustainable development, and intergenerational equity.

Codes of Engineering Ethics: Macroethics

Despite the apparent interest of professional societies in macroethical issues (at least insofar as their articulation of policy positions), the codes of ethics of the societies remain largely focused on microethical issues. One exception, mentioned above, is the prominence of sustainable development in the ASCE code. A second exception is a provision in the IEEE code of ethics on enhancing public understanding of technology: "…to improve the understanding of technology, its appropriate application, and potential consequences." The challenges posed by climate change in particular, and macroethical issues in general, would benefit from more revisions to engineering codes of ethics along these lines.

Engineers and the Scientific Consensus on Climate Change

One area of ethical responsibilities that engineers often overlook is when they challenge or ignore the overwhelming scientific consensus on the problem of human-induced climate change that has existed for many years. For example, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (2007) concluded:

> *"Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level….Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases….Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)…. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century."* (pp. 2-7)

In an essay in *Science*, Oreskes (2004) described a study of the peer reviewed science literature on climate change from 1993 through 2003 and found "[R]emarkably, none of the [928] papers disagreed with the consensus position" outlined by the IPCC. Oreskes further noted: "This analysis shows that scientists publishing in the peer-reviewed literature agree with IPCC, the National Academy of Sciences, and the public statements of their professional societies. Politicians, economists, journalists, and others may have the impression of confusion, disagreement, or discord among climate scientists, but that impression is incorrect." (p. 1686). Despite the scientific consensus, many engineers position themselves among the "politicians, economists, journalists, and others" who, whether intentionally or not, do not accept or recognize it. For example, a column in a recent IEEE publication stated: "Global warming, also known as climate change in some circles, is a politically charged topic. While it is true that the temperature on earth has increased over the past 100 years, it is still uncertain to what extent human behavior has contributed to the trend. One can find convincing arguments on both sides of the debate." (Zobrist, 2007).

In another example, despite the ASCE policy statement on limiting GHG emissions that was mentioned earlier, a recent ASCE President's blog noted:

> *"Global warming is controversial, not only in this country, but around the world.… There are many who firmly believe that unless we reduce our output of CO_2, and do other things to reduce global warming, these climatic changes will have dire consequences for humanity and our environment….There are many others who do not believe that global warming is a result of human actions, but part of long-term climatic change….So what are we, the civil engineers of this world, to believe?"* (Mongan, 2007)

It is difficult to imagine that engineering leaders are not familiar with the scientific consensus on human-induced climate change. Statements such as the above suggest that there are major disagreements on climate change within the mainstream of the scientific community and reflect a deliberate effort to mislead other engineers and the public. It is also arrogant for the authors to assume that their knowledge of climate change outweighs that of the vast majority of scientists who have been studying the problem for many decades.

The codes of ethics of the major US engineering societies are unanimous in their cautioning against engineers making false or biased claims. For example, the ASCE code states that "Engineers shall issue public statements only in an objective and truthful manner." Similarly, the IEEE code pledges its members "…to be honest and realistic in stating claims or estimates based on available data".

One might argue, as Vesilind (2001) does, that professional ethical responsibilities only apply to statements made by engineers as engineers and that different standards may arise in their role as citizens. Commenting on a case study, Vesilind notes:

> *"…as a private citizen, Tom can advise the group and even represent them in a public hearing. Tom cannot do that in his role as a university researcher or a participant in a government-sponsored study, but his knowledge can be put to good use in his role as citizen. If he strongly suspects that the power plant is causing the pH to be depressed, then he has a moral obligation to say so. In contrast to his role as citizen/adviser, in his published scientific papers he has an obligation to refrain from suggesting that the problem is caused by the power plant unless he lists this possibility as one of several.… In Tom's case, the appropriate role of the scientist is to question everything and to publish irrefutable data. As a citizen, his role ought to be to advise the people who could make a difference and perhaps save the lakes."*

One problem with this line of argument is that it may not always be possible to distinguish the role of engineer from the role of citizen, as in the writings on climate change noted above where the engineers were writing in engineering publications read by other engineers. Climate change is thus an important reminder not only of the differences between microethics (individual behavior) and macroethics (public policy) but the need to reconcile the two.

Conclusions

As this brief overview has indicated, engineers have individual and collective moral responsibilities regarding climate change including such considerations as adaptation versus abatement, risk management, intergenerational equity and international justice. Engineers should contribute to the public policy debate on climate change but should recognize and acknowledge that a scientific consensus on human-induced climate change has existed for some time.

Codes of ethics do not generally provide an adequate response to macroethical issues such as climate change and should be revised accordingly. Engineers and engineering societies when engaging in collective action on climate change should examine and articulate the ethical bases of their positions. Engineering education should devote more attention to macroethical issues in engineering, such as climate change, and their relationship both to engineering design and to the involvement of engineers and engineering societies in public policy debates.

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Chapter 25

Representing Engineers

Joseph C. Pitt

Abstract: This paper examines some of the representations of engineers in science fiction. Science fiction is an important medium in the formation of the public's perception of engineering, especially for the young. Two short stories and two films are examined. The issues explored include the possibility of intimate relations between humans and robots and the roots of moral corruption in engineers. I argue that from these representations we are left with the conclusion that, if the engineer is uncorrupted by a society of consumption and greed, he or she is seen as a paradigm of virtue. On the question of human/robot relations, love it seems once again conquers all.

Key words: Corruption, Robots, Tinkerers, "Star Trek", "Metropolis", "Helen O'Loy", "The Roads Must Roll", Cadets, Technicians, Context

Introduction

As we have already seen in previous contributions to this volume, talking or writing about *Engineers in Context* is a complicated affair. We can discuss the importance of putting engineers into various contexts, such as working engineers, international venues, consulting, as part of multinational corporations, as managers, etc. But there is yet again another context to be considered: how engineers are represented in popular culture media, in the specific case to be considered here, in science fiction.

By and large, the manner in which engineers are portrayed in science fiction is inconsistent. That is, there is no one image that dominates. There is the image of the professional engineer as a willing tool of the industrial world. We also are presented with the affable tinkerer, the guy who just likes to play around with things. Then there is the military engineer. He (always a "he") is portrayed as a kind of paragon of virtue if left alone to do his job. Of course these are idealized types abstracted from literature, film and television series. It is rarely the case that any one depiction is as simple as I have suggested. But one disturbing image does emerge from a spotty survey of some of the literature (read broadly to include film and other media), it is that of the evil or immoral engineer. This is a character that is not purely evil. As we shall see, he almost always seems to be corrupted by some aspect or another of society which leads to his moral downfall.

Helen O'Loy

For many, i.e., those who do not have the pleasure of interacting with engineers as part of our daily experience, the perception or mental picture of what an engineer is, how he or she thinks, what their professional values are, how these values affect other personal decisions, etc. come from the pictures drawn by science fiction writers. This is especially the case for young readers for whom science fiction is a favored genre. And this is doubly the case for college age American engineering students, at least in my experience.

For over thirty-five years now I have taught an introduction to philosophy course at my university, which has a large engineering college. Students here must satisfy a general education requirement. From the start, I discovered that, as soon as I mentioned a science fiction story or author, my engineering students, who had been dozing off while wondering what philosophy had to do with their chosen profession, came alive. Why? The answer is not clear. But what was clear was that they were more interested in stories that had neat problems with cool technological fixes than in other forms of science fiction. Further, they are very attuned to what is technically possible and tend to dismiss solutions they don't believe could work, even in a distant and more technically advanced future. This leads to a troublesome anomaly, one not to be pursued here: if engineering students are only interested in stories that present fixable problems in a real world context, then why are so many of them involved in the fantasy gaming culture?

Consider, for example, my students' reaction to the short story "Helen O'Loy" by Lester del Rey. The two male protagonists, Dave and Phil, are what we would today call "geeks". They love fooling around with robots, trying to make them human-like by rewiring them and working on their endocrinology. Finally they purchase "Helen", an advanced model, and work their little tricks on it and, sure enough, "she" develops human-like characteristics. One might say she became too human, "falling in love" with Dave, who is initially repelled by the idea, but then the two of them run away and live happily ever after, sort of. The reaction of the engineering students is, to a man, and I use that designator advisedly, indignation. As one of them said, "there is no way a real engineer could fall in love with a robot, no matter how sophisticated it was, since he made her." In short, no matter how "real" she appeared, she was still a robot and since the "engineer" knew this, love was impossible. This naturally raises the question as to whether fictional engineers could ever fall in love. That Dave did fall in love with Helen seems to serve a twofold point in this story. On the one hand, his basic humanity is revealed and affirmed. On the other hand, because of the first, his identity as an engineer is diminished. Two things strike me as interesting about this case. The first, obviously, is the reaction of the engineering students. The other students in the class had different reactions. Some of them found the idea that a man could fall in love with a robot and run off with her "freaky". Others bought the story line and found the story touching. The second thing of interest was the readiness with which the engineering students identified Dave and Phil as engineers. All we are told in the text of the story is that Dave had a robot repair shop and that Phil "specialized in endocrinology and related subjects." (Del Rey (1938), p. 43.) But in the minds of the engineering students they were engineers. Not so in the minds of the other students. The identification of Dave and Phil as engineers was not as apparent to them. Most, for example, thought Phil was a medical doctor. While I am not certain why the engineering students so readily identified Dave and Phil as engineers, I have a suspicion. To begin with, it is not clear that someone who runs a repair shop for, say, computers, is an engineer; a technician is more like it. What seemed to be at the heart of their insistence that Dave and Phil are engineers is Dave and Phil's eagerness to tinker with things. Most of the engineering students confessed they loved to tinker with gadgets, so maybe what we have here is a case of self-identification, i.e., (1) we are budding engineers, (2) we like to tinker, (3) Dave and Phil like to tinker, ergo, (4) they must be engineers. Not exactly a valid argument, but it seems to work for them.

I have developed this discussion of what might be considered by some to be a trivial point, because it seems to me that what is perceived to be an engineer in science fiction may be as much a function of the reader wanting the actor to be an engineer of a particular type as anything else. And that is one of the problems with assessing the representation of engineers in science fiction, or with any other character in fiction. It is never really clear how much of ourselves we read into these figures. Likewise, it is never really clear if the reader is saying "I want to be like him/her" or "Isn't it amazing how much like me he/she is?" Thus it may be more profitable to assess the representation of engineers in science fiction in examples where the protagonist is explicitly identified as an engineer. However, we will have more to say about the themes of "Helen O'Loy" later.

The Roads Must Roll

In Robert Heinlein's famous "The Roads Must Roll," professional engineers are not presented as completely admirable characters. The idea here is that the country is now heavily dependent on motorized walkways as a means to carry commuters from the suburbs to the city and home again. Automobiles have proven too costly on a number of fronts. It is the job of the road engineers to keep the system rolling and, as the story unfolds, we follow a developing disaster and its resolution. The story starts off in the middle of a speech at a guild rally. The speaker is working up the crowd with a series of questions that require their responses, and then he takes off.

> *"Did we ask for too much? Were our demands unreasonable? 'The right to resign whenever we want to.' Every working stiff in any other job has that. 'The same pay as engineers.' Why not? Who are the real engineers around here? D'yuh have to be a cadet in a funny little hat before you can learn to wipe a bearing, or jack down a rotor? Who earns his keep: the gentlemen in the control offices, or the boys down inside? What else do we ask? 'The right to elect our own engineers.' Why the hell not? Who's competent to pick engineers? The technicians – or some dumb examining board that's never been down inside, and couldn't tell a rotor bearing from a field coil?"* (Heinlein 1940, p. 52)

In this society, engineers are portrayed as "gentlemen" wearing funny little caps, selected by some sort of examining board. The suggestion here is that the "engineers" are selected on the basis of what in my part of the world is called "book-learning" or even political influence and that they don't really have the hands-on knowledge of the technicians, who the speaker thinks are the real engineers. Again here we have the idea that real engineers are the type of people who get their hands dirty taking things apart and fixing them, similar to the tinkerers in "Helen O'Loy." The official "engineer" in this society seems to be the sort of person who walks around with a clipboard checking things off on a printed piece of paper. But the "real" engineer does the dirty work.

The interesting distinction here is between the members of the guild who do the dirty work and the engineers with their clipboards. Casting these "real" engineers as members of a guild brings forth the ancient guild tradition where membership requires achieving a level of competence in the field. These are not merely members of a labor union where membership is paid for in cash in order to get a protected job. Heinlein almost casts the engineers in the mode of members of a labor union, putting the emphasis on passing exams rather than acquiring a working knowledge of their craft. That distinction is reinforced when the next speaker is introduced as a Mr. Van

Kleek, Chief Deputy Engineer of the road system. It seems he is also a member of the guild, having risen through the ranks of the guild to enter the class of engineers.

> *"Thanks, brothers. I guess our chairman is right. I always feel more comfortable here in the guild hall or in the Sacramento Sector – or any guild hall for that matter – than I do in the engineers' clubhouse. Those young punk cadet engineers get in my hair. Maybe I should have gone to one of the fancy technical institutes, so I'd have the proper point of view, instead of coming up from the inside.* (Heinlein 1940, p.54)

Since he also mentions the cadets, we should comment on another aspect of this portrayal of engineers. In the United States there is a long historical connection between engineers and military training. It begins with the establishment of the United States Military Academy, West Point, in 1802. The curriculum was modeled on that of the École Polytechnique in France, aimed at producing primarily civil engineers who were also army officers. There is no evidence that the graduates of West Point and the later Virginia Military Academy, modeled on West Point, were anything but hands-on engineers who got their hands dirty along with their soldiers building roads and fortifications. However, the identification by Congressional Charter of a military officer as a gentleman also suggested that there was a clear class distinction carried over from our British heritage. On the other hand, in the frontier society of the early days of the United States, there was a strong ethos of the rugged individualist who got down and dirty and did things for himself. Class elitism was sneered at and this carried over to engineers who earned their titles by way of having graduated from an institution of higher learning instead of coming from the bottom up. So the cadet engineer became an object of ridicule, rather than a positive role model, as we see in this story. Things actually get worse for the cadet engineers. At one point, a cadet is discovered playing cards with a technician during their duty assignment. The Chief Engineer is swift and decisive with his verdict. "Have the paymaster give Ross [the technician] his time, and turn him over to the civil authorities. Place Cadet Jeans under arrest and order him to report to me." (p. 60) One interesting feature of this exchange is the implication that civilians are to be handled by the civil authorities while cadet engineers are to be treated by military authorities, reminding us of an age-old conflict over who has authority of the military. Here it is clear, the military have jurisdiction over the military. And while this suggests some degree of military purity, that image fails when the Chief Engineer is exposed as having a pathological dedication to his mission of keeping the roads rolling. One final observation with regard to the chief engineer by way of excusing the engineering profession from charges of corruption: he is not an engineer by training. When asked if he is a graduate of the Academy, his answer is most revealing.

> *"You flatter me – I must look younger than I am. No, I'm a carry-over from the army. You see, the war department operated the roads for some three months during reorganization after the strike in '60. I served on the reconciliation board that awarded pay increases and adjusted working conditions, then I was assigned."* (Heinlein 1940, p.64)

He is interrupted at this point by a report of trouble. But the main point has been made. While his title is Chief Engineer, he has no engineering training. He is military, but without an engineering background, hence he has no moral compass to guide his actions.

The connection between the military and the cadet engineer corps is very strong in "The Roads Must Roll." Heinlein makes explicit the connection when he talks about the importance of *esprit de corps* among the engineer cadets. In the story, a new United States Academy of Transport has been established along the model of West Point. This new academy has even gone so far as to adopt the field artillery song "The Roll of the Caissons" with new words. Morale is crucial to keeping the roads rolling and so they sing,

Hear them hum!
Watch them run!
Oh, our job is never done,
For our roadways go rolling along
……
Oh, its Hie! Hie! Hee!
The rotor men are we –
Check out the sectors loud and strong!
Etc.

We might be inclined to forgive this presentation of the military engineer considering that the story was first published in 1938. A more modern account would surely be more nuanced. Thus, for example, it might be assumed that this highly focused and totally dedicated to the job portrayal of the cadet engineer or military engineer would change following World War II. After all, many attribute the victory over the Axis forces to a number of technological advances such as radar, long range bombers and, of course, the atom bomb. But the atom bomb and the apocalyptic vision of the future it spawned not only overshadowed other technical advances, but they also helped frame the engineer in a negative light in various media including science fiction. This was not only a post-WW II phenomenon.

It is unfortunate, perhaps true in some cases, but also perhaps not to be avoided, that the engineer, at least in American fiction, was for the most part associated with the plans and schemes of America's industrial engine. The representation of the engineer in “The Roads Must Roll” is as much as a tool and captive of the industrial system as a cadet dandy. But this is, as it turns out, an older vision and not necessarily an American one.

In Fritz Lang’s magnificent 1929 film *Metropolis,* that same collusion between engineer and industrialist is portrayed with terrible results for the workers. Lang gives us a prophetic vision that shows no mercy to the giants of capitalism and their stooges, i.e., the engineers who build their empires for them. And here, as in later stories such as “The Roads Must Roll,” the connection between capitalists and engineers is much stronger than the traditional connection between science and engineering. The Robber Barons of the American 19th century helped a country span a continent using their engineers who in turn supervised the building of the railroads and the dams, but the cost was high. Imported workers, often from Asia, were treated poorly and life was cheap. The job of the engineer was also to see that the job got done. This was not a pretty picture and certainly not one to inspire the young. What is fascinating about the early science fiction so far considered here is that that picture actually got painted.

Star Trek

In the United States, post-WW II science fiction takes a nasty and depressing turn with the shadow of the bomb overlaying all. Despite victory in WW II, the American public felt moral sanction over using the bomb in Japan. Throughout the Cold War the threat of total annihilation was never far from our screens. And this was all couched in the context of seeing the building of the bomb as one of our greatest *engineering* achievements. We see it in films such as *On the Beach* and *Dr. Strangelove* (ironically subtitled *How I Learned to Stop Worrying and Love the Bomb*), and it comes to us again from Japan in *Hiroshima, mon amour.*

It may be as a reaction to this dark vision that *Star Trek,* the 1960s television show, was embraced with such positive fervor. It was not so much that only the engineer was portrayed in such a glowing light but also the products of engineering. *Star Trek* showed us a future replete with neat technologies such as transporters and stun guns and miniature medical diagnostic devices. None of the sequels to the original *Star Trek* had quite the appeal or the loyal fan following that the original series had. The reasons for this are disputed, but let me suggest several. First, once the future was presented with such clarity as the vision *Star Trek* presented, all subsequent future science fiction television looked like just so many take-offs.

In the subsequent series that followed *Star Trek* nothing really new was offered, and for many viewers all were merely bad versions of the old *Star Trek.* Second, the characters in the original series were so cleanly drawn that no one could be confused over who was the good guy or the bad guy, who was the science officer and who was the chief engineer. *Star Trek* disavowed ambiguity in its characters, although ambiguity was often at the heart of many of its story lines, usually over conflicting interpretations of the Prime Directive. A third reason *Star Trek* held such tight control over our imagination was the absence of the industrialist overlord in its plot line and the counter overarching theme of military grandeur. It was a tale of exploration into the unknown. But at its heart it was a military story. The crew of the starship *Enterprise* was a military crew. There was a command structure. But there was no industrialist for whom the captain worked. He took orders from his military superiors, and they were rarely portrayed as being manipulated by commercial interests. In those cases where commercial concerns came into play, they always were defeated by the superior moral position of the Fleet. And so, in the end, *Star Trek* can be seen as a vindication of the military when it is left alone to do its job. This was a message read loud and clear during the depths of the Viet Nam war. The unspoken text is that since the crew is military, and naval in its perspective, their training must have taken place in some futuristic version of the U.S. Naval Academy at Annapolis. Therefore, as Spock would observe, logically, the military engineer, left alone, will set things right because at his core, the military engineer is a moral being. Another flawed argument, but we are dealing with human reactions to stories told and visualized, not logic.

To the extent that the professional engineer was a feature of *Star Trek,* it was in the form of Scotty, the Chief Engineer. Scotty, however, was primarily portrayed as a jolly tinkerer who got things working when they broke down. And so we return to the popular presentation of the engineer as tinkerer, an image that needs some further discussion. There is no evidence to confirm this, but at least in North America, many young boys fit the general stereotype of tinkerers. The "typical" young boy, if given a toy, will play with it for a while and then start disassembling it to see how it works. This is generally seen as "normal" boy behavior. Further, this behavior is usually encouraged, since there is a built-in assumption that boys who exhibit this behavior have a greater chance of becoming an engineer than boys who prefer to play their piano rather than take it apart. In other words, at least in North America, this boyish fascination with taking things apart to see what makes them work is implicitly tied in the popular mind as a precursor to or a necessary condition for becoming an engineer. And this is also seen as a good thing. I am sure young girls also exhibit similar behaviors, but they are usually discouraged due to some absurdly sexist attitudes regarding gender and proper roles. But the main point here is the connection between tinkering and engineering, not the negative affects of sexism.[1]

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[1] Currently there is a major initiative by the United States National Science Foundation to recruit women and girls into math, science and engineering. It is known as Advance. One of the odd things about Advance is that it does not include in its purview the opportunity to encourage young girls in the early school grades to tinker. It is also not clear the program is a huge success.

When those young boys and girls grow up and attend colleges of engineering, their natural tendencies to tinker get channeled into so-called "creative projects."[2] One of the earliest of these is almost universal across colleges of engineering. The challenge is to design a container that will keep an egg from breaking when dropped from some extended height. At the time the challenge is issued, the students usually have received minimal "training" in "how to think like an engineer." They have primarily their tinkering skills to rely on. The remainder of their engineering education is devoted to replacing those innate tinkering skills with "professional engineering procedures and methods." But, I would argue, the original connection between tinkering and engineering remains and continues to be reinforced in science fiction, if not in fact. Likewise, in science fiction the image of the "professional engineer" is not a pretty one. From "The Roads Must Roll" we have young cadet engineers with clipboards and a demonic Chief Road Engineer willing to do anything to keep his masters happy. In a more contemporary vision, *Blade Runner,* the futuristic industrialist engineer echoes in heartlessness that of *Metropolis.*

Helen O'Loy Redux: Blade Runner

Blade Runner is a dark film in more ways than one. Most importantly, it comes across as a frighteningly real, not too far away, future configured mainly by engineering visions created to enliven commercial interests. But ultimately, strange as this may seem, *Blade Runner* is a darker, more up-to-date version of *Helen O'Loy,* in which the real plot of the story concerns a man who falls in love with a female robot (called Replicants) and his efforts to protect her, ultimately taking her away to the north where they can live out their lives in peace. Well, the story is a bit more complicated than that, but what I will call the Helen O'Loy theme is what motivates the plot. The larger story takes place in a world dominated by commerce. One particular form of commerce is the construction and sale of Replicants. Replicants are biologically designed robots, and here we must read "designer" for "engineer." For reasons of human safety, they are given short life spans so they do not become too aware of their origins and rise up in rebellion against their human masters from a sense of betrayal. They are designed to be job-specific.

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[2] American Engineering schools' admissions policies remain a mystery to most. It is clear that there is a heavy emphasis on math and science success in high school and on standardized tests. However, to the extent that there is any effort to uncover the "tinker-phenomenon," it is at best informal, if even recognized as a significant component of an engineering mind-set, to the extent that there is such a thing.

The major company in this field is the Tyrell Corporation, headed by its founder Edden Tyrell, who identifies himself as a designer. He also announces that "commerce is our goal" and that the motto of Tyrell Corporation is "More human than human", whatever that may mean. The chief protagonist, Decker, is an ex-cop who specializes in detecting (using special tests), tracking down, and killing rogue Replicants. But he falls for a female version of the latest model, Rachel. These creatures have been fed memories of a past life they never experienced, so as to give them a human background and the basis for extrapolating in a human environment. One of the major designers in the firm lives alone, except for a group of toy figures, animated puppets, he designed and constructed and whom he calls his friends. These are results of his tinkering. He plays a central role in the film, since he can and does give the rogue Replicants access to Mr. Tyrell, whom they then kill. Fortunately, their life span expires before they can kill Decker, who makes his escape with Rachel.

Blade Runner has a cult following among whom much is made of the question posed by Rachel to Decker, "Have you ever tested yourself?" This gives the engineers in the audience a way-out by raising the possibility that Decker is himself a Replicant and hence that there is nothing wrong, weird, or illogical in his falling in love with Rachel and she with him, although that relation is unclear. She at least looks to Decker as a savior and defender, but she doesn't know how to master her latent human capabilities for love.

So, is Decker a Replicant? It seems unlikely since he has been at this business a long time, before the creation of the Nexus Model 6 Replicants, the rogues he is here pursuing. Also, up to this point no one has suggested that he is other than human, no one except Rachel that is. And, Rachel, being the advanced model she is, may have ulterior motives for having Decker doubt himself, i.e., distracting him from his passion for her. Now I think all this speculation about whether or not Decker is a Replicant is irrelevant to the main themes of the story, of which there are three.

- The Helen O'Loy theme: (1) boy meets robot, (2) boy falls for robot, (3) robot talks boy into betraying his supervisors and saving her.
- Commerce corrupts design, i.e., engineering.
- All design, i.e., engineering, comes from tinkering.

Conclusion

In each of the stories examined here the engineer who receives social approval, or for whom we have positive reactions, is the tinkerer. Engineers who are corrupted by commerce are negatively portrayed. Here it doesn't matter what the background of the engineer is. Since real engineers are not corrupted by such promises, the capacity to be seduced by promises of future advancement or power is sufficient to render him not really an engineer. Rather, the engineer, in at least the science fiction we have examined, is really characterized by an innocent child-like fascination with tinkering. As soon as he is distracted by social concerns, politics, power, money, etc., he has lost any legitimate claim to being a real engineer.[3] Perhaps it would be better to refer to this idealized state as being a pure engineer.

The pure engineer is context-less. That is, we tend to see engineers represented in their pure state as transcending context. They are an ideal. However, as soon as context enters the picture, the situation changes. Engineers in these contexts are represented as normal human beings, subject to all the failings we have with no claim to moral superiority. And maybe that is why *Star Trek* succeeds: since the context is the universe, there really is no context. The officers and crew of Starship Enterprise have the biggest context of all to explore and so really have no limits. But contexts are defined by limits, hence the officers and crew of Starship Enterprise have no context. Insofar as that is the case, they can be the idealized characters they are represented as: pure leader, pure logician, pure engineer. Captain Kirk is always in a state of pure wonder, Spock is the pure logician, and Scotty is the pure engineer.

These conclusions follow from a limited examination of a very narrow selection of stories, films, and TV series. I do not offer them as definitive. But I do think they reveal some prejudices, in American Science fiction at least, about what it takes to be a real/pure engineer: an unbounded fascination with tinkering.

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[3] All of this comes with a serious caveat. I have chosen to examine a number of stories here to make a point. These stories can be considered case studies. But in [Pitt 2001] I argued that case studies do no philosophical work. For if you come to the task with a preconceived idea, then the case studies can be considered contaminated evidence. If you have no preconceived idea, then following Hume, you cannot generalize from the case studies to any larger account.

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Chapter 26

Filming Engineers

Jen Schneider

Abstract: Film and media studies have been substantial fields in liberal arts education since the 1970s. It is only in the last decade, however, that engineering educators have begun to pay attention to the importance of these fields for how they might provide future engineers and applied scientists with valuable interpretive, communicative, and ethical competencies. Given that engineers trained in the United States and abroad are expected not only to exhibit excellent design skills but also management abilities and cultural fluency, film studies offer these students the opportunity to develop all three. Exposing students to film can broaden their understanding of complex historical, cultural, and ethical issues, train them in key forms of visual literacy, and educate them about how technologies make meaning in the world. This chapter suggests three approaches that engineering educators might consider when incorporating film into the engineering curriculum.

Key words: Film, Cinema, Film History, Science and Technology Studies, Engineering Ethics

Introduction

There are a number of reasons engineering educators might wish to use film in their classes. Film seems to "speak" to students in ways other mediums might not, can enable visualization and understanding of abstract concepts, and can generate participation in class discussion. Films can also establish context for particular disciplinary ideas or concepts, and provide instructors and students with concrete, shared points of reference. Movies may also appeal to visual learners or English-as-a-Second-Language (ESL) students in ways written texts cannot. Finally, there are seemingly limitless resources for educators, from educational DVDs and videos to Hollywood productions to home-made "how-to's" on video-dissemination sites like YouTube, all of which can be meaningfully incorporated into courses in an engineering curriculum.

Yet, I often hear from colleagues that they face a number of challenges when it comes to successfully incorporating film into their classes. Students may interpret films as opportunities for mere "entertainment," or worse, as an opportunity to mentally check-out or sleep in class. Given the limited space in the engineering curriculum, instructors may also struggle to find the time to both screen films in class and leave enough time for discussion and analysis. As a result, films often seem "dropped-in" and are not treated as texts to be carefully evaluated and considered. Films may feature violence, profanity, or nudity, which can be problematic for some students, and must be handled with respect and care. Furthermore, instructors who haven't received some training in film studies or film analysis may feel they lack the ability to speak about or teach film effectively. Or, conversely, they may take film language for granted, and assume that film is "obvious," or "easy." Finally, instructors tell me that they struggle most with teaching their students to write effectively about film. Even when given challenging, well-crafted writing prompts about films, students often resort to basic plot summaries. This results in boring, lifeless papers that can frustrate instructors and discourage them from giving future writing assignments about film. This in turn reinforces students' beliefs that film is only "for fun," not a serious object of study.

The purpose of this chapter is to provide some models that engineering educators might consider as they incorporate film into their classes: the "film as history" approach, the "film as technology" approach, and the "film as ethics" approach. These categories are intended to be conceptual only, to present a range of options available to engineering educators interested in seeking meaningful connections between film and engineering. It is important to understand that these distinctions are somewhat arbitrary – understanding film as a technology will no doubt involve interacting with film history. Thinking about film as technology should certainly raise significant questions about ethics. The categories below are not intended to serve as hard and fast fortifications, therefore, but as permeable membranes, ways to think about how one might structure a module or class on film for engineers.

Approach 1: Film as History

In his book *Mad, Bad and Dangerous? The Scientist and the Cinema,* Christopher Frayling argues that, with few exceptions, the dominant cultural stereotype of scientists is that they are insane, dangerous, hyper-intelligent, secretive, hard-working, and often deeply immoral. We know that these are only stereotypes, yet such images have influence over how the public imagines science as a field of study. Frayling draws these conclusions based on a series of "draw-a-scientist" experiments in which schoolchildren were asked to draw a typical scientist. In most of these drawings, says Frayling,

> *"on the one hand, scientists (almost invariably male) are dressed in white lab coats; they have frizzy hair or else none at all; they wear Coke-bottle spectacles, they work alone indoors on underground in laboratories marked 'Secret'; they are clearly remote from everyday concerns and relationship; they are middle-aged and not at all physically attractive. On the other hand, advances in science and technology have made our lives a lot better and doing science can be an absorbing as well as exciting…occupation and even an important one"* (Frayling, 2005, p.15).

Frayling argues that such stereotypes are created or reinforced in popular film, and his book goes on to provide a detailed history of these cinematic representations.

Frayling's work, though enlightening and clearly connected to images of engineering on film, is primarily focused on representations of the scientist or science. This raises important questions for the film historian who is focused, instead, primarily on engineering. Can we think of the scientist and engineer on film in the same way? What identifiers denote an "engineer" as opposed to a "scientist"? How do audiences distinguish between the two, if at all? In fact, it can be challenging to find films that feature engineers as characters or that are otherwise explicitly about engineering. We know that media images about science, engineering, and technology (SET) can impact how young people, specifically, think about science and engineering. For example, stereotypes of engineers may negatively affect public perceptions of the profession (Yurtseven, 2002), and stereotypical or absent representations of women scientists and engineers in film may negatively impact how young women perceive these fields as sites for future careers (Steinke, 2005). But is this because viewers think of science and engineering as the same thing? Or because there is a relative absence of representations of engineers altogether?

In fact, in media studies of SET, engineering and science *are* often treated as one and the same thing. There are a number of possible reasons for this. Perhaps it is difficult to separate the practice of science from the practice of engineering as it is depicted in the popular media, and the public may not be particularly discerning about the difference either (Yurtseven, 2002, 20). Hollywood certainly is not: as film scholar Vivian Sobchack points out, in science fiction films, whether a film accurately represents "science" is beside the point: "It is the very plasticity of objects and settings in [science fiction] which help define [it] as science fiction, not their consistency" (Sobchack, 1980, 87).

Science, therefore, can connote multiple meanings and messages about progress, industrialization, hubris, the designed world, the built world, and so on, and these many messages need not distinguish between the actual work of scientists and engineers to impact how both are perceived.

It also seems possible, however, that there are so few depictions of engineers in American film, rather than scientists, that to perform a study of engineers as characters alone proves difficult. In Steinke's excellent 2005 study of female scientist or engineer characters in films from 1991-2001, she identifies 74 films in which scientists or engineers were main characters. However, she does not distinguish between the two groups. Herein lays a paradox: there *are* many examples of engineers or the products of engineering in Hollywood film. In fact, it is hard to imagine science fiction films, horror films, and melodramas without them. Yet, within the films themselves, engineers are rarely identified *as such*. The engineering identity is itself incredibly "plastic."

For example, the film *Apollo 13* (Howard, 1995), features a number of "geeky engineers" that made the U.S. National Aeronautical and Space Administration's (NASA) launch and harrowing return of the malfunctioning Apollo 13 possible (Launius, 2008). Some of the astronauts themselves are engineers, white-shirted, bespectacled engineers fill the room at mission control, and engineers repeatedly develop innovative solutions to the technical problems encountered by the Apollo crew. However, the word "engineer" is only mentioned twice throughout the film, and the astronauts are never identified as such. I would argue that the average viewer would primarily identify the drama as being about "astronauts," "scientists," or maybe even "technicians," but not about "engineers." This assumption remains theoretical: studies of audience reactions to such films would be necessary to confirm this hypothesis.

In any case, engineering, as an activity or practice, is not terribly cinematic. Particular technologies are, of course, very cinematic, and certain narratives featuring emergency design or engineering "failures" – such as in *Apollo 13* – also lend themselves well to the exigencies of film. But, in general, the process of engineering itself can be difficult to capture in a meaningful or entertaining way in a Hollywood-style movie. Film requires visual interest and pacing, which engineering activities (particularly design work) may lack. Furthermore, beyond the stereotypes alluded to by Frayling, there are not many visual shorthands that connote "engineer" (other than stereotypes) to the average viewer. It is for these reasons that engineers and engineering are perhaps easier to represent in literature, where an author can explicitly define a character as an engineer and explore the work of engineering at greater length (Bourne, 2006), or in documentaries, in which engineering can be explored more carefully than in feature-length fiction film. There are also a handful of television shows that either feature engineers as characters (as in the long-running American series *MacGyver*, 1985-1992) or that showcase engineering feats and know-how (i.e., *Great Industrial Wonders* in Britain and *Design Squad*, a children's show available on public broadcasting in the US, and a number of Discovery Channel programs about engineering, including *Extreme Engineering*, *Engineering Thrills*, and *Prototype This!* to name a few).

That said, there *are* films that do feature engineers, explicitly or implicitly. The film historian must grapple with the difficulties of identification listed above, but we do know that a number of films are in some way related to engineering. These films may provide engineering students with a sense of how their profession has been portrayed over the last one hundred years or so. Furthermore, examining questions of the relationship between science and engineering, and examining what engineering *is*, can be educational in and of itself, and may form the backbone of any course wishing to trace a historical chronology of engineers on film. The films listed below form only a partial list, and a summary and analysis of each is beyond the scope of this chapter. But this list should suggest possibilities for films that could be featured in a course on the history of the engineer in film, or the basis for a more complete scholarly historical analysis of cinematic engineers. The list includes primarily American films, and excludes documentaries, of which there are a growing number that deal meaningfully with engineers and engineering:[1]

Le Voyage dans la Lune (*Trip to the Moon*, 1902)
The Iron Horse (1924)
Metropolis (1926)
The Story of Alexander Graham Bell (1939)
Young Tom Edison (1940)
Western Union (1941)
The Fountainhead (1949)
No Highway in the Sky (1951)
The Dambusters (1955)
The Spirit of St. Louis (1957)
The Bridge on the River Kwai (1957)
The Time Machine (1960)
The Flight of the Phoenix (1965; 2004)
Hellfighters (1968)
Colossus: The Forbin Project (1970)
The China Syndrome (1979)
War Games (1983)
The Right Stuff (1983)
Emerald Forest (1985)
Pale Rider (1985)
The Mosquito Coast (1986)

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[1] I am particularly indebted to film historians Joseph Heumann and Robin Murray at Eastern Illinois University, whose work on representations of ecology and extractive industries such as mining greatly informed the writing of this chapter (Heumann & Murray, 2004; Murray & Heumann, 2006). They graciously provided me with this list of films featuring engineers and engineering. A special thanks also to Carl Mitcham and Joe Herkert, who suggested many of the films above.

Top Gun (1986)
Tucker: The Man and His Dream (1988)
Fat Man and Little Boy (1989)
The Voyager (aka *Homo Faber*, 1991)
Apollo 13 (1995)
Box of Moon Light (1996)
October Sky (1998)
Pi (1998)
Space Cowboys (2000)
Spider-Man (trilogy: 2002, 2004, 2007)
Primer (2004)
The Prestige (2006)

In any case, practicing engineers seem to have noticed the absence of engineering characters in film, and are working to reinforce the relationship between engineering and cinema. For example, engineers and engineering societies seem to believe that the nexus of engineering and entertainment may serve to recruit potential engineers interested in innovation. The Royal Academy of Engineering in Britain has tried to connect filmmakers with engineers (Film meets innovation at BRITDOC '07, 2007), as has the National Academy of Engineering in the U.S. (Innovative Young Engineers Selected to Participate in NAE's 2004 U.S. Frontiers of Engineering Symposium, 2004). Various organizations and societies have also proposed or produced various television programs and specials related to engineering (Yurtseven, 2002, p.220). Finally, a number of recent articles in science and engineering publications have also emphasized possible collaborations between Hollywood insiders and engineers (e.g., see Balmford *et al.*, 2004; Bhattacharjee, 2008; Jones, 2004; Knight, 2004).

Approach 2: Film as Technology

Thinking about film as a technology requires students to think through issues that have long concerned those in studies of science, technology, and society, questions including but not limited to:

- the innovation, dissemination, and limits of technologies (Rogers, 2003; Winner, 1986);
- the cultural, political, social and economic contexts from which science and technologies emerge and are shaped by (Latour, 1987);
- the histories and social constructions of technologies (Bijker, 1995);

- philosophy and the role artifacts play in our culture (Mitcham, 1994; Verbeek, 2005);
- and beliefs about technological determinism and progress (Smith & Marx, 1994).

Furthermore, engineers have been instrumental in designing and building film technologies, and yet they remain almost entirely concealed from the public, as do the modes of film production. Studying film therefore offers an opportunity for the engineer to think through the relationship between his or her own work, the identity of the engineer, the technological artifact, and public consumption of film "products."

In his book *Inventing the Movies*, Scott Kirsner writes that the history of film must be understood as a history of technology. Specifically, it is a history that developed out of tensions between "preservationists" – those in Hollywood who resisted technological innovation – and the "innovators," those who championed technological innovation. According to Kirsner, the innovators have often been stymied by the preservationists, "who couldn't see the world more differently" (Kirsner, 2008, p.5). Kirsner writes, "All change is the story of how innovators combine new ideas and new tools to create something spectacular and compelling, overcoming…resistance (whether active or passive)" (Kirsner, 2008, p.5).

Kirsner offers as an example the figure of Thomas Edison. According to Kirsner, Edison was both an innovator *and* a preservationist, depending on the context. As inventors, Edison and his colleagues developed the kinetoscope – a device for exhibiting motion pictures to individuals, one at a time – around 1890. Soon after, the brothers Otway and Grey Latham proposed to Edison that he modify his kinetoscope so that it could project to multiple viewers at once (this idea would, of course, eventually lead to the theater experience we are accustomed to today). To the Lathams' surprise, Edison refused, believing that the projectors would decrease sales of his kinetoscopes: "If we put out a screen machine there will be a use for maybe about ten of them in the whole United States. With that many screen machines, you could show the pictures to everyone in the country – and then it would be done. Let's not kill the goose that lays the golden egg" (Kirsner, 2008, p.9). Similarly, Edison would also later argue that there was no future for sound pictures, believing that "Americans require a restful quiet in the motion picture theater" (Kirsner, 2008, p.15). Edison was, of course, proven wrong on both counts.

Kirsner's history, though fascinating and entertaining, seems an overly simplistic formulation of the ways in which technologies emerge from particular contexts and then shape those contexts. His framework is appealing because of its simplicity, but also raises intriguing questions about the role particular technologies play in the histories we write about film as technology. For Kirsner, there is no stopping the onward push of innovation in film technology, and those who stand in innovation's way do so because they "view change as a threat" (Kirsner, 2008, p.5). This model represents a sort of "soft determinism" that has been the subject of much scholarly inquiry. In the introduction to their collection *Does Technology Drive History?* Merritt Roe Smith and Leo Marx write that, in narratives such as Kirsner's,

> *"technology is conceived in almost exclusively artifactual terms, and its materiality serves to reinforce a tangible sense of its decisive role in history. Unlike other, more abstract forces to which historians often assign determinative power (for example, socio-economic, political, cultural, and ideological formations), the thingness or tangibility of mechanical devices – their accessibility via sense perception – helps to create a sense of causal efficacy made visible. Taken together, these before-and-after narratives give credence to the idea of 'technology' as an independent entity, a virtually autonomous agent of change"* (Smith & Marx, 1994, p.xi).

One of the problems with technological determinism is that it conceals the human choices embedded in the many forms technology takes and the uses to which it is put. Technological determinism may be particularly appealing to engineering students, whose technical training has prepared them to prefer clean, causal relationships between technology and society, and who may be more invested in the power and potential of certain technologies because they are involved in building and designing them. After all, as Martin and Schinzinger put it, technological determinism "has some intuitive appeal, for each of us has at times felt pushed or pulled by technology" (Martin & Schinzinger, 2005, p.281). But it is important to acknowledge that "None of us controls every aspect of our lives. An appreciation of our vulnerability, as individuals, to economic and political forces is part of humility and intelligence" (Martin & Schinzinger, 2005, p.281). It seems fair to say, therefore, that efforts to educate engineers about social/political/economic contexts may often miss their mark if they do not engage students' commitments to technological determinism.

Technological determinism is but one topic that could apply here. But thinking about film as a technology, subject to debates within Science and Technology Studies (STS) and engineering ethics, is one possible way in which the engineering educator might bring film into the engineering curriculum. Film offers exciting pedagogical opportunities in this sense because students can experience and think about film on a number of different levels: as a piece of entertainment, as a historical artifact, as an ideological apparatus, and as a technology. Studying film as technology reveals to students particular modes of production and consumption, suggests theories of subjectivity, agency, and resistance, and provides opportunities for thinking through the meaning of engineering, both as a historically-situated activity and as a professional activity.

For example, students in a class on technology and film might be invited to watch the *Matrix* trilogy of films (Wachowski & Wachowski, 1999, 2003a, 2003b).

The theme of the *Matrix* films is essentially about technology: in them, we meet Neo, a computer hacker who comes to learn that the "real" world he inhabits is in fact a simulacrum, a soothing creation of android-like creatures who keep humans enslaved and away from the truth. This dystopic narrative is, in itself, worth exploring with engineering students interested in philosophical questions about technology. Rosalyn W. Byrne argues that the film can be used to encourage questions about "metaethics:" "Is living immortality morally permissible? Should we protect the integrity of the biological body and mind? Under what circumstances ought we pursue potentially self-destructive technologies? What moral claims can be made on the human consciousness?" (Byrne, 2006).

At the same time, however, the *Matrix* films are technically "sweet," both for the average spectator and the technologist (e.g., see Borshukov, 2005; Bregler, 2007; Ndalianis, 2000). In particular, the films are noted for developing what is known as "bullet-time technology," which allows for spatial and temporal manipulation of a scene in a computer-generated environment. In *The Matrix* (1999), bullet-time has the effect of slowing things down to hyper-slow-motion, allowing the viewer to experience a 360-degree perspective of an object or character. Such shots are typically followed by hyper-saturated color shots, cut in quick succession and with fast-tempo music, heightening the viewer's sense of surreal, manipulated pacing and action. Electrical and audio engineers and computer scientists might find the history of bullet-time, and the process of executing it, particularly fascinating (Haberfellner, 2004).

The viewer of *The Matrix* is thus faced with an odd contradiction; on the one hand, the film's plot seems to be critical of technology, arguing that, in the future, "we will have technologized our way to the point where, for better or worse, our technologies permit few alternatives to their inherent dictates" (Smith & Marx, 1994, p.xii). The film threatens a future in which all humans, like Neo, will be "plugged-in," without even realizing it. On the other hand, the production of the film itself heartily embraces technology, using "savvy visual vocabulary" to "transfix fans of computer gamesmanship" (Maslin, 1999). In fact, the film won four Academy Awards for technical achievement (Giannetti, 2005, p.36) and grossed $171 million (Cook, 2004, p.908).

In other words, the fact that *The Matrix* was so widely hailed by reviewers as being technologically innovative offers an opportunity to think about the political economy of Hollywood film, and perhaps also the social construction of "innovation." According to film scholar David Cook, the *Matrix* films are almost *not* entirely innovative and are in fact "Cliff Notes" versions – intellectually and thematically – of films like David Cronenberg's *eXistenZ* (1999) and the Hong Kong martial arts cinema from which most of its "balletic martial-arts and gun battles…were lifted" (Cook, 2004, 526; 908). Yet it is the Hollywood *Matrix* productions and not the semi-independent Cronenberg production, nor the Hong Kong films that are so often credited with "innovation" or "influence" (e.g., see Greydanus; Leong, 1999; "The Matrix"). This seems to be so much the case that an informal survey of internet film reviews of *The Matrix* suggests a popular belief that the film practically invented computer-generated imagery (CGI). There is no doubt the *Matrix* films were influential, but the reasons for this go beyond the viability of the technology.

For example, we know that bullet-time itself was not an invention of the film's technicians – it could be seen as having evolved from very basic animation practices developed at the turn of the 20th century by Eadweard Muybridge, and then adapted by Thomas Edison (Bullet Time, 2008). But engineering educators could use students' fascination with the films' special effects to ask important questions about filmmaking, such as:

1. What are the social, economic, or political forces that shaped the use of technology in the making of *The Matrix*?
2. What factors contributed to the success of *The Matrix* in 1999?
3. How can we theorize the conflict between the film's message about technology with the film's embrace of particular film technologies?
4. What are the different ways in which we might explain reviewers' framing of *The Matrix* as technologically innovative or groundbreaking?

It may be possible, therefore, to guide students in an exploration of the relationship between film as technology and our understanding of scientific or technological innovation. It seems worth noting that numerous studies dealing with representations of science on film have been written by film scholars (Frayling, 2005; Perkowitz, 2007; Sobchack, 1980; Telotte, 1995; Tudor, 1989; and Vieth, 2001, to name a few). There are also excellent histories of particular film technologies, such as sound technology, which has been heavily influenced by the work of sound engineers (e.g., see Lastra, 2000). A definitive study of engineers and engineering on film and in film, however, remains to be written.

Approach 3: Film as Ethics

There is an ongoing discussion among philosophers of science and technology about the role of "macroethics" vs. "microethics" in engineering education and practice (Herkert, 2001; Wulf, 2003). According to Joseph Herkert, "microethics" is typically used to refer to "individuals and the internal relations of the engineering profession," while "macroethics" can refer to "both the collective social responsibility of the engineering profession and to societal decisions about technology" (Herkert, 2001, p.404).

A review of the use of film to teach ethics across the disciplines suggest that film is primarily used as a tool to teach microethics, or the ethics of individual action within professions such as business and management, education, or health care (e.g., see Berger & Pratt, 1998; Self, 1993; Tyler & Reynolds, 1998). This also holds true for some approaches to teaching or reinforcing engineering ethics. For example, the corporation Lockheed Martin has designed a series of short films on "ethics," which are required viewing for all employees (many of whom are engineers). These videos address workplace ethics, such as whether an employee should use the company photocopier for personal business, or what constitutes sexual harassment (Video Archive, 2008).

Other teaching films have been developed, however, which attempt to broach both microethical issues and macroethical ones, to varying degrees of success. Two are briefly summarized here: the National Institute for Engineering Ethics' (NIEE) video *Gilbane Gold* (1988); and a second NIEE video entitled *Incident at Morales* (2003).

Gilbane Gold ("Gilbane Gold," 1988) is a fictional video case study produced by the NIEE for the National Society of Professional Engineers. The video tells the story of a fictional junior environmental engineer, David Jackson, who discovers that a corporation is discharging excess toxic effluent into a sewage system that the hypothetical city of Gilbane uses for fertilizer on agricultural crops. According to Texas A&M University's ethics website,

> *"Although the primary ethical issue raised in the case is whistle blowing, secondary ethical issues include the obligations of engineers with respect to environmental issues, management problems having to do with honesty and trust between business and its host community, the issue of the fairness of a community towards local manufacturing plants, the problems raised for individuals and groups by the necessity for action in the face of inconclusive scientific evidence, and the relationship of law and morality". (Engineering Ethics: Gilbane Gold).*

The statement above suggests that *Gilbane Gold* is attempting to teach both microethics and macroethics in a complex scenario which, though fictional, mimics real-life situations engineers could face. Although it is unclear how widely *Gilbane Gold* has been used in engineering classrooms in the United States and abroad, the producers claim that it was used in "nearly every U.S. engineering school" (Producers: Great Projects Film Company, Inc.) and numerous websites are dedicated to teaching guides for the film (e.g., see (Engineering Ethics: Gilbane Gold; Frey, 2008).

In 2003, NIEE came out with a second documentary dealing with engineering ethics, *Incident at Morales*. Like *Gilbane Gold*, the 36-minute video *Incident at Morales* tells the story of a fictional engineer, Fred Martinez, who learns that a chemical plant he has designed for use in the Mexican city of Morales is going to be used for processes other than originally specified. The plant suffers malfunctions as a result, and a worker is killed. Similar to the *Gilbane* video, *Incident at Morales* invites the engineer or engineering student to reflect on a number of ethical issues. According to the NIEE study guide for the video, *Incident at* Morales is designed to make viewers more aware that

- Ethical considerations are an integral part of making engineering decisions
- A code of ethics will provide guidance in the decision-making process
- The obligations of a code of ethics do not stop at the United States border
- The obligations of engineers go beyond fulfilling a contract with a client or customer (Incident at Morales: An Engineering Ethics Story Study Guide, 2003).

The appeal of both of these films is that they are short and accessible, and could be used in a wide variety of engineering courses that wish to include some sort of ethics component. Both also come with a wide array of teaching guides and supplementary materials, all available on the world-wide web.

I wonder, however, whether these are the most effective films we could use to teach engineering ethics in our courses. In my experience, these films often strike students as contrived or manipulative. Generally speaking, our engineering students are sophisticated in terms of visual literacy, and may be cynical about being "force-fed" ethical behavior: they recognize when the production values of a film are not high (compared with Hollywood films), or when they are being pandered or condescended to. My fear with the NIEE films mentioned above, which cannot compete in terms of production values with Hollywood-style films nor with the authenticity of the average YouTube video, is that they will reinforce engineering students' sense that ethics is "soft," boring, or contrived, and perhaps also fundamentally external to the work of engineering. Furthermore, both videos are based on hypothetical cases, and if not taught carefully, run the risk of reinforcing the idea that ethics is not "real," can be constantly deferred or ignored, or is ahistorical. The same can be said of teaching the feature-length fiction films above; instructors must be conscious and careful of how hypothetical ethical cases are presented.

Instead, engineering educators might consider some of the excellent documentaries available about *real* engineers and engineering projects, such as

- the History Channel's *Modern Marvels: Engineering Disasters* and *Technology*
- the 1981 film *The Day after Trinity* (about work on the Manhattan Project)
- a 2006 videotaped lecture by William LeMessurier, structural engineer involved in the "59-story crisis," available free online (William LeMessurier-The Fifty-Nine-Story Crisis: A Lesson in Professional Behavior)

There are also a number of documentaries that, though not specifically about engineering, can provide students with historical, social, and political context that shape engineering decisions. These include films such as *The Future of Food* (2004), which deals with bioengineering, and *Who Killed the Electric Car?* (2006), about the automotive industry in the United States. Even feature-length fiction films based on historical engineering events can be useful, including the film *Chinatown* (1974), loosely based on Los Angeles water manager William Mulholland, and *Erin Brockovich*, a 2000 film about corporate responsibility and water contamination. These films address both microethics *and* macroethics, and thus can be valuable teaching tools for introducing both, and examining the connections between them.

Conclusion: Film as Art

In this chapter, I've tried to suggest some ways engineering educators might effectively incorporate film or film classes into an engineering curriculum. These approaches have suggested that film can be both a teaching tool and an object of study. I would like to conclude this chapter by also suggesting that film is, almost always, also an art form. Any class that uses film or that is about film will be most effective if the "film as art" approach is also integrated.

For example, an instructor who screens *The Matrix* in class can most effectively lead discussion about bullet-time technology if her students understand the meaning of "mise-en-scène" in film, which "resembles the art of painting in that an image of formal patterns and shapes is presented on a flat surface and is enclosed within a frame. But cinematic mise-en-scène is also a fluid choreographing of visual elements that are constantly in flux" (Giannetti, 2005, p.48). In other words, students need to understand that there are myriad decisions – those of the producer, director, cinematographer, actor, computer programmer, etc. – that go into crafting the visual space of a particular scene. Each decision will have a different impact on the final product of the film, and in what kind of messages it communicates.

In other words, students would benefit from a basic understanding of how meaning is made in film. A cinematographer's choice to film a woman in soft-focus rather than in ultra-exposed light translates into particular *meanings* for the film viewer. Framing a villain off-center, and shooting him from a low angle also creates meaning. Students who have a basic film vocabulary and who have discussed and understood how meaning is made on film are going to be better equipped to discuss it meaningfully in class and to write about it with some sophistication.

In a perfect world, students and instructors would all have taken an introductory course in visual literacy, media studies, or film studies, but this is not always possible. Instructors who have not taught film before may also be overwhelmed with the huge number of texts and websites about film, some of which are difficult to understand and use without training in film studies. Still, instructors and students have a number of resources available that can make discussing and writing about film more enjoyable and successful. There are textbooks that are appropriate and accessible introductions to film form and language for non-majors: I have had good success using these with engineering and applied students who have had no other education in film. They include Louis Giannetti's *Understanding Movies* – in particular, the chapters on mise-en-scène and photography can be excerpted and used effectively in courses across the disciplines (Giannetti, 2005). David A. Cook's *A History of Narrative Film* (Cook, 2004) and Jill Neimes' *An Introduction to Film Studies* (Neimes, 1996) are also good choices. All three refer broadly to films produced outside of the United States. Timothy Corrigan's *A Short Guide to Writing about Film* (Corrigan, 2001) is also a helpful, brief primer for instructors and students new to film analysis, and can be effectively excerpted for use in a variety of courses.

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Chapter 27

Social Risks of Engineering

Wayne Ambler

Abstract: While modern engineering has produced marvels and generally enjoys the great respect its advances have earned, it is also subject to three major categories of concern. One is a concern linked to particular technologies whose benefits are wedded inextricably to risks that might under some circumstances outweigh these benefits. The atom bomb is the classic example. A second concern is linked to the technological way of thinking in general: has it led us to think that nature is nothing more than material to be manipulated for our own benefit, or even that we human beings are ourselves nothing but complicated chemical computers to be reprogrammed as we see fit? Heidegger and both his knowing and his unwitting followers are the most powerful voices in this domain. A third concern may be posed as a question: can the dynamism required in engineering coexist with the stability required by political society, or do ongoing technological changes weaken the social fabric?

Key words: Francis Bacon, Scientific Revolution, Social Stability, Critiques of Technology, Western Rationalism

Introduction: Engineering's Contribution to Society

The engineering profession presents itself not as good in and of itself but as good for society. The National Academy of Engineering in the United States, for example, refers boldly but not surprisingly to the important role engineering has played in the advance of civilization. Its recent publication entitled *Grand Challenges for Engineering* presents the following impressive list of engineers' accomplishments: "the metallurgists who ended the Stone Age", "the shipbuilders who united the world's peoples through travel and trade", the creation of "increasingly sophisticated tools for agriculture", "technologies for producing textiles", "inventions such as the mechanical clock and the printing press", "machines [that] supplemented and replaced human labor", "improved systems for sanitation", and the steam engine that "facilitated mining, powered trains and ships, and provided energy for factories" (2008, 2). This amounts to a bold claim; indeed, it amounts to proclaiming that "throughout human history, engineering has driven the advance of civilization" (3). Even so, the contributions here noted are only the tip of a vast iceberg of contributions for which engineers rightly take great pride. Numerous other accomplishments remain below the surface of our consciousness, for we simply take them for granted, as we can learn again by heeding the panic that ensues whenever the power goes out for an hour or two.

Even if the claim that engineering drives civilization should prove to be overbold, it is not so bold as to defend engineering as good in and of itself, or as a good higher than society. Engineering wishes not merely to be powerful but especially to be powerful in conveying benefits to individuals and to society in general. As the NAE document just cited puts it, engineering now must turn itself to the challenge of "sustaining civilization's continuing advancement, while still improving the quality of life" (4). Engineering is thus understood as a force for good, and it understands the good it seeks as in need of "continuing advancement" and "improving quality." Engineering also implies dynamism, change, progress. Engineers long to produce new inventions as important as the steam engine; they don't long to reinvent the steam engine.

Although his prose is old-fashioned, elegant, and difficult for modern readers, Francis Bacon – who might well be dubbed "the founder of modern scientific engineering" – is the best author in which to see these related features of engineering: that it exists for an end beyond itself and that its pursuit of this end is a dynamic and on-going project.

Bacon's metaphors in the *Great Instauration* stress the productive function of modern science and engineering. They should lead to new "births", they should not be "barren of works", they should produce "fruit", they should not be like statues (which are merely "worshipped and celebrated"), they should result in "new mercies" (1965, 303). This active, transforming spirit of Bacon's new science also leads him to a military simile: the new engineer is "like a general who means to take possession" (313); he or she is to "command nature in action" (314). Leaving metaphors aside, engineering exists for "the benefit and use of life" (310) or to "overcome the necessities and miseries of humanity" (318), and "to endow the human family with new mercies" (309). Never is there a hint that society might exist for the purpose of advancing science or engineering (except as the best means to its own best interest); engineering is subordinated to the higher end of society's good.

Bacon does not stress that engineering may have effects contrary to the ends for which it exists. He is aware of the issue, however, and both correctly and cleverly notes that many good things can be put to a bad use. So why, then, should technology be singled out for criticism in this regard? As Bacon puts it, *"[I]f the debasement of arts and sciences to purposes of wickedness, luxury, and the like, be made a ground of objection [to technology], let no one be moved thereby. For the same may be said of all earthly goods: of wit, courage, strength, beauty, wealth, light itself, and the rest. Only let the human race recover that right over nature which belongs to it by divine bequest, and let power be given it; the exercise thereof will be governed by sound reason and true religion."* (New Organon, CXXIX).

Although Bacon is correct that technology is not the only two-edged sword we wield, the optimism expressed in the last quoted clause is breathtaking. This optimism may well be the unstated premise of many individuals and many a college of engineering, but few commentators miss the chance to note that very powerful new technologies bring with them significant risks as well as benefits. Even exotic threats like rebellious robots or grey goo are occasional news items. Indeed, if a vast generalization be permitted, western society as a whole seems awash with foreboding about technology run wild or, worse, consciously exploited for some nefarious purpose, while scientists and engineers go merrily about Bacon's business of increasing its powers.

A Common Concern and Reservation: some Technology is Harmful

Even if the founder of modern science and engineering should not have seen fit to dwell on the problem that powerful tools can be used both to benefit and to harm, it has become commonplace to note that technological advances are sometimes a mixed blessing. Even those who argue that the atomic bomb helped to end the Second World War and helped to keep the peace in the ensuing Cold War, for example, do not deny that these benefits came with unprecedented and enduring risks. Stressing the benefits of genetic manipulation to cure disease does not blind us to the need for special care when species are changed permanently. Improved pharmacology does not quiet fears of the accidental or purposeful use of potent man-made pathogens. While the blessings of technology are often taken for granted and, iceberg-like, may be submerged beneath our consciousness, fears of wholesale disaster frequently break the surface. Indeed, discussions of global warming rarely go far without indicating that technology has contributed mightily to aggravate the problem (which is not to say it is not commonly seen also as a huge part of hoped-for solutions).

Detailed knowledge is surely needed in order to understand and minimize the risks of particular technologies (Jonas, 1984, 10). Even the pure heart of, say, a Saint Francis of Assisi would not suffice to assess the risks of nano-carbon "buckyballs" or to formulate a prudent policy concerning genetically modified foods: if engineering is to face up to its grand challenges for the future, it will have to acknowledge and address the problems created by its very success. Or, to put it in a more positive matter, the expertise of engineering will surely be needed to understand how best to ward off the potentially harmful consequences of the new technologies engineers put at our disposal. No one claims that the engineer *qua* engineer is well-suited to guide the best use of technology, but the sound regulation of a particular technology requires as one of its preconditions a good understanding of that technology. The regulation of increasingly numerous new technologies will require increased participation by those who understand the technologies to be regulated. Might this be a case where, by publicly calling attention to these sorts of social risks from engineering, engineers and colleges of engineering might be invited to participate in formulating the policies that strive to reduce these risks? If creating new technologies is an engineer's first business, the regulation of newly created technologies will be an increasingly important second calling.

Although I do not expect any engineering societies to write it into their ethical codes, engineers should frequently repeat the thought that particular technologies can do more harm than good. The point is an obvious one, but the general enthusiasm for technological development runs so high that emphasizing risks is hardly superfluous.

Is "the Technological Way of Thinking" a Problem?

More general, fundamental, abstract, and difficult to understand are the concerns surrounding technology (and hence engineering) that consider the whole technological way of thinking to be misguided and harmful to vigorous human life. Rather than focusing on what engineering can do *for* man's material lives, these concerns focus on what the technological way of thinking does *to* man's character and way of understanding himself. While it is beyond the scope of this paper to explore this area of concern in detail, a sketch is possible and useful. Or, since I am drawing on an array of different thinkers here, perhaps I should speak of a collage rather than a sketch.

We may think of technology as merely a tool, but extreme reliance on certain tools changes the person using them. As we become dependent on GPS devices, IPods, and email, we cease to look at the stars, understand the constellations, make our own music, or write letters. The pace of our lives increases, little demands become more urgent, and contemplation is resisted by the social dynamo in which we find ourselves (Helprin, 1996, 1-3). Moreover, we lose the ability to fend for ourselves if left alone in nature, so the increase in our effective strength, thanks to our revolutionizing tools, is accompanied by a decrease in the personal strength that is ours alone (Deneen, 2008, 69-70). Our lives become longer and more comfortable, at least if our polity remains stable and the war zones remain remote, but what we can do, and who we are, has changed. Albeit in different ways and for different reasons, such disparate critics of the technological way of thinking as Martin Heidegger (1977), Jacques Ellul (1964), Wendell Berry (Deneen, 2008), and Jean-Jacques Rousseau (1986) associate it with a fundamental weakness of Western rationalism. Man becomes weaker, less satisfied, morally diminished, and less truly human even though science or modern science was supposed to have produced wholly beneficial results. It surprises us, but perhaps should not, that modern Western rationalism is bitterly resisted in some corners of the globe.

A parallel question asks whether it is better to think of Nature as a home and a source of ordered principles by which to live, or to think of nature as a reservoir to be exploited for the indefinite extension of our lives, deepening of our comfort, and prolongation of our amusement. Is the value of mountains to be measured by the minerals they contain, of oceans by the fish that can be farmed from them, of prairies and deserts by the oil or tar sands beneath their surface? Surely there are natural resources, but is all of nature but a resource? Critics of the technological way of thinking deny it (Kalt, 2006). Technology, in this view, distorts the proper relationship between man and nature.

But if there is a problem to the technological way of thinking itself, this comes to light especially when it is applied to man himself. Having engineered with apparent success so much of our environment, making rivers run and stop when and where we want them to, for example, or extracting fuel from miles deep, why not re-engineer ourselves? Rather than worry that athletes use drugs to enhance their performance, why not think there is an obligation to enhance ourselves and our offspring however possible? Cosmetic surgery is trivial by comparison with what a dedicated effort will make possible: if only we are willing to look upon ourselves as a proper object of scientific manipulation, we can change out our genes and, perhaps, even download our consciousness into waiting computers of vast potential (Joy, 2000). As exciting as this is from a certain point of view, it is troubling from the point of view now under consideration, however: humanity itself will become what humans make it to be, and thus it will lose any claim it might have had to transcendent dignity or a divine connection. Rather, since humanity will be routinely adjusted and remade according to the wishes of its human creators, it would be more accurate to say it will cease to have a durable meaning; it will cease to exist. Once we begin to change our natures, and some would say we already have, no single change can be called "unnatural" or "inhuman," for all will be (Saletan, 2007). If it is good for man to use all the tools he can to remake nature and to remake himself, the advance of technology should occasion rejoicing, but this is where the question lies.

To raise this issue is not to join forces with fearful "Luddites" and to try to stop the march of modern technology. One might conclude there is no turning back. But it is useful nonetheless to bear in mind that reason and the arts (*technai*, in Greek, from which we get "technology") have long since been viewed with some ambiguity even by their defenders, and critics now have the weighty name of Heidegger to embolden them. Altogether apart from the dangers of particular technologies, this sort of concern addresses the technological way of thinking itself: its psychological impact, its moral ambiguity, its demeaning or destruction of human dignity, and its absence of limits in its race to master or possess everything.

Engineering and Social Stability

Engineering as an active enterprise raises also a third sort of concern, one which pertains to a possible link between technological change on the one hand and social and political change on the other. This relationship would prove to be of special importance if it is inevitable that modern technology seeks change, as was suggested in my introduction, above.

Karl Marx expressed well what might be the extreme or limit case in this regard: technological change is *the* cause of social change. As his more abstract formulation put it, "the means of production" determines "the mode of production," and the mode of production establishes the main characteristics of society (1998, 54-57). Or, in different language, "the infrastructure" determines the "superstructure," and with the superstructure come all of the identifying characteristics of our society. Indeed, within the superstructure we find even our defining thoughts, including thoughts on how society should be organized (70-73).

When summing up this group of ideas, Marx put it like this:

> *"Social relations are closely bound up with productive forces. In acquiring new productive forces men change their mode of production; and in changing their mode of production, in changing the way of earning their living, they change all their social relations. The hand-mill gives you the society with the feudal lord; the steam-mill the society with the industrial capitalist. The same men who establish their social relations in conformity with the material productivity, produce also principles, ideas, and categories, in conformity with their social relations. Thus the ideas, these categories, are as little eternal as the relations they express. They are historical and transitory products."* (1967, 480).

To zero in on the two key points, "The hand-mill gives you the society with the feudal lord; the steam-mill the society with the industrial capitalist," and with these two societies come distinct and opposed views on "principles, ideas, and categories." Thus the technology that gives us the prevailing means of production is the ultimate driver of social change and of the revolutionary ideas that accompany and assist social change. Even if we think we fight for or oppose revolutions on the basis of our own independently embraced opinions of justice, advantage, or nobility, these opinions are themselves dictated by the social relations that grow up around different productive technologies. We don't drive technology; it drives us. (Whether it drives us ineluctably in the direction of advances for civilization, a claim implied both by Marx and in the quotation with which this paper began, "throughout human history, engineering has driven the advance of civilization," is another question.)

To state Marx's view is not to establish that it is correct. But even if one doubts, as I do, that Marx's "means of production" is by itself sufficient to produce the "mode of production" that guides or limits social change, it is hard to deny that the former is often a powerful influence on the latter. Whole industries grow up around particular technologies, and these industries of course have legions whose fortunes and futures depend upon their continued success. At a minimum, these legions – whether in pharmaceuticals, oil and gas, or genetically modified organisms – become forces to be reckoned with. A useful historical example to keep in mind is that of Eli Whitney's famous cotton gin. The gin helped to make slavery profitable again and hence to have given a powerful boost to an institution in decline. Even if one cannot say, with Marx, that "wherever there are cotton gins, there slavery will also reside," the powerful influence of the cotton gin on society cannot be denied. When thinking of the *potential* for technology to have massive social consequences, it is good to remember Marx's bold views on this issue.

Moreover, since human beings are known to have a general inclination in favor of their own interests, even when they do not recognize this bias, our judicial procedures do not allow them to preside over their own trials. It thus bears emphasis that technology not only influences society, it also or thereby influences our perception of our own interests and of what is just or unjust. For Marx and his enthusiasts, the verb "influences" could be changed to "dictates" or "determines."

Let me conclude this reminder of Marx's view by underscoring the main point: for Marx, technological change and changes in the means of production give rise to changes in the mode of production. As the mode of production changes, society must also change, even and especially in the form of revolution. Seen from the perspective of the established order, then, technological change is fraught with subversive potential. For those confident that change means progress, the word "subversive" should be changed to "progressive" or "revolutionary."

Let us now consider a related but more modest view, the view not that technology drives the movement of history in a particular direction but that the dynamism expected of engineering, and sought by it, is in conflict with the stability necessary for political society.

This view is hardly a congenial one, for we in the West are accustomed to thinking that open and dynamic societies are an unalloyed blessing. Free speech will allow the truest argument to make its winning case, we think, and new truths can only mean progress. And with regard to technology in particular, even the brief US Constitution goes so far as to specify that Congress has the power to "promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries" (I.8.8). Far from thinking that science and technology could weaken society, the American Framers and classical liberalism in general are enthusiastic about reaping the benefits of technological progress.

The germ of a provocative contrary view emerges in Aristotle's *Politics*, as he offers his criticisms of a certain Hippodamus of Miletus. Hippodamus had proposed a measure according to which people recommending improvements to society would be honored, and Aristotle perhaps surprisingly criticizes the idea. He also takes the occasion to reflect more generally on the requirements of social stability.

Most striking is the fact that Aristotle's brief analysis stresses points that appear to be extreme opposites of one another. On the one hand, he shows that he is not an old, hidebound conservative: customs in olden times were barbaric, he notes, and it is good that they have been abandoned. Moreover, the arts and sciences have improved over time, and we clearly seek what is better, not merely what is traditional (1268b34-1269a14). These points are all congenial to the modern reader, and Aristotle seems for a moment like a firm believer in progress.

But no sooner does he make his general case in favor of change than he issues a caution. The core of the caution rests on the proposition that social society rests ultimately not on known truths but on (mere) habits. As he puts it, "the law has no power to compel obedience beside the force of custom, and custom only grows up in long lapse of time" (1269a19-23). Could it be true that laws are obeyed especially because of custom and that customs depend on time?

If social norms derive their strength from their goodness, then making them better also makes them stronger. Or, to be more concrete, if citizens see that their laws have been improved, they should also support them more earnestly. But what if citizens are not generally able to see what is best? By stressing the importance of habit as *the* key prop of social stability, Aristotle denies that improvements are readily seen or known to be such: if what is "good" is fraught with controversy and hard to see directly, what is traditional is not only seen but is felt as well. Habit, custom, and tradition are thus a sort of practical stand-in for what is good: if traditions often or always fall short of what is best, they have a clarity and compelling force that "best" lacks.

A more modern and more moderate view of Aristotle's position helps to clarify the key points. In the course of explaining the proposed US Constitution and urging the states to ratify it in 1787, James Madison – writing under the penname "Publius" – rejected Thomas Jefferson's view that constitutional controversies should be settled by appealing directly to popular conventions called for this purpose. His statement is a brilliant formulation of a point similar to Aristotle's, but not quite identical to it, and it deserves to be quoted at some length:

> *"[I]t may be considered as an objection inherent in the principle, that as every appeal to the people would carry an implication of some defect in the government, frequent appeals would, in a great measure, deprive the government of that veneration which time bestows on every thing, and without which perhaps the wisest and freest governments would not possess the requisite stability. If it be true that all governments rest on opinion, it is no less true that the strength of opinion in each individual, and its practical influence on his conduct, depend much on the number which he supposes to have entertained the same opinion. The reason of man, like man himself, is timid and cautious when left alone, and acquires firmness and confidence in proportion to the number with which it is associated. When the examples which fortify opinion are ANCIENT as well as NUMEROUS, they are known to have a double effect. In a nation of philosophers, this consideration ought to be disregarded. A reverence for the laws would be sufficiently inculcated by the voice of an enlightened reason. But a nation of philosophers is as little to be expected as the philosophical race of kings wished for by Plato. And in every other nation, the most rational government will not find it a superfluous advantage to have the prejudices of the community on its side."* (Madison, 1961, Federalist 49).

Madison here makes with admirable clarity the point that human beings are not rational, so governments must be designed for imperfect creatures. All governments require support, but even in the best cases, reason cannot be counted on to supply this support: citizens are not philosophers (and neither are rulers). What can supply this support is "prejudice" or to be more precise and give it a nicer name, "veneration"; but veneration comes only with habit and only over time, and it is eroded by changes and hints of imperfection in the established order (and of course such hints of imperfection are true: laws, traditions, and social norms are never perfect).

Whereas Madison implies that the need for veneration is reduced in the case of "the most rational government," Aristotle's view of the power of reason as a source of stability in politics is so limited that he does not even refer to it; but both agree that changes in fundamental norms pose problems even when they represent improvements. A similar line of argument is advanced by St. Thomas Aquinas in his *Summa Theologiae*, I.II. Q. 97 (esp. A.2).

These uncongenial arguments are directed against changes in the law or social norms, however, not against changes in technology or engineering methods. They raise, then, but do not answer, the question of whether and how far the dynamism on which engineering thrives can be confined to an arena that has no effect on norms or laws. Might technology charge along without begetting fundamental changes in established social norms?

The magnitude of the changes wrought by technological dynamism warrants the preliminary suspicion that they have been accompanied by important social changes as well. Now that technological development is an established feature of modern Western life, our lives change rapidly and profoundly. It was really not that long ago that the sailing ship and Conestoga wagon were the chief agents of long-distance travel, while now the jumbo jet is commonplace, everyone has a car or two, Space Shuttle launches are routine, and the space elevator is a gleam in engineers' eyes. The telegraph revolutionized communications just a century and a half ago, while now we drive, shop, and walk while talking non-stop on our cell phones. And as far as medical care is concerned, the anesthetic-free remedies of the Civil War have given way to drugs, procedures, and prosthetics such that hearts are transplanted and growth and activity-levels are regulated by hormones and drugs. Almost all areas of human life, even the most intimate, have been touched or even transformed by dramatic changes wrought by engineers and applied scientists. Thus the American President-elect has made commonplace the unqualified assertion that "technology has changed the way we live" (Obama, 2008).

Caution suggests a narrowing of the question, however. Rather than asking whether the massive changes introduced by engineering always tend to invite social instability, let us first ask whether they do under some circumstances. We have Marx's testimony, discussed above, which suggests that new technologies call forth new means and modes of production, which in turn beget revolutions; but this applies especially to the revolution ending feudalism and the one that was to have ended capitalism. It has less to say about technologies that do not transform the way people produce.

More apt in light of the question at hand is the case of engineering in a closed society like North Korea. Such a society needs energy, weapons, transportation, and many of the other things that only engineers can provide, but cell phones, cameras, Internet access, and scanners help people to associate and share information and are thus potentially worrisome to the established regime. The former Soviet Union sought to keep people dissociated and hence blocked access to telephone books and copy machines. Even so *samizdat* literature, aided only by carbon paper and hand or typewriter copying, helped to bring the regime down. In a closed society, technologies that foster communication are subversive.

Such observations might lead one to conclude that technological change is a threat only to regimes that ought to be changed. Is technology a force for instability but only in the direction of progress?

In keeping with Aristotle's reservations about the risks posed to political stability by changes in laws or customs, he is similarly ambivalent about the location in which to situate his model of the "best regime" (*Politics* 1327a12-1327b17). Should it be on the seacoast, in order more easily to take advantage of the trade that is facilitated by sea travel? Or would such advantages be outweighed by the flood of sailors and traders who, coming from other parts of the world, would not share the habits of the local population and hence might weaken them? Living as we do (in the West) in societies open to, or even eager for, constant technological innovation and open as well to a multicultural mixing of peoples, Aristotle's hesitation seems out of place and perhaps even cowardly: why conjure up the uncertain nightmare of instability to restrain the obvious advantages of technological and social progress?

The record so far suggests that a remarkable level of technological and social dynamism is compatible with an underlying political stability. Technology has helped to change not only the ways we travel and communicate but also our ways of war and even our family and sexual practices; and yet all this dynamism, so far as I can see, has not led to a single amendment to the US Constitution, for example, much less to a general undermining of the open societies most eager for constant technological innovation. (Whether it has been morally beneficial or brought us into an improved relationship with nature is a distinct question, as noted above.)

It is our own enthusiasm for intellectual openness that leads us to take seriously Aristotle's alien ideas on the need to protect political stability against changes in social habits, even if the relative success of modern western liberalism entitles us to doubt his unseasonable thoughts. This said, the scientific revolution supported by Bacon is still relatively young, its numerous and profound effects on society are still hard to assess fully, and we of course need foreign perspectives like Aristotle's if we are to free ourselves from bias as we attempt to judge our own situation. If Aristotle can help us question the notion that society rests upon perceived truths – or "self-evident truths" as the American Declaration of Independence would have it – and consider instead the possibility that mere habit is the essence of our social cohesion, we owe him gratitude for a stimulating train of reflections.

Conclusion

Engineering is an established profession and has bestowed many benefits upon those affected by it, even if it is not the sole driver of civilization's advances. At the same time, however, its power, underlying premises and dynamism occasion the three general categories of concern noted here. Of these, the first is widely acknowledged and easily understood: some new technologies can do great and perhaps irreparable physical harm. The second group of concerns is more abstract, for the notion of "harm" is no longer merely physical: does man's conquest of nature through technology enrich him morally? Does it strengthen what is highest and finest about him? Does it distort his proper relationship with Nature (with a capital "N")? I find the third concern only or especially in an ancient source, Aristotle, and again find it best expressed by a question: how can it be that the deep-seated dynamism associated with ongoing technological change can be compatible with a stable society? What durable ideas and principles hold the technological society together, and how is it that they and they alone avoid change?

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