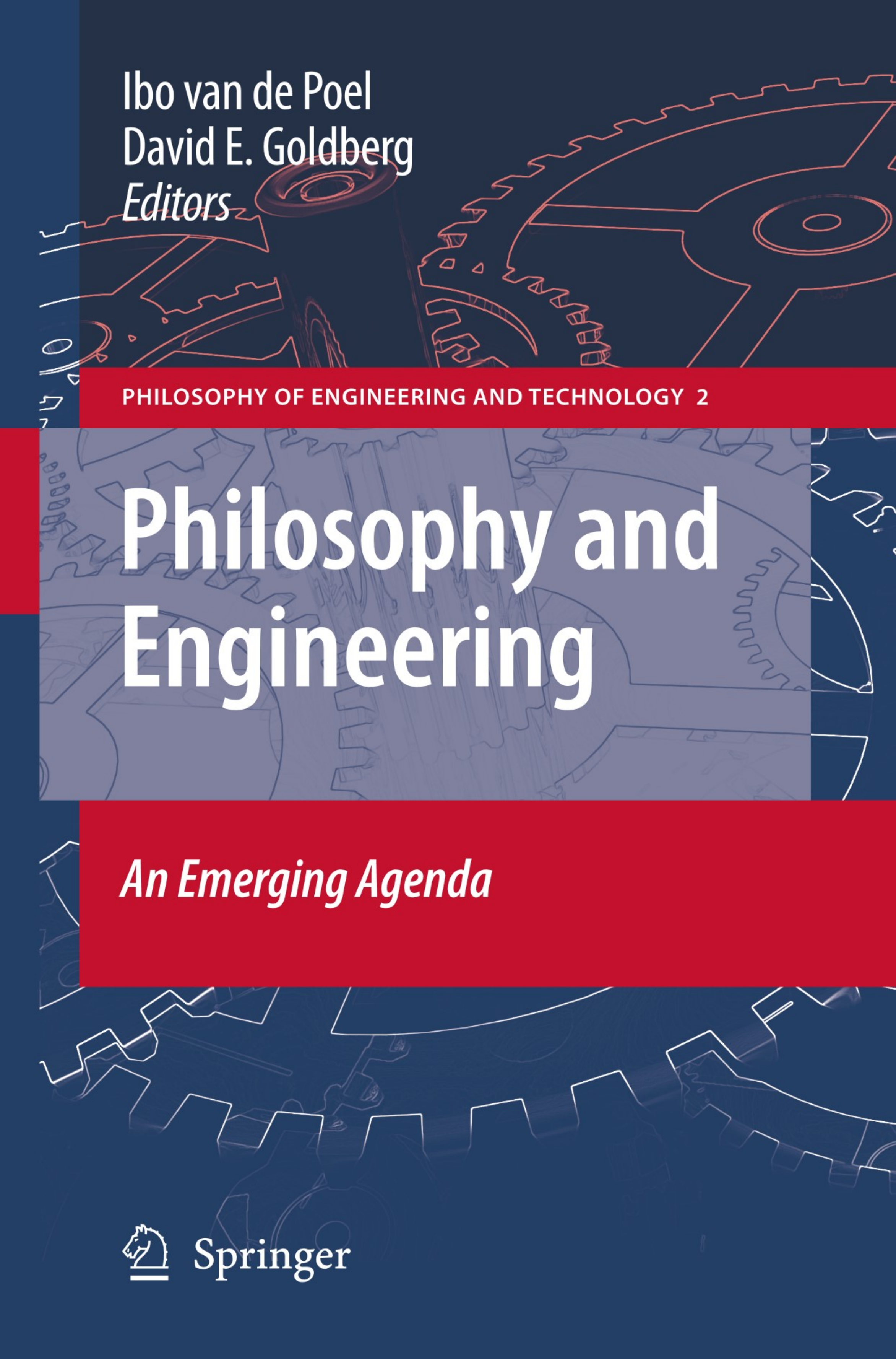

Ibo van de Poel
David E. Goldberg
Editors

PHILOSOPHY OF ENGINEERING AND TECHNOLOGY 2

Philosophy and Engineering

An Emerging Agenda

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Philosophy of Engineering and Technology

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Philosophy and Engineering

An Emerging Agenda

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Chapter 1
Philosophy and Engineering: Setting the Stage

Ibo van de Poel

Abstract Philosophical inquiries into technology are still rare and most investigations are of a recent nature. This contribution introduces a number of general themes that are investigated in the volume *Philosophy and Engineering*. It pays attention to the difference between philosophy of technology and philosophy of engineering, discusses possible definitions of engineering and the relation between science, technology and engineering. An inventory of philosophical issues in engineering is offered and attention is paid to how engineers and philosophers can cooperate to make the new area of philosophy of engineering a success.

1.1 Introduction

Philosophy and engineering seem to make a strange couple. Whereas science and, to a lesser extent, technology have spurred dedicated philosophical investigations, philosophical reflection on engineering is still rare. Philosophy of science is now a well established discipline and even if the philosophy of technology is still a maturing discipline, it has its own society (SPT: Society for Philosophy and Technology) and journal (Techne). A philosophy of engineering is as yet non-existent. One area of philosophical reflection seems, nevertheless, to be an exception: ethics. Engineering ethics has developed since the 1980s as a more or less specialised effort, first mainly oriented to teaching ethics to engineering students, but increasingly also as research on the ethical dimensions of engineering (see Davis 2005 for a good overview of the area).

One might wonder what, if anything, would distinguish the philosophy of engineering from the philosophy of technology. The answer obviously depends partly on how we define technology and engineering vis-à-vis each other. As the

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contributions to this volume testify there is no agreement on this issue. Most authors, nevertheless, seem to agree that engineering and technology are distinct topics. As a first approximation we might characterize engineering as an activity that produces technology. Producing is here to be understood very broadly, including such activities as research, development, design, testing, patenting, maintenance, inspection, and so on. As we will see below, this is a first approximation at best. Nevertheless, it has the virtue of suggesting an agenda for philosophical reflection on engineering that is distinct from at least the traditional philosophy of technology. It means a shift away from philosophical reflection on technology as such, technological objects and the social, cultural and political impacts of these towards attention on what engineers actually do. This shift fits in with what has been called the empirical turn in the philosophy of technology (Kroes and Meijers 2000; Achterhuis 2001). This fit with the empirical turn in philosophy of technology raises again the question whether we need a philosophy of engineering distinct from the philosophy of technology. Nevertheless, it seems clear that engineering raises a number of issues that deserve more philosophical scrutiny than they have received as yet.

1.1.1 The 2007 Workshop on Philosophy and Engineering

This volume is the outcome of the first Workshop on Philosophy and Engineering (WPE) that was held in October 2007 at the Technical University Delft. The workshop itself grew out of a gathering of a number of philosophers and engineers at the Engineering Systems Division of MIT in 2006 that was headed by Taft Broome, Howard University. The Delft workshop brought together 81 participants, 40 paper presentations, 5 posters, 6 invited speakers, and attendees from 14 different countries. As far as we are aware this was the largest organised activity bringing together engineers and philosophers in the last two decades. This volume contains a selection of the papers that were presented at the workshop.

WPE was organized not only out of the conviction that engineering raises philosophical questions, but also that fruitfully dealing with those questions requires the involvement of both engineers and philosophers. It has to be recognized, however, that the cultures of engineering and philosophy are quite different (see Goldberg's contribution to this volume). Whereas philosophers like to reflect and to problematise, engineers are action-oriented and want to solve instead of create problems. Philosophers often value conflicting perspectives on an issue, whereas engineers want to avoid ambiguity. For philosophers language is the main medium; engineers often prefer to draw diagrams or make sketches and are engaged with the material world. Engineers make fancy PowerPoint presentations where philosophers read their papers presenting at best one black-and-white slide. Philosophers judge contributions to their discipline mainly by the soundness of arguments, while engineers often stress criteria like effectiveness and efficiency in solving a certain problem. Given those differences, it is to be expected that engineers and philosophers tend to disagree about what makes a good contribution to the new field of philosophy and engineering. Therefore it was decided to organize the workshop in three distinct subject areas or (as we chose to call them) "demes": philosophy, ethics and engineering reflection.[1] Each deme had its own review and selection procedure. For the first deme, the deme chairs were philosophers and for the third engineers; the ethics deme combined philosophers and engineers, testifying of the more mature status of engineering ethics and the experience in this area with interaction between engineers and philosophers. One might object to this set-up that it results in irrelevant philosophy and in contributions of engineers that do not meet the traditional philosophical criteria for quality. Even if this objection makes some sense, we feel that at this stage of the effort, this strategy is the best.

1.2 Towards a Philosophy of Engineering

Since a philosophy of engineering is still to be developed, there is not a commonly agreed set of problems that define the field. Still, based on the workshop and earlier philosophical reflections on engineering, we can identify a number of topics that belong to the philosophy of engineering. Below, we sketch a number of such topics to give an impression of what a philosophy of engineering might look like, without the aim of being complete or exhaustive.

1.2.1 What is Engineering?

A first issue is how to define engineering, an issue that emerges in several contributions to this volume. All contributors agree that design is central to engineering (see e.g. the contributions by Davis, Luegenbiehl, Didier, Moses and the recent volume *Philosophy and Design* edited by Vermaas, Kroes, Light and Moore). Beyond this, disagreement seems to rule. Durbin, for example, looks at engineering as guild, suggesting that engineering is not or at least not necessarily based on science and mathematics, whereas Luegenbiehl defines engineering as "the transformation of the natural world, using scientific principles and mathematics, in order to achieve some desired practical end" (Luegenbiehl, this volume, p. 153). As he notes, this definition "reflects the modern scientific foundation of engineering, rather than the crafts tradition" (Luegenbiehl, this volume, p. 153).

Li Bo-cong and Didier include other actors than just engineers in the engineering community like managers, other technologists, workers and investors. Davis, who wants to distinguish engineers from other technologists, would probably disagree: engineering is what engineers do in their capacity as engineers.

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[1] In biology, a deme is another word for a local population of organisms of one species that actively interbreed with one another and share a distinct gene pool. If demes are isolated for a long time they can become distinct subspecies or species. Definition from: http://en.wikipedia.org/wiki/Deme_(biology).

In fact, the contributors do not agree on the best approach to defining engineering. Luegenbiehl gives a stipulative definition (see above). Mitcham and Mackey in contrast propose a linguistic philosophical approach to characterising engineering:

> what engineering is might be better determined by how the word "engineering" and its cognates and associated terms (such as invention, innovation, design, technology, science, etc.) are used, especially in relation to each other. From a linguistic philosophical perspective, it would be appropriate to begin not so much with our experiences of engineering but with the words we use to talk about such experiences (Mitcham and Mackey, this volume, p. 55).

Davis in his contribution criticizes both philosophical definitions of engineering and a linguistic approach. With respect to the latter he remarks that "[t]he term 'engineer' (or 'engineering') is no guarantee that what is in question is an engineer (or engineering)" (Davis, this volume, p. 16). This is so because, for example, locomotive engineers are not engineers in the sense we are interested in here. Moreover, in some languages, there are no clear distinctions between engineers and technologists. With respect to philosophical definitions of engineering, Davis argues that

> [a]ll attempts at philosophical definition will: a) be circular (that is, use "engineering" or a synonym or equally troublesome term); b) be open to serious counter-examples (whether because they exclude from engineering activities clearly belonging or because they include activities clearly not belonging); c) be too abstract to be informative; or d) suffer a combination of these errors (Davis, this volume, p. 17).

As an alternative he proposes a historical approach:

> engineering, like other professions, is self-defining (in something other than the classical sense of definition). There is a core, more or less fixed by history at any given time, which determines what is engineering and what is not. This historical core, a set of living practitioners who—by discipline, occupation, and profession—undoubtedly are engineers, constitutes the profession (Davis, this volume, p. 16).

In relation to ethical reflection, a major issue is, as noted by Luegenbiel, whether a definition of engineering should "emphasize the requirement of engineering activity to benefit humanity" (Luegenbiehl, this volume, p. 153) or should choose a more value-neutral approach. The first approach is prominent in traditional engineering ethics where engineering is conceived of as a profession (see e.g. Davis 1998) and it also seems at work in the contributions by Gunn and Bowen. Luegenbiehl and Didier in their contributions prefer a more value-neutral approach. Luegenbiehl does so because he is interested in global cross-cultural ethical principles for engineering, and a more value-neutral approach to defining engineering "avoids having to deal initially with the questions of culturally based ideas of benefit and harm." (Luegenbiehl, this volume, p. 153) Nevertheless, he believes that "some value element is unavoidable, in that I assume that engineering activity should leave the world no less well off and that disbenefits created by engineering not be catastrophic in nature." (Luegenbiehl, this volume, p. 153)

According to Didier, engineering has in history had both morally positive and negative (and value-free) connotations. She prefers to conceive of engineering not as a profession that by definition makes a positive contribution to society but rather as an activity that can be ethically evaluated. Didier's proposal has the advantage of not assuming a culturally-bound notion of profession. (As she argues the Anglo-Saxon notion of profession does not have a clear counterpart in France.) Moreover, her neutral definition opens the ways to ethical reflection on engineering activities like design (see the contribution by Robison and see Van de Poel 2001) and innovation (see the contribution by De Kreuk et al.) that are somewhat neglected in traditional engineering ethics. It might also broaden the discussion about the responsibilities of engineers beyond what is stated in codes of ethics for engineering (see e.g. the contributions by Coeckelbergh and by Pols).

1.2.2 The Relation Between Science, Technology and Engineering

An issue that is related to the definition of engineering is how to understand and characterize the relation between science, technology and engineering. This issue surfaces in several contributions to his volume. Despite differences, there is at least one point of agreement: engineering is not applied science. Pitt looks at the real-world interaction between science and engineering and suggests that science may depend on engineering rather than the reverse. Moses argues that design differentiates engineering from science and mathematics. Broome suggests that engineering employs a different (formal) language game than science and mathematics, one in which there is room to express error and incertitude.

Li Bo-cong argues for what he calls the trichotomy of science, technology and engineering: science, technology and engineering are three distinct though related activities. According to him, the core activity of science is discovery, of technology invention and of engineering making. Science produces scientific knowledge like theories; technology produces technological knowledge, like patents and blueprints for an invention and engineering produces the actual material products. Two things are worth noting about Bo-cong's account in relation to other possible accounts of the relation between science, technology and engineering. First, what he calls technology, some others would call engineering science (as distinct from natural science). Aspects of engineering science, and differences with natural science, are discussed in the contributions by De Vries and Pirtle. Second, Bo-cong conceives of technology as an activity, rather than as the product or object of engineering.[2] In his book *Thinking Through Technology*, Mitcham describes two other common conceptualisations of technology, in addition to technology as object and technology as activity, i.e. technology as knowledge and as volition (wilful or purposive action). Each of these conceptualisations of technology foregrounds different philosophical questions and each would probably account for a somewhat different relation between technology and engineering and, hence, between the philosophy of technology and the philosophy of engineering.

---

[2] Note that engineering activities like inspection, research, etc. do not produce technology, but still may be said to have technology as the object.

1.2.3 Other Philosophical Issues in Engineering

The issues discussed above are largely conceptual: how to best define and understand engineering, technology, and science and how to understand their relation? Such conceptual questions may also be asked about specific activities and concepts in engineering like design, function, invention, creativity and patents. For example, Vermaas in his contributions sets out the ICE-theory that tries to solve a number of conceptual (and metaphysical) issues with respect to technical functions. In addition to conceptual issues, engineering raises a range of other philosophical questions.

One additional kind of issue is *epistemological*: what is the nature of engineering knowledge and the justification of such knowledge? The seminal work here is still *What engineers know and how they know it* by Walter Vincenti – an engineer and historian of technology. Vincenti distinguishes different types of engineering knowledge. (For a recent discussion of epistemological issues see Houkes 2006.) The contributions by the philosophers De Vries and Pirtle in this volume also address epistemological issues.

Another kind of issue is *methodological*, i.e. questions about the methods employed in engineering and their adequacy and justification. The engineer Billy Koen has argued in his book *Discussion of the Method* that all methods in engineering are fundamentally heuristic in nature (see also his contribution to this volume). Philosophers have critically examined a number of methods used in engineering like multi-criteria decision-making (Franssen 2005), design methods (Vermaas and Dorst 2006) and quality function deployment (Van de Poel 2007). In this volume, one of the pioneers of systems engineering, Joel Moses, discusses different approaches in systems engineering. The philosopher Ottens provides a critical analysis of methods in systems engineering for the design and management of socio-technical systems. Engineer Abbott discusses a number of issues in software development.

Engineering also raises *metaphysical* and *ontological* issues, for example, about the status of design or functions. It might seem that such issues are less relevant to practising engineers than, for example, conceptual, epistemological and methodological issues. Vermaas in his contribution, for example, suggests that the ICE-theory for technological functions that he and Houkes developed needs to be stripped off from its philosophical assumptions to make it relevant to engineering. Despite Vermaas' scepticism, engineers have engaged in applied ontology as a means for developing (better) design methods, databases of engineering parts and the like (e.g. Kitamura et al. 2006).

Engineering obviously also raises *ethical* issues, as is witnessed by the development of engineering ethics. As argued above, some authors in this volume further extend the scope of engineering ethics. Again, this is an area to which both philosophers and engineers have made a contribution. Typically, the main textbooks in engineering ethics are written by a combination of philosophers and engineers (Vesilind and Gunn 1998; Martin and Schinzinger 2005; Harris et al. 2008).

Engineering does not only raise new philosophical problems, it might also sometimes shed new light on existing philosophical questions. McCarthy in her contribution suggests that an examination of engineering knowledge would create new insights into existing epistemological questions. With respect to ethics, it might be argued that engineers in the design process deal with conflicting values by creatively thinking of new designs and innovations that soften or even solve existing value conflicts (Van de Poel 2005). This is a way of dealing with value conflicts that has been overlooked in the philosophical literature on value conflict. The later, indeed, suggests another important theme for philosophical reflection in engineering: creativity and innovation.

The above list of issues may be a bit biased towards an analytical approach to the philosophy of engineering. As the contributions by Durbin and by Mitcham and Mackay illustrate other approaches are possible as well.

1.2.4 Interaction and Cooperation Between Philosophers and Engineers

The above overview shows that both engineers and philosophers have been and are working on conceptual, epistemological, methodological, ontological and ethical issues in engineering. This is not to say that they have always done so in cooperation or that they always agree on the quality standards for such work. Above, we have suggested that they do not necessarily do so, and this is in fact underlined by the experiences described by Vermaas in his paper. Still, this volume also shows examples of good cooperation between engineers and philosophers, for example in dealing with ethical issues in innovation (De Kreuk et al.) and in developing teaching materials for engineering ethics (Kroesen and van der Zwaag). Typically, the main examples of fruitful cooperation between engineers and philosophers are from ethics.

One might wonder what would be required for a further fruitful cooperation between philosophers and engineers. As earlier noticed, philosophers and engineers come from different (academic) cultures. Cooperation then seems to require some changes in the mind-set of both disciplines. For philosophers, it requires at least the willingness to pay attention to the reality of engineering practice; the empirical turn in the philosophy suggests that at least some philosophers are now making this move. For engineers, it would require a willingness to reflect on their own practices even if this is not immediately useful or even undermines current practices. (This is not to say that philosophical reflection cannot be useful for engineering eventually, but one should not expect immediate results.) Goldberg in his contribution to this volume suggests that engineering is now increasingly facing a global crisis that spurs, at least temporarily, a turn to philosophy.

The further cooperation between philosophers and engineers, and more generally the philosophical reflection on engineering, will be facilitated by the continuation of the WPE workshops.

1.3 The Contributions

1.3.1 Philosophy

The first part contains nine contributions to the philosophy deme. Davis in his contribution discusses how to define engineering. He applies the historical approach, which he proposes, to understand the differences (and similarities) between engineering and architecture. Li Bo-cong discusses the relations between science, technology and engineering and the importance of a distinct philosophy of engineering.

The next two papers – by Durbin and by Mitcham and Mackay – discuss various approaches to the philosophy of engineering. Durbin's paper is more historical: he gives an overview of approaches to the philosophy of engineering that can be found in the SPT community. Mitcham and Mackay distinguish six different possible approaches to the philosophy of engineering: phenomenological, postmodern, analytic, linguistic, pragmatist, and Thomist. They argue for more attention for the linguistic approach.

Vermaas in his papers describes his experiences as a philosopher cooperating with engineers. He argued that the ICE theory that he and Houkes developed for technical functions is not immediately relevant for engineering practice and can only be made more relevant by making is philosophically less interesting.

The next five contributions all focus on more specific philosophical issues in engineering, in particular in engineering science. Pitt discusses and criticizes the characterisation of engineering as applied science. He suggests that most of today's science cannot be conducted without what he calls the "technological infrastructure," in the making of which engineering plays a major role.

De Vries discusses the nature of generalization in the engineering sciences. It is often suggested that generalisation in engineering is more difficult than in science due to the action-oriented nature of engineering. De Vries studies four cases of generalisation in the engineering sciences and suggests that these exemplify three different generalisation patterns in engineering: from artefact-token to artefact-type, from artefact to function and from artefact to artefact-structure.

Pirtle is interested in the role of models in engineering. He discusses three examples of models in engineering: flush riveting, control volume analysis. and the models used in the failure analysis of the New Orleans levees. He argues that models in engineering have not yet received the philosophical attention they deserve and that an important philosophical question is whether models in engineering and science are different enough to require a different (philosophical) understanding.

Ottens discusses the limits to systems engineering through the example of electric power systems. He argues that the current approaches in systems engineering relegate certain system elements, like the users and legislation, to the environment of the system, while these elements may be crucial for the proper functioning of the system.

1.3.2 Ethics

The second part contains ten contributions to the ethics of engineering. Gunn describes engineering as the oldest profession and one of the most demanding ones. He discusses the importance of integrity in the ethics of engineers. Like Gunn, the contributions by Bowen and by Luegenbiehl start with the traditional responsibilities of engineers as laid down in codes of ethics, but both try to extend this traditional perspective. Bowen is interested in an aspirational engineering ethics that prioritises people. In doing this, he draws from unusual sources for engineering ethics: Buber and Levinas and MacIntyre's virtue ethics. Luegenbiehl is interested in ethical principles in a global context. He argues that this requires a new foundation of ethical principles on the basis of the nature of engineering. Luegenbiehl's efforts in effect move in an opposite direction as Bowen's. Whereas Bowens tries to enlarge the scope of responsibilities of engineers (by including doing good), Luegenbiehl looks for a minimal version that is globally acceptable.

The responsibility of engineers is also an important theme in the contributions by Coeckelbergh and by Pols. Coeckelbergh argues that traditional approaches to responsibility assume transparency in the relation between action and consequences and between my action and what is under my control. Such transparency is, however, usually absent in engineering. He looks for a solution in approaches that foster moral imagination and takes inspiration from two philosophers of technology: Jonas and Anders. Pols discusses how, and under what conditions, responsibility is transferred from the designers of an artefact to the users. In doing so, he combines philosophical work on responsibility with recent insights from the philosophy of technology about design.

Didier presents a French perspective on engineering ethics, which is illuminating because, as Luegenbiehl also notes, engineering ethics is still largely an American affair. She suggests that the focus of engineering ethics is nevertheless already widening from engineering as a true profession to engineering as a type of activity that raises ethical questions.

The next two contributions by Robison and by De Kreuk et al. indeed mark such a widening of the scope of engineering ethics. These contributions focus on activities, i.e. design (Robison) and innovation (De Kreuk et al.) that are central in engineering but have until now only received limited attention in engineering ethics. Robison suggests that "benign by design" would be a fundamental ethical principle for engineering design. De Kreuk et al. describe the uncovering of ethical issues in the innovation process of a new sewage treatment plant. This happened in close cooperation between engineers and ethicists, while the cooperation was fruitful in recognizing ethical issues and improving design decisions, it also introduced new ethical issues, especially about the role of ethicists in such cooperation.

The papers by Kroesen and Van der Zwaag and by Danielson also deal with cooperation between ethicists and engineers. Kroesen, a philosopher, and Van der Zwaag, an engineer, describe the development of a new role play game for teaching engineering ethics. Robison describes a computer platform for doing experiments in the ethics of technology that extends the cooperation between engineers and others in three directions, i.e. by including social scientists, the public and other technologists.

1.3.3 Reflection

The reflection part contains contributions by practising engineers. Goldberg asks the question why engineers and philosophers are now meeting. He suggests that a discipline is more willing to consider philosophical questions as it faces a crisis. According to him, engineering is now facing such a crisis, which will turn the engineering mind to philosophy for at least some time.

McCarthy discusses the work of the philosopher and former engineer Wittgenstein. She argues that there are interesting correlations between Wittgenstein's approach to philosophy and the engineering approach: both try to dissolve or overcome certain problems. She illustrates this by applying the two approaches to epistemological questions about engineering knowledge and more general philosophical issues in epistemology.

The next two contributions, by Moses and by Abbott, are good examples of professional engineers reflecting on their own discipline. Moses discusses three major approaches to the design and architecture of large scale engineering systems. Abbott describes a number of issues in software design and development.

The contributions by Broome and Fritzsche try to characterize engineering in relation to issues of determinacy and indeterminacy, certitude and incertitude. Broome is interested in the formal language games employed by engineers on the one hand and scientists and mathematicians on the other. Fritzsche discusses engineering as determinate operation, even if we cannot fully escape indeterminacy in practice.

The final two contributions take up ethical issues in engineering. Koen discusses how engineering can take up the challenge of sustainability and ultimately the survival of the human species. He is especially interested in what types of engineering heuristics would be needed to deal with this issue. Moriarty discusses an approach for the ethical assessment of engineering projects based on Borgmann's notion of focal product.

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Part I
Philosophy

Chapter 2
Distinguishing Architects from Engineers: A Pilot Study in Differences Between Engineers and Other Technologists

Michael Davis

Abstract This chapter points out some differences between engineers and architects in curriculum, standards of evaluation, and allied fields, provides an historical account of the origins of those differences (emphasizing the last three hundred years), and reflects on the method that makes the differences so clear and alternative methods of study that might make them appear much less so (a focus on discipline, occupation, and profession rather than function). The conclusion is that we must be careful to identify what method we use to study engineering, since the choice of method is often also the choice of conclusion (or, at least, the ruling out of some promising alternatives).

> "All is water."—Thales
>
> "All is air."—Anaximenes
>
> "None of the other things either is like any other."—Anaxagoras
>
> "Those, then, who say the universe is one and posit one kind of thing as matter, and as corporeal matter which has spatial magnitude, evidently go astray in many ways."—Aristotle, *Metaphysics* Bk.I. Pt. 8

2.1 Introduction

Philosophers tend to divide into those who, like Thales or Anaximenes, search for the overarching generalization that includes everything ("the one"), and those who, like Anaxagoras or Aristotle, like distinctions ("the many"). Since our subject is "philosophy and engineering", it may be a useful exercise, especially for the non-philosophers, to ask (in imagination) of contributors (whether philosophers or engineers) whether they are seeking the one or the many. Since advisors who do not take

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their own advice are rightly suspect, I shall begin this chapter not only by asking that question of myself but answering it: *though I like a good generalization now and then, I belong with those who prefer the many – as will soon be obvious.*

2.2 The Name and the Thing

The subject of this volume is (in part) engineering. What then is engineering here? What is this activity for which we are to do philosophy-of? That is not a question about how the term "engineering" is used, a question of lexicography. In some of the languages we speak, there is not even a clear distinction between "engineer" and "technologist". Even in English, which has both words, there is some confusion. The term "engineer" (or "engineering") is no guarantee that what is in question is an engineer (or engineering). The custodian of my apartment building, with only a high school education, has an "engineer's license" that entitles him to oversee operation of the building's two boilers. A few miles south of those boilers is the local office of the Brotherhood of Locomotive Engineers and Trainman. Neither my building's "licensed engineer" nor those "locomotive engineers" are engineers in the sense this volume requires. They are engineers in an old sense indicating a connection with engines, that is, they are technicians much like mechanics, trainman, or bus drivers. Then there are the knockoffs of engineering proper: "genetic engineering", "social engineering", "re-engineering", and so on.[1]

Equally confusing, I suppose, is that there is at least one field of engineering *not* called "engineering": *naval architecture*. In the US, programs in naval architecture are accredited as engineering programs, describe themselves in those terms, and in fact look much like other engineering programs. Naval architects are called "architects" only because there was once a tradition of English shipbuilding in which gentlemen, not trained as engineers, used detailed drawings to instruct tradesman how to build large sailing ships. Having a classical education, they knew Greek and preferred to use the Greek term, "architect", rather than the English, "master shipwright" (a term analogous to "master carpenter" or "master builder", suggesting a tradesman with dirt on his hands). The name outlived the tradition.[2]

What, then, distinguishes engineers, in the sense appropriate for this volume, from other technologists – assuming, for the moment, that architects, computer scientists, industrial chemists, industrial designers, and so on are technologists but not engineers. The answer cannot be the *function* of engineers. Like other technologists, engineers design, "build" (or, at least, manage the building), and otherwise contribute to the life (and death) of technological systems (that is, relatively complex and useful artifacts embedded in a social network that designs, builds, distributes, maintains, uses, and disposes of them). *Equating* engineering with designing, building, or the like involves at least two mistakes.

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[1] The confusion is even greater when the term is "marine engineer". Some marine engineers are a kind of licensed mariner (those who operate and maintain the mechanical systems of modern ships) – while others practice a branch of engineering called "marine engineering" (the subject of which is the *design* of those same mechanical systems).

[2] Applied physics (sometimes called "engineering physics") is another of these misnamed fields; it is not physics but engineering. "Rocket science" would be another – if the term ever appeared anywhere but in (something like) the humorous observation, "It's not rocket science".

The first, already noted, is that equating designing, building, or the like with engineering makes distinguishing engineers from other technologists impossible. Architects, computer scientists, industrial chemists, and so on also design, build, and so on. Indeed, even ants, beavers, and coral do that (more or less).

Second, and equally important, is that equating engineering with designing, building, or the like gives a misleading picture of what engineers in fact do. Some engineers simply inspect; some write regulations; some evaluate patents; some attempt to reconstruct equipment failures; some sell complex equipment; some teach engineering; and so on. Whether all of these activities are properly engineering, indeed, whether any of them are, is a question for the philosophy of engineering. My point now is that inspecting, writing regulations, evaluating patents, and so on are functions that engineers routinely perform not simply in the sense that they are functions some engineers happen to perform but in the philosophically more interesting sense that they are functions that some engineers are supposed to perform. Employers sometimes advertise for engineers rather than other "technologists" to perform these functions. I agree that design (engineering design) is central to understanding engineering, but I do not see how designing can be *the* (defining) function of engineering – because, as I see it, there is no function that engineers, and only engineers, seem to perform (except, of course, engineering itself, which is what we are trying to define).

If not defined by its function, what can define engineering? I have elsewhere given a double answer to this question. One answer is that if "define" means giving a classic definition (by genus and species), there are only practical definitions, useful for a particular purpose. There can be no philosophical definition, that is, one that captures the "essence" of engineering (because engineering no more has an essence than you or I do). All attempts at philosophical definition will: (a) be circular (that is, use "engineering" or a synonym or equally troublesome term); (b) be open to serious counter-examples (whether because they exclude from engineering activities clearly belonging or because they include activities clearly not belonging); (c) be too abstract to be informative; or (d) suffer a combination of these errors.

The other answer, the one that explains in part this first, is that engineering, like other professions, is self-defining (in something other than the classical sense of definition). There is a core, more or less fixed by history at any given time, which determines what is engineering and what is not. This historical core, a set of living practitioners who – by discipline, occupation, and profession – undoubtedly are engineers, constitutes the profession. They decide what is within their joint competence and what is not. They also admit or reject candidates for membership in the profession, using criteria such as similarity in education, method of work, and product. Often these criteria function as algorithms. So, for example, the ordinary lawyer clearly is not an engineer (that is, competent do engineering), while the typical graduate of an ABET-accredited engineering program with a few years experience successfully working as an engineer clearly is an engineer. But perhaps as often these criteria cannot be applied without exercise of judgment. Does someone with a degree in chemistry who, say, has successfully managed a large chemical plant for five years, count as an engineer because what she has been doing is, in effect, “chemical engineering”? (For a defense of these claims, see Davis 1995, 1996, or 1998, Ch. 3).

I have, I said, argued for this double answer elsewhere. I shall not repeat the arguments here. Instead, I shall provide indirect evidence for that double answer by comparing engineering to a closely related discipline, architecture. My thesis is that architects, though clearly technologists, are just as clearly not engineers. If architects are technologists but not engineers, not all technologists are engineers and engineering cannot be equated with technology. The philosophy of engineering is *not* simply the philosophy of technology (or even the philosophy of technologists).

Architecture is a good choice for comparison with engineering because engineers have a tendency to claim some “architects” as engineers, for example, the chief builder of one of the great Egyptian pyramids or Renaissance artisans such as Michelangelo or Leonardo da Vinci (Kostof 2000). I put scare quotes around “architect” here because these are only proto-architects (as well as only proto-engineers). Why? I will soon explain.

There are at least three other reasons why architecture is a good choice for this comparison. First, engineers have often tried to integrate architecture into engineering. For example, the first attempt to found an American society of civil engineers (1852) was called the “American Society of Civil Engineers *and Architects*”.[3] The idea was that architects and civil engineers had enough in common to form one (technical) society. Second, the original plan for the École Polytechnique in Paris (1794), the mother of engineering schools, included a program in architecture.[4] Several of the first American schools of architecture began as programs within engineering departments and with curricula borrowing much from engineering. Even today, many engineering schools, such as IIT or RPI, have a school of architecture (though the École Polytechnique still does not). Third, architecture is also a good choice for comparison with engineering because architecture’s history parallels engineering’s. Architects and engineers appear in history at about the same time, in the same countries, and sometimes even doing the same work (for example, designing bridges).

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[3] This might have worked. Only five years before, the American Medical Association was founded with an equally inclusive ideal, admitting surgeons as well as physicians (who, by history and training, were then at least as distinct from physicians as architects were from engineers). The AMA’s inclusiveness was not unlimited, however. It declined to admit dentists (who, in those days, would have been oral surgeons). The admission of surgeons to the AMA was successful (as the admission of architects to the ASCE was not). The exclusion of dentists was also successful. They remain a separate profession.

[4] The claim that the *École Polytechnique* is the mother of all modern engineering schools, especially the great number of 19th century schools that put “polytechic” in their name, is, I think, uncontroversial. But that claim is consistent with another, the claim of several schools of the *ancien régime* seem to have developed the curriculum the *École Polytechnique* made famous. History has few bright lines. Most are a device of historians trying to put what they know in a form short enough to be useful.

Architecture and engineering are in fact siblings, sometimes competing and sometimes cooperating. Yet, as often happens with siblings, they are unmistakably different individuals.

My argument proceeds in three stages. The first stage identifies several ways in which architecture (what architects typically do) differs from engineering (what engineers typically do). Though each of these ways is significant in itself, what matters here is their accumulation. The *overall* difference between the two disciplines is surprisingly great – as great, say, as that between accounting and law, or medicine and dentistry. The second stage briefly contrasts the history of architecture with that of engineering. While explaining how engineers and architects might claim the same ancestors, this history also sharpens our sense of how different the two disciplines are. The third stage draws conclusions about how to approach the philosophy of engineering. One conclusion, of course, is that any philosophy of engineering should be able to distinguish engineering from architecture. Technologists are not one but many. Each discipline is an historic individual, not a Platonic form.

2.3 Some Differences Between Architecture and Engineering

How do architects today differ from engineers? Let us begin with their education, the basis of their discipline. One important difference is that architects learn less mathematics and science than engineers do, much less, and what they learn is also different. Engineers are generally required to take both physics and chemistry. At some schools, such as IIT, architects will have to take one or two semesters of physics. At others, such as RPI, the only natural science architecture students must take is biology. There is not, I think, any architecture school that requires its students to take chemistry.

More important is the difference in the math that engineers and architects learn. Engineering students must take two years of calculus. Architects are nowhere required to take more than one semester of calculus and at some schools are not required to take any or only to take a watered-down version of what the engineers take their first semester. While engineers in practice may seldom use calculus, attempts to eliminate it from the engineering curriculum have failed. Even substantially reducing the calculus requirement seems to turn an engineering program into a program training technical managers. Engineering seems to be a calculus-based discipline (in a way we do not understand); architecture is not.[5] That, I think, is a fundamental difference between the two disciplines (even though much architects do depends on someone using calculus now and then).

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[5] Non-engineers are unlikely to appreciate how central calculus is to the training of engineers. The four courses in calculus are only a part of the story. The rest of the story is three years of engineering courses in which students regularly use calculus to solve problems. Few architecture classes – and none of the core – use calculus at all.

What do architects learn instead of calculus? One thing is free-hand drawing. Free-hand drawing seems to be important. Many schools have a two-semester sequence students must take (in addition to computer-assisted design). While engineers do a lot of sketching, they are not taught to draw free-hand. And, in fact, the average engineer seems to draw about as well as the average philosopher.

Another thing architects learn instead of calculus is the history of architecture. This is more important than it may seem. While calculus has had a central place in the education of engineers since well before the founding of the *École Polytechnique*, the history of engineering never has. The history of engineering is not a course required for engineers. Indeed, many engineering schools do not offer the course even as an elective. Apart from a few stories about classic engineering disasters, engineers know little about the history of their discipline (not even the names of "famous engineers"). History has little to do with what engineers typically do – or, at least, little *explicitly* to do with it. Much history is embedded in technical standards, methods, and attitudes.

In contrast, the history of architecture (often a two-semester sequence) is everywhere a requirement for architects. The history of architecture is also often explicit in how architects are taught to work. Until the 1950s, the first thing an architecture student given a design problem was supposed to do was go to the architecture library to check for historical antecedents. In some schools, that is still the first thing a student should do. The names of "famous architects" appear regularly in the architect's classroom; and, indeed, even in the informal discussions of architecture students outside the classroom. Architecture students sometimes "quote" earlier buildings in their designs. They are *supposed* to use history as a source of inspiration – even if practicing architects use history no more (and perhaps no less) than practicing engineers use calculus. Architecture is a history-based discipline much as engineering is calculus-based.[6]

The rhythm of architectural study is also different from that of engineering study. Engineers divide their time between classes and labs. Though engineers generally work harder than the average liberal arts student, the engineer's semester is otherwise similar, building to a peak at midterm and again at finals. Architecture students not only have "design studios" in addition to class and the rare lab, those studios dominate their lives for the full four or five years of the bachelor's program. It is the studios that require the large, well-lit spaces typical of architecture schools. Studios are organized around "projects", particular design problems. Being "best in your class" means being best at such projects. As the date a project is due nears, architecture students tend to drop everything else – social life, classes, and even sleep. They disappear from campus life for a week or two and then reappear (different students disappearing at different times). Though there was always some logic to teaching architecture in an engineering school, the studio has, I think, tended to separate architecture from engineering even when, as at IIT and RPI, architecture was brought into the institution. A senior design course, itself relatively new to engineering education, demands much less time than an architect's studio, demands it only for one or two semesters, and tends to respect the demands of other classes in a way the studio often does not.

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[6] Architecture is also a discipline that relies on "precedent", generally following modes of design and construction that have proved their reliability. In this respect, architecture resembles engineering. Engineers hate to "reinvent the wheel" (as they often put it). That, however, is a different point from the one I am making here. While architecture is history-based, architects are, in some respects at least, less attached to precedent than engineers are. For examples, architects love to "reinvent the house".

These differences in the way the two disciplines are taught deserve more attention than they have received. They do not seem to have an obvious explanation founded on differences in how architects and engineers practice (a purely "functionalist" explanation). In practice, architects and engineers work in ways that appear much more alike than their schooling would suggest. For example, both work on "projects". Both do a good deal of "designing" (though the engineers do engineering designs while the architects do architectural designs). Both are likely to adjust the hours they work to what the work demands. Even the physical spaces in which they work are often similar (much more alike than either is like the space in which lawyers or physicians typically work).

Of course, there are also differences between architects and engineers at work. There are the obvious but superficial differences, for example, that architects tend to dress better than engineers. More interesting, I think, is the way they work. There are at least three differences worth mention here. First, when an engineer makes a presentation, he is likely to use flow charts, graphs, mathematical tables, diagrams, and blueprints. The architectural presentation is likely to keep such things to a minimum. Instead, the architect is likely to use physical models (like those architecture students carry around campus), color renderings (complex multi-color drawings in chalk, water color, or ink), and (recently) computer-simulations of buildings. Architects emphasize appearance in a way engineers generally do not.

That is not surprising, of course. Architects are trained to pay attention to appearances in a way engineers are not. Indeed, architects understand themselves to be responsible for the appearance of the "built environment" – what the American Institute of Architecture (AIA) Code of Ethics calls "aesthetic excellence", E.S. 1.2. Architects regularly comment on the aesthetics of their own work and that of other architects. Aesthetic evaluation, so central to architecture, is largely missing from engineering. While many products of engineering, from bridges to circuit boards, are in fact beautiful, engineers seldom comment on that beauty. They certainly do not treat beauty as a routine design criterion. That is not because engineers as individuals do not care about beauty. Many do. The reason engineers do not treat beauty as a design criterion is that beauty is not part of their discipline. What engineers tend to emphasize in place of beauty is cost, safety, and efficiency.[7] That is a second difference in the way engineers and architects work.

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[7] I am, of course, talking about public presentations or the major presentation that "sells" the design. Architects are quite capable of discussing cost, safety, and efficiency – and regularly do it when dealing with technical issues of design. My point is simply that such considerations do not have as prominent a place in their discipline as they have in engineering.

Perhaps that difference explains a third. Architects not only routinely design for crafts, they are also supposed to. So, for example, the AIA Code of Ethics (E.S. 1-5) explicitly asks architects to “promote allied arts”. In contrast, engineering has a long history of trying to substitute unskilled labor or machines for skilled craftsmen. Engineers have no corresponding duty to any “allied art”. Engineers tend to standardize work; architects to individualize it.

Closely related to these three differences in the way architects and engineers work is the way they present themselves. Engineers tend to present themselves as “scientists” – applied scientists. Though their training, the emphasis on math and natural science, may explain this, presenting themselves that way is nonetheless misleading. The point of saying that engineers are applied scientists is to claim the authority of the natural sciences for what they do. But most of what they know is not natural science but the special knowledge engineering has itself developed. My point here is not that engineers design and scientists do not (Vincenti 1990). Scientists also design. Most scientists design experiments; and a few, such as synthetic chemists, design other things as well (for example, molecules unknown to nature). My point is rather that much of what makes an engineer an engineer is not scientific knowledge, whether abstract or applied, but engineering knowledge, something scientists do not have.

Architects could claim to be applied scientists just as engineers do. Architecture does apply knowledge of materials, environment, and so on, much as engineering does. Instead, architects present themselves as artists.[8] They emphasize their creativity rather their science. When searching for a job, they present a “portfolio” of their work rather than a “resume” (as engineers typically do). The portfolio will often contain their own free-hand renderings as well as computer-generated floor plans, sections, and “elevations” (that is, the façade, sides, and back of the structure).

Another difference between engineers and architects is not in how they work or present themselves, but in what they work on. Engineers often work on weapons. Architects do not work on weapons, not even fortifications. This is odd because the most famous book about architecture, and one of the most influential, is Vitruvius’ *Ten Books on Architecture*. Vitruvius took up architecture only upon retiring from a Roman legion after a long career as a “mechanic” (that is, a siege master or “military engineer”). Architecture is an art of peace in a way engineering is not.[9]

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[8] In my experience, this is the dominant form of presentation. It is certainly not the only one. For example, some architects present themselves as craftsmen (rather than artists), emphasizing durability and comfort over beauty; some, as “social engineers” (changing the way people live and think); and so on. This variety suggests the variety of things any architect must actually do in the course of a single design. Engineers also have ways of presenting themselves other than as “applied scientists”, but there are fewer of them – and they are different. The most common are, I think, businessman, manager, and inventor.

[9] Early “architects”, for example, the proto-architects of the Renaissance, often did work on fortifications. But the point here is that, despite this early history, architecture today is (and for at least three centuries has been) “an art of peace”. That it was not always so simply suggests the importance of history in defining architecture as a discipline, a point I shall come back to.

The last difference between architects and engineers I shall point out here does not concern how they work or what they work on but how they have organized. Architects and engineers are organized more or less independently. They are taught in separate schools even when those schools are in the same university. They take different degrees. They belong to separate associations. They have separate accreditation systems, separate codes of ethics, and separate professional publications. Computer science is organizationally much closer to engineering than architecture is.

These are, I think, the most important differences between architecture and engineering today. I may, I admit, have overlooked some differences, and may have overstated some of the differences noted. But all I need claim, all I do claim, is that this list is close enough to right that we are entitled to conclude that architecture is not a kind of engineering (or engineering a kind of architecture).

2.4 Historical Contributions to These Differences

Like engineers, architects like to trace their history back at least to the ancient Greeks. Architects have a somewhat better claim to that linage, though. Unlike the relatively new "engineer", the word "architect" does come from ancient Greek (thanks to Vitruvius). And the architects (chief builders) of ancient Greece did build structures similar to those modern architects built until quite recently. Yet, the fact is that any history of architecture beginning even with the ancient Greeks would have several discontinuities. The most important of these is the European middle ages, a period of almost a thousand years in which great buildings – not only churches and castles, but also guild halls, hospitals, bridges, and so on – were built without anyone called "the architect" and, indeed, using methods, styles, decorations, and even proportions different from those the ancients used. The term "architecture" was raised from the dead as part of that general revival of ancient learning we call "the Renaissance". A Gothic building was just a building, but a classical building was "architecture".[10]

The revival of architecture took place in at least three related ways. The first was an act of scholarship. The general revival of classical learning seemed to generate a desire to build in the classical style. The builders of the day, stonemasons, did not know how to do that. Trained in guilds, they carried on (and developed) the local building traditions, usually some mix of Gothic, Moorish, and Romanesque. Those who wanted to build like the ancient Greeks (or their Roman successors) had to study Greek or Roman writing – largely in the original language – or travel to places where classical buildings survived in sufficient numbers, especially, Rome.[11]

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[10] Oddly, Vitruvius' use of "architecture" (rather than the Latin synonym) may itself have been a revival, a word choice signaling that he wanted to bring back Greek styles at a time when the Romans were developing their own. Vitruvius' revival 1500 years after he first published is almost an accident. Only one copy of his book survived the dark ages. One copy less and "architect" might not have been our word for the builder of classical buildings. We might instead have had the architectural equivalent of "engineer" (or the Italian word, "artificer").

Those who chose to study texts had to be "learned" (that is, to have a reading knowledge of one or two ancient languages). A good example of such a scholar is Leon Battista Alberti (1404–1472), a Florentine graduate of the University of Bologne, a canon lawyer by training. He first wrote a book about architecture (*De re aedificatoria*) addressed to patrons (rather than to builders or architects) and only later began to receive commissions (Ettlinger 2000, pp. 113–114).

To "build like the ancients" did not mean using classical methods of construction. Much of what the Greeks and Romans knew, their oral or tacit knowledge of construction, had been lost, and what little survived in Vitruvius was not easy to apply. Instead, building like the ancients meant achieving the same effects using contemporary methods. So, when Alberti used his classical knowledge to design a building (or, more often, to design new facades for existing building), he consulted a stonemason to determine what was in fact practical (Kostof 2000, p. 114). He knew the elements and proportions that were necessary for classical forms but not how to build them to be durable at reasonable cost.

The second way in which the revival of architecture occurred was through the work of artists. Michelangelo (1475–1564) is fairly typical in this respect (though unusual in most others). Both engineers and architects like to claim him as their own, but Michelangelo was properly neither. He generally identified himself as a "sculptor"; his career looks like that of an artisan, that is, someone trained to make beautiful objects using stone, precious metals, paint, and so on. Michelangelo's formal education ended before his teens. He picked up knowledge of classical architecture from scholars in Florence, from observing recently-constructed buildings in Florence, and from observing classical buildings old and new in Rome. Classical facades appeared in his paintings for many years. Eventually, at age 50 (1525), he was asked to design the Laurentian Library for his patron, Lorenzino de'Medici, then the ruler of Florence. Michelangelo did as asked, and oversaw the construction, and that (along with a few unrealized designs) made him an "architect". Later commissions, including work on St. Peter's in Rome, gave him a portfolio of achievements sufficient for an enviable career in architecture. But, for Michelangelo, architecture was a sideline. His claim to be an engineer has even less foundation.

Soon after Michelangelo finished the Laurentian Library, the Florentines revolted, drove the Medici out, and declared a republic. A supporter of the republic, Michelangelo was asked to help prepare the city's fortifications. He did his best for about a year, 1528–1529. In 1530, the city fell to Medici allies and Michelangelo fled, never to return.

These facts do not show that Michelangelo was an architect or an engineer. What they show instead is that Italy then had neither architects nor engineers. What Italy had were people who, at the whim of a patron or in a pinch, could function as an architect or engineer (or, rather, as an architect or engineer would later function). The Laurentian Library, though a wonderful building, is not the work of someone with a career in architecture. Would we be willing to call Michangelo an architect if, all other facts being the same, the Library and all his later buildings had been disasters instead of successes? I assume the answer is no. It is, then, important that we have some way of identifying architects that is independent of their actual achievements. If a failed architect is still an architect, then a successful builder is not necessarily an architect.

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[11] Compare Vasari 1963, 151: "Rule in architecture is the measurement of antiques, following the plans of ancient buildings in making modern ones."

The same point applies to engineers. The fortifications constructed for Florence under Michelangelo's supervision, though apparently satisfying the standards of the time, were his only "engineering". His qualifications for the job seem to have been that he was a famous artist, that he was a republican who had just overseen a large construction project (the Library), and that there was no one else better qualified. That is not enough to make someone an engineer; it is, at best, a start.

One reason there was no one better qualified to oversee the fortification of Florence was that increasingly powerful artillery was then changing the principles of fortification. The high, thick walls in which stonemasons specialized, once almost certain to force a long siege, could not withstand cannon for more than a few days. Low earthworks were required instead. Their design was not well understood in 1528. There were in fact no experts in fortification anymore. Even an artist might have a good idea. Michelangelo was not alone among artists to offer ideas. Leonardo da Vinci did something similar – though, it seems, no one ever carried his out.[12]

Central Italy thus had a double tradition of classical building, one scholarly and the other artistic. About this time, a third tradition was developing in northern Italy. Andrea Palladio (1508–1580), a stonemason, undertook a series of large country houses, beginning with the Villa Godi in 1537–1542. He seems to have learned the classical style in part from scholarly patrons, though he also studied briefly in Rome in 1541, a perceptive patron suggesting the trip to the 33 year-old stonemason and paying his way. Thirty years later, after a successful career, Palladio gathered his designs into *The Four Books of Architecture* (1570) – a work in Italian, the language of stonemasons, not Latin, the language of scholars. Except perhaps for Vitruvius' book, Palladio's is the most influential in the history of architecture.

Palladio was an architect in a way neither Alberti nor Michelangelo was. Unlike Alberti, he understood the materials with which he worked. Unlike Michelangelo, he made a career of designing and constructing buildings. His book on architecture helped to define the new discipline, the design, construction, and retrofitting of buildings in the classical style. But there remained the problem of how to train architects. Palladio, a stonemason, was – like Alberti and Michelangelo – a self-taught architect – or, at least, not formally trained as an architect.

The three Italian traditions of architecture – the scholarly and artistic of central Italy, and the stonemason's in the north – remained more or less separate while influencing the others. There was no curriculum to define the discipline of architecture, only books, traditional guilds having related skills, buildings to study, public discussion of architectural design, and various educational experiments. We must wait a century for the next important step in development of the discipline – and go to another country.

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[12] For two less well-know "architect-engineers" of about the same time, see Vasari 1941, 211–221, Guilano and Antonio da S. Gallo, both trained in "wood-carving and perspective".

Cardinal Mazarin, an Italian, was chief minister of Louis XIV during much of that king's minority. Mazarin thought France deserved modern art, something better than French artisans were providing, and conceived of a school to train the most talented students in France in drawing, painting, sculpture, engraving, and other media necessary for the proper construction of the classical public building he was planning. In 1648, that school became a reality, the Royal Academy of Painting and Sculpture. The Academy itself was an association of prominent artists, much as the Royal Academy of Science was an association of scientists. The school operated under the auspices of the Academy, taking its name. Some of its members served as faculty. The members of the Academy were to provide the government with a convenient pool of mature talent; its school, to prepare the next generation. The French in this period were organizing schools for many purposes as a way to teach large numbers of students more quickly than apprenticeship did and to teach skills apprentices were unlikely to be taught. Often the school resembled an apprenticeship except that the students did not work in anyone's shop, had several masters rather than one, and had a set curriculum.

Though the Academy of Painting and Sculpture seems to have trained architects from the beginning, it was not until 1671 that the French established a distinct "Academy of Architecture" with its own school. The separate academy was, of course, a recognition that training architects differed significantly from training painters or sculptors. This recognition appeared in two ways. First, the later years at the Academy included more design of buildings than before. Second, preparation for practice was now to include a term in an "atelier" of a royal architect, a formal apprenticeship under the supervision of the Academy.

Like many French institutions, the Academy of Architecture then remained more or less unchanged until the French Revolution. The only important change seems to have been the addition of formal lectures on design, mathematics, materials, and history during the mid-1700s. The Academy's graduates provided France with most of those who made a career of constructing large buildings of stone in a classical style. If the Italians invented architecture, the French invented architects.

The French Revolution initially abolished all the academies and then, after discovering the need for them, reestablished them in some form or other. After the restoration of the monarchy, the academies were reformed again. In 1816, the Academy of Architecture was combined with the Academy of Painting and Sculpture and the Academy of Music to form *l'Académie des Beaux-Arts* (the Academy of Fine Arts). Though merged for administrative convenience and some economies of scale, the three academies maintained distinct curricula. The architecture curriculum was again more or less what it had been before the Revolution.

The curriculum of the Academy of Architecture focused on classical arts and architecture. All architecture students were required to prove their skills in basic drawing before advancing to figure drawing and painting just as the art and sculpture students were. Only then did the architecture curricula diverge from painting and sculpture, focusing on building facades and floor plans rather than on the composition of paintings or sculpture. Architecture was understood – and therefore taught – as one of the "fine arts".

One distinctive feature of the Academy's curriculum was a series of competitions around which all the work of the year was organized (the predecessor of today's studio). The competitions were judged by an outside panel of experts who did not know who had produced the drawing, plan, or design. The winner of the senior competition received the "Prize of Rome", an all-expenses-paid period in Rome to study classical buildings, send back reports, and prepare a design to justify admission into the academy as an architect.

The *Académie des Beaux-Arts* was an extraordinary architectural success. Its graduates produced many fine buildings; its curriculum was copied by similar institutions in other European states and then in much of the rest of the world. So, for example, many of the "engineer-architects" who built the world's first skyscrapers in Chicago were civil engineers who, deciding they wanted to design exteriors and interiors of their buildings, went to Paris for a year or two to learn how – or to one of the new American schools of architecture offering something like the Beaux-Arts curriculum.[13]

Modern construction seems to have put pressure on architecture schools to include more about building than the Beaux-Arts curriculum did. That may explain why the United States began to have its own schools of architecture two decades before the first skyscrapers began to appear, why those schools were generally part of a university or engineering school (rather than independent entities like the French or like many contemporary schools of art or design), and why the curriculum typically had much more about construction than the Beaux-Arts curriculum did (though there was considerable variation until after the Second World War). Something similar seems to have been going on in Germany about the same time. The architecture curriculum of the *Académie des Beaux-Arts* slowly lost status during the 20th century – until, in 1968, its own students went into the streets demanding an "American-style curriculum". Within a few months, *l'École Nationale Supérieure d'Architecture* was created as part of the University of Paris.

I shall not retell the history of engineering in the detail I have just told the history of architecture because I assume the typical reader of this volume is familiar with its general outlines. It is enough for our purposes to note that the history of architecture laid out here is largely independent of the history of engineering. So, for example, the first engineers in France, officers in the *corps du genie*, were soldiers, not civilians, as the architects were. The engineers were designing fortifications, roads, bridges, warships, and other military works when the first architects were designing palaces, hospitals, theaters, and other public buildings. Only in the 19th century did engineering become useful enough for non-military purposes that large numbers of engineers could make careers as civilians. Even then, they tended to work on projects different from those architects worked on. For example, an engineer was more likely to design a factory or canal; an architect, a house or department store. Engineering schools were generally separate from architecture schools (even when, as became increasingly common, they shared a campus). The skills of engineers and architects are probably more alike today than in 1700, 1800, or 1900.

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[13] Cuff (1991) and Draper (2000). The first of these American schools was MIT (1865). By 1900, there were eight more: Cornell (1871); Illinois (1872); Syracuse (1874); Columbia (1881); Pennsylvania (1890); George Washington (1894); Armour Institute, later IIT (1895); Harvard (1895). The University of Michigan's opened a school of architecture in 1876 but closed it two years later. (Parenthetical date is date when a distinct department or complete four-program was established.) Weatherhead 1941, 33–62 and 90–108.

2.5 Conclusions

If we return to the long list of differences between architects and engineers in Section 2.3, we can see the origin of most, if not all, in the differences in history of the two disciplines. The chief difference between early architects and early engineers is that the early architects were civilians working in or near large cities while the early engineers were military officers often working in hostile country. The architects had access to all the skills of those cities: stonemasons, carpenters, painters, chemists, and other "allied arts". They were seldom in a rush. They worked like other artists. The engineers, in contrast, generally had to work in places, whether urban or rural, in which little skilled labor was available; where experts were far away; and where time was important. Their labor pool was the military itself, mostly soldiers whose only trade was war. Engineers therefore had to know much more about construction than architects did, had to plan much more carefully than architects did, and had to design for efficient use of unskilled labor. Beauty was not important to the military. Being able to put something up quickly, using only unskilled labor was. The engineer's knowledge of math, physics, and chemistry was necessary to an engineer's work in a way it was not to an architect's.

There is, I admit, nothing inevitable about these differences between architects and engineers. A different history might have given us different differences – or none at all – and might still do so in the future. Indeed, I not only admit that lack of inevitability but stress it. The history of a discipline is not the unfolding of a plan even in the way gestation of a child from a fertilized egg is. Much depends on historical contingencies. Past societies have arranged things differently; ours might have done the same.

The history of a discipline is not, let me emphasize, the history of the discipline's achievements – or, at least, not primarily that. We cannot work backward from artifacts to the social arrangements that produced them. For example, many societies have had canals that much resemble the canals civil engineers now build. Yet we know that some of those canals were the work of people whose training was radically different from what we expect today of civil engineers. So, for example, the Erie Canal (1817–1825) seems to have been designed by, and built mainly under the supervision of, self-taught surveyors who, in those days, were more likely to be involved in selling real estate or resolving boundary disputes than in doing anything resembling engineering. No one with formal training as a civil engineer was involved in the Erie Canal (though the person in charge of the project held the title "Chief Engineer").[14]

A discipline is a distinctive set of practices taught to novices by adepts and the learning of which is a condition of being accepted as adept in the discipline. What constitutes the discipline is, at any time, largely a matter of history. Curriculum is important. A "discipline without a curriculum", a settled course of study, is not a discipline. In this respect, poetry, though an art, is not a discipline. The same is true of invention. Part of understanding engineering is comparing the way engineers approach certain problems with the way those in closely related disciplines, not only architects but computer scientists, industrial designers, or public health officers, in fact approach them. For example, in what ways do these disciplines approach safety differently? But part of understanding engineering is comparing the way engineers work with the way mere inventors do. Before we accept someone as an engineer – whatever her title or achievements – we should ask how she was trained. If she lacks proper training, she is not an engineer.

Are any differences we discover in this way merely historical or the product of some underlying logic? For example, does accident or necessity explain why we now have chemical engineers as well as chemists but not anthropological engineers as well as anthropologists? When does "science" need engineers to "apply" it? That is another question for the philosophy of engineering: in what ways, if any, might engineering have been different?

This chapter has focused on engineering as a discipline rather than on engineering as a profession. That was necessary because the history of engineering is much longer than the history of the profession (Davis 2003). But differences in profession are, where they exist, often important aspects of a discipline. I have hinted at how different by quoting a few passages from the AIA Code of Ethics in Section 2.3. Comparison of codes of ethics for engineers with codes of ethics for other professions would, I think, highlight other revealing differences (Davis 2002). The comparison would, of course, also highlight important similarities. But, as I warned at the beginning of this chapter, I tend to emphasize the differences. Where all is one, there's not much to study.

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[14] See, for example, http://en.wikipedia.org/wiki/Erie_Canal (October 11, 2007): "The men who planned and oversaw construction were novices, both as surveyors and as engineers – there were no civil engineers in the United States at the time. James Geddes and Benjamin Wright, who laid out the route were both judges who had gained experience in surveying as part of settling boundary disputes." Both Geddes and Wright seem to have been frontiersmen with, at best, a primary-school education (though Geddes did briefly teach school in his native Kentucky before leaving for upper New York State). Those who worked under the two judges (such as Canvass White or Nathan Roberts) were at the time also at best "amateur engineers" – without formal training in engineering and, indeed, generally without any advanced education at all – and almost no experience of any sort of canal building, much less of a canal so large as the Erie. Building the Erie Canal was a school for a whole generation of canal builders, the last before civil engineers took over canal building in the United States.

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Chapter 3
The Rise of Philosophy of Engineering in the East and the West

Li Bo-cong

Abstract Philosophy of engineering, a new branch of philosophy, came into being both in the East and the West at the beginning of the 21st century. Although Chinese and Western scholars in the field of philosophy of engineering worked independently and did not come into immediate contact with each other during the developing process, they synchronized their steps forward unexpectedly. Their efforts made philosophy of engineering score substantial progress in academic and institutional aspects. Nevertheless, there are still some important problems in philosophy of engineering that need to be worked out. One of the most important problems is whether it is possible and necessary to establish philosophy of engineering. The kernel of this problem is the relationships among science, technology and engineering. This article puts forward the triism or trichotomy on science, technology and engineering. Science, technology, and engineering are three kinds of different activities and have important differentiations. There are many differences between scientific community and engineering community. Engineering is a complex phenomenon and philosophy of engineering is and should be an important branch of philosophy.

3.1 Introduction

Philosophy of engineering is a new branch of philosophy that only recently came into existence. At the end of the 20th century philosophy of science and philosophy of technology became well established. However philosophy of engineering remained in an embryonic stage. In 1991, *Critical Perspectives on Nonacademic Science and Engineering* edited by Paul T. Durbin, was published in USA. This book, in which some authors focused their attention on philosophy of engineering, is an important contribution to philosophy of engineering. It is the fourth volume in

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the series *Research in Technology Studies* edited by Steven L. Goldman and Stephen H. Cutcliffe.

In the foreword of that volume, the series co-editors Goldman and Cutcliffe said, “The resulting collection of essays ranges very widely indeed, from a technical analysis of one facet of engineering reasoning to the politics of design. Taken together, the essays begin to define the parameters of an as yet virtually nonexistent discipline, namely, philosophy of engineering.” (Goldman and Cutcliffe 1991, p. 7)

Although several authors of that volume, such as Goldman, Taft H. Broome, Billy T. Koen and Carl Mitcham, fully supported that philosophy of engineering was a new discipline, there were also some others who did not make their attitudes to philosophy of engineering clear.

In the Introduction to the volume, Durbin was skeptical about philosophy of engineering being a new discipline. As the editor of the volume, Durbin prudently avoided using the term of “philosophy of engineering”. He wrote, “When I first conceived this project, I had in mind a narrower focus – the so-called R&D community” (Durbin 1991, p. 11). It seemed that he preferred to express the need for a philosophy of R&D rather than the need for a philosophy of engineering.

Taft H. Broome was an active pioneer of philosophy of engineering. In his essay “Bridging Gaps in Philosophy and Engineering”, Taft H. Broome mentioned three different modes: philosophy and engineering, philosophy in engineering, and philosophy of engineering. He pointed out that philosophy of engineering was still in its embryonic stage at that time (Broome 1991, pp. 265–267).

In fact, the situation that philosophy of engineering was still in its embryonic stage was also reflected in other authors’ attitudes towards the establishment of this new discipline.

At the same time in China, just as in the West, there were also a few Chinese scholars who tried to open up a new academic field: philosophy of engineering. Bo-cong Li submitted a presentation “On Engineering Realism” to an international conference held in Beijing in 1992. In the next year Li revised the paper and published it in *Studies in Dialectics of Nature* (Li Bo-cong 1993).

At the end of the last century, while philosophy of science was centrally situated in the field of philosophy, philosophy of technology, as Pitt (1995), Ihde (1995) and Rapp (1995) pointed out that, was only situated in a marginal region of the field of philosophy. Since some philosophers regarded philosophy of engineering as a part of philosophy of technology, philosophy of engineering was just situated in a marginal region of the marginal region of the field of philosophy.

Goldman considered that engineering was an extremely complex phenomenon that deserved to be studied in its own right. He sighed with emotion, “Today, then, philosophy of science is a fully accepted and highly respected branch of philosophy, while philosophy of engineering carries as much professional distinction as philosophy of parapsychology” (Goldman 1990, p. 140).

These above-mentioned facts showed that philosophy of engineering was not yet formed as a new branch of philosophy until the beginning of the 21st century.

3.2 Substantial Progress of Philosophy of Engineering at the Beginning of the 21st Century

This situation of philosophy of engineering has varied along with the running of times.

At the very beginning of the new millennium, philosophy of engineering emerged as a distinctive discipline of philosophical inquiry in the United States, Britain, Western Europe, as well as in China. The first several years of the 21st century witness the rise of philosophy of engineering both in the East and the West.

Meanwhile, some encouraging progress in the field of philosophy of engineering was made in publications, academic activities and institutions. This progress may be viewed from two aspects, the academic aspect and the institutional aspect.

In the first place, four monographs on philosophy of engineering, which were published one after another from 2002 to 2007, have attracted considerable attention separately in China and the West. Li Bo-cong's *An Introduction to Philosophy of Engineering* was published in China in 2002 (Li Bo-cong 2002). In the next year, Louis L. Bucciarelli's *Engineering Philosophy* came off the press in Europe (Bucciarelli 2003). In 2007 other two monographs, *Philosophy of Engineering* edited by Yin Rui-yu, Wang Ying-luo and Li Bo-cong et al. (Yin Rui-yu et al. 2007b) and *Philosophy in Engineering* edited by Jan F. Frederiksen, Steen. H. Christensen and Jørn Jensen et al., appeared separately in China and Europe (Frederiksen et al. 2007).

Although the titles of above-mentioned books are similar, their contents and target readers are quite different. Besides above-mentioned books, another one on philosophy of engineering has been written by Goldman (2004). The fact that four monographs came out in such a short time certainly marked an important milestone in the development of philosophy of engineering. Besides monographs, two annals, *Engineering Studies* (Du Cheng and Li Bo-cong 2004, 2006, 2007) and *Engineering and Philosophy* (Yin Rui-yu et al. 2007a), appeared in China in succession.

From the point of view of scientific sociology, academic institutions play a very important role in academic progress. In 2003, the Graduate University of Chinese Academy of Sciences established the Research Center for Engineering and Society, which is dedicated to interdisciplinary studies of engineering and do research in the fields of philosophy, sociology and history of engineering. The Research Center has edited and published yearbooks Engineering Studies since 2004.

In May 2004, Chinese Academy of Engineering (CAE) held a workshop on philosophy of engineering Xu Kuang-di, the president of the CAE, addressed at the workshop, and a number of academicians of the CAE and philosophers attended. This event was considered as a milestone in the development of philosophy of engineering in China, because it was the significant prologue to a striking progress of philosophy of engineering in China.

A forum on philosophy of engineering sponsored by the CAE was held in Beijing in December, 2004. Most important of all, the First National Conference on Philosophy of Engineering was held in December 2004 in Beijing, and the Chinese Society for Philosophy of Engineering was formally organized at that conference.

The Second and the Third National Conference on Philosophy of Engineering were held in Shanghai in September 2005 and in Xi'an in July 2007 respectively. They were organized in cooperation with the CAE, and took place jointly with a forum on the frontiers of engineering sponsored by the CAE. The Chinese National Conference on Philosophy of Engineering will be held every two years in the future. The Chinese Society for Philosophy of Engineering has decided to edit the annals *Engineering and Philosophy* every two years.

By and large, tremendous progress is being made in the field of philosophy of engineering in China at the beginning of the 21st century. It is interesting that although Chinese and West scholars in the field of philosophy of engineering did not come into immediate contact with each other during last two decades, they synchronized their steps forward in progress unexpectedly.

In contrast to the humble situation of philosophy of engineering in the last two decades of the 20th century in the West, more and more attention was drawn to the field of philosophy of engineering from the beginning of 21st century. In the first place, the Steering Committee for the Philosophy of Engineering was founded in USA. In 2005, an e-forum on engineering and philosophy was held in UK. In the next year, the first organizational meeting of ETSI (Engineering and Technology Organizational Studies) was held in Illinois, USA.

Surprisingly, in 2007 two series of seminars, spring 2007 seminar series in USA and a philosophy of engineering seminar in UK, and two international conferences on philosophy of engineering, International Research Conference on Occupational Bildung and Philosophy in Engineering held in Denmark in May and WPE-2007 (Workshop on Philosophy & Engineering) in Netherlands in October, were held separately in Europe and in USA.

From the facts above-mentioned it is reasonable to assert that philosophy of engineering is rising in the East and the West at the beginning of the 21st century.

3.3 Trichotomy of Science, Technology and Engineering

In order to open up a new branch of philosophy, philosophy of engineering, we need to answer a crucial question "is it possible and necessary to form a new branch of philosophy: philosophy of engineering?"

In the 20th century, scholars from various countries had much discussion on the mutual relationship among science, technology and engineering. Many scholars claimed that technology is applied science and engineering is applied science too. Under this view that I called monism on science, technology and engineering it is impossible and unnecessary to define philosophy of engineering as well as philosophy of technology as a new branch of philosophy, because both philosophy of technology and philosophy of engineering are only a small part of philosophy of science.

Another view on science, technology and engineering is dualism, under which technology is independent of science and engineering is regarded as a part of technology. Under this dualist view on science, technology and engineering, it is possible and necessary to define philosophy of technology as a new branch of philosophy, but it is impossible and unnecessary to define philosophy of engineering as a new branch of philosophy.

I put forward a new doctrine called triism or trichotomy on science, technology and engineering (Li Bo-cong 2002, p. 3). On the basis of this triism or trichotomy of science, technology, and engineering, it is natural that not only philosophy of science and philosophy of technology but also philosophy of engineering should come into existence.

In order to express my view on the relations among science, technology, and engineering fully, I coined the term triism according to which science, technology, and engineering are three different kinds of activities (Li Bo-cong 2002, pp. 3–6). Science should not be confused with technology, and technology should not be confused with engineering.

Because technology should not be confused with science, philosophy of technology should be separated from philosophy of science. And for the same reason, philosophy of engineering should be separated from philosophy of science.

It is noticeable that few scholars paid their attention to the discussions on mutual relationship between technology and engineering. But it is a big issue indeed. On one hand, technology and engineering are closely related – there is no engineering without technology and technology can be applied to engineering. On the other hand, they are different – engineering always involves non-technological factors, and is the unity of both technological and non-technological factors. So engineering shouldn't and can't be confused with technology. Engineering activity contains economical factors, management factors, social factors, political factors, ethic factors and psychological factors, besides technological factors. The "non-technological factors" often play a more important role in engineering. Since engineering should not be confused with technology, philosophy of engineering should be separated from philosophy of technology.

In brief, the trichotomy thesis or triism of science, technology and engineering gives a basis for defining a new branch of philosophy, philosophy of engineering.

The differences of science, technology and engineering are in the focus of trichotomy thesis or triism of science, technology and engineering.

The following are some important differentiations among science, technology, and engineering.

(1) Viewed from their content and nature, scientific activity takes discovery as its core, technology activity takes invention as its core, and engineering activity takes making as its core. The thesis that science, technology, and engineering are three different kinds of activities is a fundamental one in the ontology of engineering.
(2) Viewed from their achievements, scientific activity, technological activity, and engineering activity yield three different kinds of achievements. Scientific activity results in academic achievements, or new scientific knowledge, such as new theories, new scientific principles, new scientific concepts, or academic dissertations. Technological activity results in technological achievements, or new technological knowledge, such as a patent for an invention, "know-how", or

blueprints. Engineering activity results in engineering achievements, or material products and material facilities that mean material wealth, such as a power station, a building, a new railway, a new car, or a new computer. Scientific knowledge belongs to all mankind, while technological knowledge, such as patents, belongs to their inventors or a certain company. As to engineering achievements, its nature is not knowledge, but material wealth.

(3) From an epistemological viewpoint, scientific thinking, technological thinking, and engineering thinking are three different thinking styles. Scientific knowledge, technological knowledge, and engineering knowledge are three different kinds of knowledge.

(4) Scientific community, technological community, and engineering community are three kinds of different communities. Scientific community consists of scientists. Technological community consists of inventors, engineers, designers and technicians. However engineering community consists of investors, managers, engineers, workers, and other stakeholders.

(5) Scientific activity, technological activity and engineering activity should be measured by different standards. Scientific standards are different from technological standards, and technological standards are different from engineering standards.

(6) When we study scientific activity, technological activity, and engineering activity, we find that they are quite different in their institutional aspects. Scientific institution, technological institution and engineering institution are three kinds of different institutions. They have different institutional arrangement, institutional environment, operational modes and norms of activities, different evaluating standards and evolutional methods, and different management principles, developing modes and goal orientation.

(7) Scientific culture, technological culture and engineering culture have different contents and characteristics.

(8) In the field of sociology, the problem of public attitude to science and the problem of public attitude to technology have aroused scholars' concerns, but the problem of public attitude to engineering has not aroused scholars' concerns so far.

Emphasizing on differences of science, technology and engineering does not mean that we deny the close relationship among them. On the contrary, the triism or trichotomy of science, technology and engineering gives prominence to problems of transformation from science, such as theoretical principles, into technology, such as patents, and from technology into engineering.

3.4 Scientific Community and Engineering Community

Although the term "scientific community" was not proposed first by Kuhn, it became very popular due to Kuhn's influential work *The Structure of Scientific Revolutions*. We should pay attention to the fact that besides scientific community there are many other communities. Among various communities in society, engineering community is of an extreme importance. Engineering community is larger than scientific community. Especially, engineering community plays a more important role in society.

While philosophers paid great attention to scientific community, they neglected engineering community nearly completely. However, engineering community should be the focus of attention in the field of philosophy of engineering and sociology of engineering. Scientific community and engineering community are different in their goal orientation and memberships.

Scientific community pursues truth, while engineering community pursues benefits. Scientific community comprises scientists, and engineering community comprises engineers, managers, investors, workers and other stakeholders. There are a lot of important and complex issues about engineering community, such as why different individuals have to form an engineering activity community, such as a firm, how they organize an engineering activity community, and what kinds of relations exist in the engineering activity community, and so on.

The fact that engineering community is an important category both in the field of philosophy of engineering and in the field of sociology of engineering suggests that philosophy of engineering should be closely related to sociology of engineering. In order to enhance the research in the field of philosophy of engineering, we should do sociological research on engineering at the same time.

Engineering community is a very important subject in the field of philosophy of engineering. However it has been totally neglected. It should be noted that we have to pay more attention on the study of engineering community. From the point of view of engineering community, Karl Popper's theory of "three Worlds" has some serious defects.

Popper regarded the third world or World 3 as the essential products of the human mind. From the point of view of philosophy of engineering, in addition to the three worlds proposed by Popper, there should be the fourth world or World 4, which is parallel to World 3 but different from World 3. I regarded world 4 as the essential products of the human body. It is engineering community which creates objects that consists of world 4. While World 3 comprises spiritual products, World 4 comprises material products.

Although both World 1 and World 4 are material worlds, they are qualitatively different. The former is a natural world, and the latter that consists of artifacts, such as power stations, railroads, airlines, computers, and clothes, is a new one created by humans. Basing on philosophy of engineering I would like to develop a new kind of realism, dubbed "engineering realism", In the field of traditional realist philosophy philosophers focus their attention on what reality is, while in the field of philosophy of engineering philosophers focus their attention on why and how engineering reality is created and used by engineering community or human beings.

According to Popper, World 2 refers to human minds, but according to the theory of four Worlds, World 2 refers to engineering community that consists of individuals as the unity of mind and body. Because the real agents in engineering activities are human groups with machines, issues of organizations and institutions become supremely important.

World 4 is qualitatively different from World 3. In contrast to World 3, which does not act on World 1 by itself, World 4 can act on World 1 by itself (Li Bo-cong 2002, pp. 411–430).

3.5 Why Philosophy of Engineering is Important

From discussions above, we can draw a conclusion that we need not only philosophy of science and philosophy of technology, but also philosophy of engineering as well.

Goldman pointed out that philosophers had neglected research on engineering practice for a long time. He said, "[the] Western intellectual tradition displays a clear preference for understanding over doing, for contemplation over operation, for theory over experiment" (Goldman 1990, p. 127). In fact the Chinese intellectual tradition displays a same preference as the Western intellectual tradition does.

Nowadays, a lot of things, including cultural circumstances, engineering practice, philosophical community and engineering community, have been radically changing over time.

Gaps in engineering and philosophy are being filled gradually. We expect that philosophy of engineering will move from a marginal region of the marginal region in the field of philosophy to the central region in the future.

More and more philosophers and engineers have realized that philosophy of engineering is of great importance. Mitcham stated: "Why is philosophy important to engineering? Ultimately and most deeply it is because engineering is philosophy and through philosophy engineering will become more itself" (Mitcham 1998). I entirely agree with this conclusion. In addition to his statement, I'd like to say: "Why is engineering important to philosophy? Ultimately and most deeply it is because philosophy is engineering, and through engineering philosophy will become more itself."

I consider Karl Marx's *Eleventh Feuerbachian Thesis*, "Until now philosophers have only attempted to interpret the world; the point, however, is to change it", as the first principal of philosophy of engineering. Engineering practice is the most important approach for human being to change the natural world. Engineering activity is not only technological activity but also economic activity, political activity, social activity, ethical activity, and so on. Managers, engineers, leaders, researchers of engineering must pay their attention not only to technological aspect of engineering but also its economic aspect, political aspect, social aspect, environmental aspect, and ethical aspect. Both philosophers and sociologists need to focus their attention on these issues.

There are two different opinions about human nature that is the nucleus of philosophy. Many philosophers define human beings as rational animals, but others define human beings, in Benjamin Franklin's words, as tool-making animals.

From the point of view of epistemology, the dictum "Cogito ergo cum" is the basis of philosophy. However from the point of view of philosophy of engineering, the dictum “I create therefore I am”, or “I make therefore I am”, is the basis of philosophy (Li Bo-cong 2002, pp. 12–19). I think that philosophy of engineering may not only be a branch of philosophy that is parallel to philosophy of science and philosophy of technology, but also philosophy in itself.

Engineering practice is the direct productive force. In engineering practice people have established not only the relationships between human and nature, but also the relationships between different persons and the relationships between individuals and society. Consequently, there are many important and profound philosophical issues that are related to and get involved with engineering practice.

In fact, philosophy is above all about how to lead a better life with wisdom. The very vitality of philosophy roots deeply in the real world, especially in engineering practices, which are the most elementary and common activity in human society. From such a perspective, wisdom is first of all the wisdom of engaging in engineering activity. It is impossible for human beings to survive and flourish without engineering.

To deal with a lot of issues concerning engineering, philosophy does matter. Under the new historical conditions, philosophers need to build a closer relationship with engineering, to probe into the essence of engineering, and, furthermore, to explore the field of philosophy of engineering and the frontier of philosophical studies. It is through philosophy of engineering that engineering and philosophy can be related more closely.

As a new discipline, philosophy of engineering has opened up unlimited possibilities for us. In order to exploit them effectively, engineers, philosophers, and other people who are interested in studies in that field, need to get involved in a research nexus in which they can learn from each other, exchange ideas rationally and freely, and make further progress in philosophy of engineering.

Considering the relation between philosophy of science and philosophy of engineering, Goldman pointed out, “Philosophy of engineering should be the paradigm for philosophy of science, rather than the reverse” (Goldman 1990, p. 140). I agree with this entirely. It is said that philosophy of science is a discipline that has had a great past. At present it is certain that philosophy of engineering is a discipline that has a glorious future.

Nowadays, philosophy of engineering is situated on a new starting point. Philosophy of engineering is expected to have a glorious future.

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Chapter 4
Multiple Facets of Philosophy and Engineering

Paul T. Durbin

Abstract Is there a philosophy of engineering (singular)? My answer is no, though I don't intend that to discourage anyone who would want to produce one. I use the metaphor of a diamond with many facets to bolster my negative answer, but also to suggest the complexity if anyone were to do so. And this is not just my opinion. I base my view on a variety of discussions of engineering in the literature of the Society for Philosophy and Technology. And, following the guidelines of engineer Billy Vaughn Koen, I mark the time period as 1975–2005, from the beginning of the society until the SPT conference in Delft in 2005. The diamond metaphor seems useful to me, to suggest looking at the phenomenon of engineering both from the inside – the inner crystalline structure, so to speak – and from the outside of external criticism. Among inner facets, I look at engineering as a guild, with its own self-selected guidelines, professional associations, educational system, and place within the larger society in which it thrives. I hope that what I say reflects changes in the world of engineering, outside philosophical circles, in the same time period, not only in my home country of the USA but in the Netherlands, Germany, Great Britain, Spain (and indirectly in other countries, including Poland, Russia, China and Japan, among others), with which SPT has had contacts. But my primary focus is on what philosophers (and a few engineers) have said in publications associated with SPT.

4.1 Introduction

I base my views here on two of my books, *Critical Perspectives on Nonacademic Science and Engineering*, a collection of essays intended to produce a philosophy of engineering; and *Philosophy of Technology: In Search of Discourse Synthesis*

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(published online in *Techne*, the journal of SPT). In the latter book, a history of 30 years of controversies in SPT, I include three chapters directly devoted to competing philosophies of engineering – engineering in general, computer and engineering ethics, and bioengineering/biotechnology – as well as discussions of engineering philosophies in the Netherlands, Germany, and Spain. The theme throughout those discussions is that controversies in SPT related to engineering have sorted out fairly neatly into four types of philosophical approaches that emphasize (1) connections to science, (2) metaphysical critiques of the narrowness of the engineering approach to problem solving, along with two political approaches – (3) pragmatic and (4) radical – which combine a positive use of engineering with political critiques of its social arrangements. My remarks here follow that outline, after which I include a very brief mention of engineering education and professional regulation within engineering societies, based on the same sources.

4.2 Inside the Diamond: The Structure of Engineering as Engineers See It

The oldest tradition of philosophical discussion of engineering within SPT focuses on its relation to science and begins with the approach of the Canadian (originally Argentine) philosopher Mario Bunge. He calls his approach "exact philosophy" – and he has many followers in many countries, from Spain (Miguel Angel Quintanilla) to Germany (Friedrich Rapp, with reservations) to Czechoslovakia (Ladislav Tondl) and Poland (praxiology) and, indeed, all over the world. Bunge's view in general is that engineering (or technology more broadly) is applied science. Even when he laments the failure of "exact" philosophers to produce an adequate approach to biotechnology – as one example – he says that such work as has been done is simply an application of the biochemistry and physiology of disease organisms to medicine as an "engineering" application.

But even Bunge himself recognizes the narrowness of this approach if pushed too far, and he relates it to systems theory – even the General Systems Theory of Ludwig van Bertalanffy – to make sure that the approach covers the full breadth of values and other aspects of engineering, including its democratic political control. Systems engineering is closely related to this broader aspect of Bunge's approach, and it too has a following throughout the world – not least in the approach of the German philosopher Gunther Ropohl. A number of Dutch philosophers of technology, including several at the University of Delft, provide formal, analytical approaches to technology that can easily be linked to this broader neo-Bungean systematic approach.

There are even further variations on the theme. American philosopher Joseph Pitt emphasizes the reverse direction, of the influence of *technological instruments* on developments in science. And the Spanish follower of Quintanilla, Ana Cuevas Badallo, directly challenges Bunge by emphasizing the central role of the so-called "engineering sciences" in technology – as does the American philosopher of science, Ronald Laymon, following a totally different philosophical path. For the two of them, there are scientific-cum-practical aspects of engineering and technology that can in no straightforward way be derived from so-called pure science theories, whether by "application" or otherwise.

Then there are two American engineers-turned-philosophers – Billy Koen (mentioned earlier) and Samuel Florman – who emphasize other aspects of engineering. Koen downplays the role of applied science, relegating it to one of the "state of the art" influences on engineering *heuristics*, which he takes to be central to a philosophical approach to engineering.

Florman emphasizes the teamwork of the whole range of engineers often involved in massive projects (he likens it to the intricacy of staging an opera); and he explicitly opens the door to government regulation when engineers' self-regulation breaks down.

So much for the inside of the diamond. Few engineers quibble with these philosophical characterizations, though different engineers are likely to emphasize different ones of these philosophical approaches. The "external facets," so to speak, to which I turn next, are more controversial.

4.3 Values and Engineering

Usually thought to be the polar opposites of those who emphasize the scientific aspects of engineering and technology are philosophers I lump under the perhaps unfortunate heading of metaphysical critics.

For example, American philosopher Carl Mitcham explicitly opposes "humanities philosophy of technology" to what he calls "engineering philosophy of technology," saying that the former must "take the measure of technological culture as a whole" – where he explicitly refers to the German existentialist philosopher of technology and technological culture, Martin Heidegger, as well as the more moderate American neo-Heideggerian philosopher Albert Borgmann.

(On another other hand, it should be noted that Mitcham has also resurrected the thought of another German engineer-philosopher, Friedrich Dessauer, for whom metaphysics offers a positive near apotheosis of engineering as having a "transcendent moral value.")

Other metaphysically-inclined philosophical critics of technological culture (they rarely mention engineering in particular) include the American, Donald Verene – a follower of the French technocritic Jacques Ellul (who calls his approach "sociological" rather than philosophical). I assume Ellul's writings are known to some engineers and need no elaboration here (however much engineers may dislike this mode of thinking).

Another American metaphysician, Frederick Ferre, does talk about some engineering practices, including biotechnology, though he wants them to be limited by a "metaphysical organicism."

There are other opponents of a "scientific" approach to engineering and technology, such as another American, Don Ihde, for whom close phenomenological analyses of individual practices, including engineering in a variety of forms, is much better than the science-aping analytical philosophy so dominant in the USA and Britain. Ihde's approach is well known in Europe, and possibly even more so in the Netherlands, where it is not perceived as being at odds with what I might call the "Delft School. "

Another well known American is the critic of Artificial Intelligence, Hubert Dreyfus, who also acknowledges debts to phenomenology in general and Heidegger in particular. Dreyfus's critique of AI is well known enough that I don't feel the need to elaborate it here.

(Neither Ihde nor Dreyfus should be thought of as hostile to engineering, but only to some exaggerations in its practices; and both philosophers have much to offer to engineers.)

Should engineers pay any attention to these philosophers? I would say that the phenomenological approaches should by no means be ignored in philosophical discussions of engineering. And in my experience many engineers are religious people who would be wise not to leave metaphysical or values issues for "church on Sunday. "

Addendum: There is also a whole school of thought – so-called Social Construction of Technology – strong in the Netherlands (where it is not viewed as in any sense hostile to engineering), as well as in Spain, Britain, and the USA, which emphasizes the intertwining of engineering and technology with society in the actual practice of engineering within what is often called "technoscience." I do not think any engineer who has a serious interest in philosophy can afford to ignore this approach.

4.4 A Philosophy Positive About Engineering: American Pragmatism

American Pragmatism, best represented in SPT by Larry Hickman's work on John Dewey, represents a philosophical approach to engineering and science that is simultaneously *positive* in its recommendation of their utility in technosocial problem solving, while at the same time being *critical* of engineers' too easy incorporation within capitalism in the form of large science-for-profit corporations and large government laboratories – a situation that is dominant in the USA, but is also common enough within the European Community. (I might be tempted, because I am a follower of this school of thought, to expand on the positive points here; but I'll resist and offer no more than the brief hint that I'm offering for the other views listed here.)

Another American Pragmatist, and former president of SPT, Paul Thompson, takes Dewey's thought in another direction: he says, for example, that philosophers should *work constructively* with bioengineers and other members of the biotechnology (including agricultural technology) communities, *including* government regulators (often themselves technically trained).

And one of the first presidents of SPT, the Canadian philosopher Alex Michalos, regards suggestions like that of Florman (above) – that engineers should regulate their own affairs until there is a breakdown that requires regulatory intervention – with profound suspicion. According to Michalos, both scientists and engineers ought to recognize, and shoulder, *social responsibilities* as an *intrinsic* part of their professional work.

I am convinced of the high value of these approaches as contributing a great deal to the philosophical understanding – and, more important, the *improvement* – of engineering practice.

4.5 Even Radicals Deserve a Hearing

Radical critics of technology, including engineering, such as another American, Langdon Winner, are rarely welcomed warmly within engineering circles – though it should be noted that Winner teaches at Rensselaer Polytechnic, that bastion of engineering education. Winner's thesis, usually viewed as being radical, is that engineers and other technical personnel need to think about the often anti-democratic implications of their grand ventures, not after but before undertaking them.

Another radical critic of engineering, the American philosopher Steve Goldman, also teaches at a well known engineering school, Lehigh University. He describes his thesis as the "social captivity of engineering," and he maintains that engineers (and applied scientists such as chemists in industry) are culturally blind when they buy into the notion of engineering as "scientific. " They are thereby shielding themselves from the obvious, the social and managerial determination of what goes on in engineering and applied science, even to the point of determining what is good engineering knowledge: engineers rarely, he says, do what they know to be their best work, deferring instead to managers, to what the customer (or the market) will accept.

(I have worked with many engineers who readily accept Goldman's analysis but see nothing wrong with the situation: that's the world we live in, they say, and we have to accept it.)

Explicitly radical is the American philosopher Andrew Feenberg (strongly influenced by the neo-Marxist German philosopher Herbert Marcuse). But where Marcuse and the Frankfurt School were highly critical of engineering, Feenberg sees possibilities of reform within managerial circles, *if* both workers and managers (often engineers) can be persuaded of the advantages of more equitable – and environment-friendly – arrangements within technoscientific corporations and the governments they serve.

Should engineers pay any attention to these radical critics? What I would say is that an honest engineer, if one wants to be genuinely philosophical about his or her work, cannot ignore radical critiques. At the very least, their views should be taken as warnings about extreme excesses or extreme failures on the part of not only individual engineers but also engineering societies and the other organizations within which engineers typically work.

4.6 Engineering as a Guild and Engineering Education

To talk about engineering as a guild – especially in terms of professional self-regulation – I turn to one of the chapters in my online book, “Philosophy of Technology: In Search of Discourse Synthesis.” There I look at the record of engineering societies in the United States with respect to the enforcement of ethics rules among their errant members, and I find it to be woefully lacking. But this is not just my opinion. Studies have been done of the phenomenon, and they conclude that bad actors are rarely if ever called to task by the rules enforcers of the societies. If anything is done about negligence or other failures, it is more likely to be done by the courts or by government regulators. I don’t think that this argues for the elimination of engineering society regulatory bodies, but in my opinion it does argue for a great deal of soul searching about the mechanisms of enforcement.

With respect to engineering education, I turn to the other book I have used as my source here, my edited volume, *Critical Perspectives on Nonacademic Science and Engineering.* There our German colleague Gunther Ropohl argues that engineering students need to be educated better than they are – to the point of substituting for 20% of the technical curriculum carefully designed courses on humanities and social science related to the systematic character of contemporary engineering. And Taft Broome argues that engineering faculty need much more experience with interdisciplinary teams than they typically have if they are going to be able to help their students deal with complex problems in the real world. Furthermore, radical critic Langdon Winner, referred to earlier, has argued in other SPT publications that the way engineering ethics is normally taught these days does not prepare them for the *political* tasks that they *must* be prepared for if they are to do their professional best in today’s world.

I could but won’t say more here about these dual failures in contemporary engineering – I see them as failures, as do our SPT authors – but I can say at least this: that adequate approaches to philosophy and engineering cannot ignore the two issues of enforcement of ethical guidelines and better education of engineering students in the *relevant* humanities and social sciences.

A final note: One reviewer found this inventory of topics that SPT authors have claimed to be relevant to an *adequate* philosophy of engineering dull. But all I promised was an inventory of relevant SPT writings, and inventories often make for dull reading. What we are after here is not dull; it’s no less than a comprehensive philosophical discussion of engineering and its practices today, and I believe such a comprehensive approach would do justice to the thinking of all my SPT colleagues.

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Chapter 5

Comparing Approaches to the Philosophy of Engineering: Including the Linguistic Philosophical Approach

Carl Mitcham and Robert Mackey

Abstract This chapter compares six different possible approaches to the philosophy of engineering. One of these, somewhat less well developed than others, is the linguistic approach to the philosophy of engineering. The possibility of a linguistic philosophy of engineering is considered in some detail in order to advance a case for this approach. The conclusion, however, argues for a pluralistic pursuit of the philosophy of engineering, although one that includes linguistic philosophy.

What follows is philosophically incomplete. One feature of this incompleteness is that the coauthors do not fully agree about what should be included – or even what is included. This chapter is thus a provisional presentation of what has emerged from an extended discussion that often has the character of a disagreement. In addition, the chapter is methodologically naive, accepting as given certain meta-philosophical distinctions that are in fact controversial – and failing to include all that might be considered. In the current context of the relative underdevelopment of the philosophy of engineering we nevertheless hope that our effort may encourage others to consider a greater range of possibilities than might initially be imagined. To anticipate our conclusion, we want to argue for the pursuit of pluralism in the philosophy of engineering – as a way to transform engineering itself. The goal is not just to understand engineering but to change it. But in order to advance such a thesis it will be necessary to indicate more about the kind of pluralism we have in mind.

5.1 Introduction

Philosophy is composed of different branches and practiced in different schools or traditions. The branches include at least epistemology, metaphysics, and ethics. What might be called a conventional philosophical pluralism would thus simply emphasize the importance of each of these branches, along with others such as

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political philosophy and aesthetics. Philosophy in the comprehensive pluralism of all its branches, however, also comes in distinct historical schools or traditions.

Historically, for instance, it is common to distinguish between Platonism and Aristotelianism, Augustinianism and Thomism, rationalism and empiricism, and more. In the contemporary world the two most widely recognized distinctions are between the phenomenological school of continental Europe and the analytic school of Anglo-American provenance – although the geographies are less significant than their differing methodologies. In considering possibilities for pluralism in the philosophy of engineering it is thus also useful to reflect on how this new regionalization of philosophy might take shape within different philosophical traditions. A pluralism that includes not just the different branches of philosophy but is open as well to contributions from different schools of philosophy is a richer and more robust pluralism.

With slightly more specificity than the phenomenological/analytic differentiation, it is possible to identify six currents in contemporary philosophy: (1) phenomenological philosophy, (2) postmodernist philosophy, (3) analytic philosophy, (4) linguistic philosophy, (5) pragmatist philosophy, and (6) Thomist philosophy. These six currents or schools are not mutually exclusive and often overlap. To this particular set one can easily add a number of others such as Marxist philosophy and critical social theory, feminist philosophy, or environmental philosophy. Yet for purposes of initial inventory and orientation in relation to possibilities for a philosophy of engineering, our particular set of contestable meta-philosophical distinctions should be sufficient. Beyond the review of opportunities in the six schools considered here, however, one approach will be outlined in slightly more detail. This detail will focus on what the philosophy of engineering might look like from the perspective of linguistic philosophy.

To these introductory qualifiers, let us add two more. First, by beginning with philosophy rather than engineering, we acknowledge a bias in favor of philosophy. Our approach might well be complemented by considering the philosophy of engineering from the perspectives of a widely diverse number of types of engineering: civil, mechanical, electrical, chemical, electronic, nuclear, social, computer, biological, and more – perhaps also in relation to their various historical or cultural forms. But our bias is one in favor of a philosophy of engineering for philosophers rather for engineers, although we hope that some engineers might find it useful. Second, engineering is seldom fully and carefully distinguished from technology. Indeed, we believe that the engineering-technology distinction is itself a philosophical problem – one that will be dealt with in different but complementary ways in various philosophical traditions. With all these qualifiers in mind, let us now provide summary presentations of six contemporary currents or approaches to philosophy and how they might engage with engineering.

5.2 Six Basic Types

Let us reiterate that the distinctions among these six basic types of contemporary philosophy can be debated. In an increasingly globalized and interconnected world – with fusions in music, cuisine, and literature – we could expect crossovers to occur in philosophy as well. Nevertheless, differences remain. Acknowledging the porosity of boundaries, the argument for a pluralism that accommodates different schools of philosophy may still sketch how each might approach the phenomenon of engineering.

(1) A phenomenological approach to the philosophy of engineering would take engineering and/or some of its diverse manifestations as phenomena calling for more careful description and attentive, critical reflection than they may have previously been accorded. Human practices tend to become sedimented with received interpretations, and the phenomenological effort is constituted by a return "back to the things themselves" (Edmund Husserl), to inspect with a stance of fresh interest what has become routine or occluded by worn assumptions and cliches. This effort to disclose with freshness the engineering experience is well illustrated in the work of Don Ihde. Although Ihde seldom refers directly to "engineering" – preferring instead the term "technics" and "technology" – what he says about technology can in many instances apply to engineering as well.

Consider, for instance, Ihde's (1990) distinction of embodiment and hermeneutic relations between humans and technology. Embodiment relations are exhibited by such simple tools as the blind person's cane or the dentist's probe. As Ihde says, for the sightless person the world begins at the end of the cane; the cane is experienced as incorporated into the sensing and perceiving body. Hermeneutic relations are, by contrast, exhibited by such simple instruments as the thermometer. The thermometer, as an instrument "out there" apart from the body, has to be read or interpreted. Such phenomenological distinctions of embodiment and hermeneutic relations are manifest in engineering practice. Many of the once ubiquitous drafting instruments such as pencils and triangles function as if they were extensions of the hand. Today, however, sensors and computational devices that function only insofar as they are read or interpreted have become increasingly prominent elements in engineering practice.

One historical associate of phenomenological philosophy, existentialism, deserves special notice. As is well known, Samuel Florman's *Existential Pleasures of Engineering* (1976) is an effort to adapt this school to a description of the engineering experience. That Florman did not find dread or "fear and trembling" to be distinctive features of the engineering experience places him in good company with Ihde – as both exhibit a confident optimism that it is important for any philosophy of engineering to acknowledge although not necessarily endorse.

(2) Postmodernism most commonly refers to the work of such figures as Michel Foucault, Jean-François Lyotard, or Jacques Derrida. In each case philosophical thinking typically undertakes to historicize or destabilize some subject matter, often by playful or ironic means. A postmodernist philosophy of engineering might, having noted some of the variegations of its alleged history and different contextualizations, question whether there even really is such a thing as engineering.

One distinction to keep in mind here is that between postmodern and postmodernism. Postmodern thought seeks to demythologize or demystify a belief or practice, to help us see – almost after the manner of descriptive phenomenology – how things really are. What is disclosed in the demystifying process is something one did not previously suspect. Foucault's disclosure of how everything from prisons to knowledge can serve to maintain and promote power relations is such a demystification, one that finds power everywhere, in places most people have not previously located it. In a structurally analogous manner, we might suggest, Billy Vaughn Koen (2003) has attempted to demystify engineering as heuristics – and then argued for the presence of heuristics in all aspects of human behavior.

Postmodernism carries the postmodern approach one step further. Whereas postmodern thought tends to presume that disclosure can at some point come to a conclusion or be finalized, postmodernism is more skeptical and undertakes an ironic and repetitive pursuit of one demystification after another. Certainly the ironic and playful style typical of postmodernism is also present in Koen's ironic and playful prose.

(3) An analytic philosophy of engineering is easily if inadequately illustrated by the work of Mario Bunge. (Bunge, it should be noted, calls his philosophy scientific rather than analytic, but for us this is a distinction without a difference.) From the 1960s to the present, and with repeated verve, Bunge has advanced analytic distinctions between science and engineering by arguing for recognition of special forms of logic and knowledge in engineering, even when he wants to describe engineering as a kind of applied science, and by proposing an engineering transformation of ethics. Without necessarily accepting all of Bunge's positions, one could nevertheless argue that a proper philosophical analysis of engineering would attempt to rethink engineering in terms broader than those of engineering itself, while considering how engineering methods might be used to rethink many other aspects of human experience.

In brief, an analytic philosophy of engineering would seek to resolve engineering into its constitutive elements, which it would attempt to clarify conceptually. In addition it would criticize and attack misconceptions and false beliefs such as those associated with such general theories as those of technological determinism or the technological fix – often by arguing their incoherence or dependency on category mistakes. We take it that Joseph Pitt (2000) and his effort to practice Wilfrid Seller's "finding one's way around" in the world of technology and engineering provides a good complement to Bunge's exemplification; the Dutch school of analytic empiricism that began with technology but in ways that emphasized the centrality of engineering is a further development (see Kroes and Meijers 2000). As the philosopher Deborah Johnson (2001) has described her own efforts with regard to computer science and engineering, the analytic philosopher readily seeks to reject fuzzy conceptualization and hype – whether positive or negative in character – surrounding and associated with technology or engineering.

(4) Linguistic philosophy takes the analysis of language as its starting point and, as in the later Ludwig Wittgenstein, suggests that clarification of language use can enable us to see through certain conundrums that have accumulated in both popular and professional philosophical thought. What more precisely this might mean with regard to engineering remains to be explored. This approach to the philosophy of engineering will be considered in more detail below.

(5) Pragmatism in the last quarter of the 20th century became divided into epistemological and social philosophical schools. The epistemological school, as

represented by such figures as Willard Van Orman Quine and Donald Davidson, has paid little if any attention to engineering, perhaps because engineering does not engender epistemological or logical puzzles the way science does. Instead, the possibilities for a pragmatist philosophy of engineering can be most clearly discerned in the social pragmatist philosophy of technology of such figures as John Dewey, Paul Durbin, and Larry Hickman. Durbin, in fact, edited a book titled *Critical Perspectives on Nonacademic Science and Engineering* (1991) that brought together the works of people commonly associated with the philosophy of technology to address questions concerning the relation between engineering and social reform. In the efforts of Dewey to understand science itself as instrumental, and to use especially the social sciences to advance what is often called piecemeal social engineering, we see another possibility for a pragmatic, social philosophy of engineering. Hickman's version of the pragmatist approach is to call for a philosophy of technological culture – but which might with equal legitimacy be termed a philosophy of engineering dependent on and heavily influenced by culture.

At the foundation of the social reformist school of pragmatism is a view of society as an evolving, humanly constructed order. In this sense a pragmatist philosophy of engineering could make common cause with or be implicitly allied with work in the social constructivist studies of science and technology. Bruno Latour (1988), Wiebe Bijker (1995), and Harry Collins and Trevor Pinch (2002) – in quite different approaches to social constructivism – have all mentioned engineering, at least in passing. Additionally, engineer and philosopher Louis Bucciarelli's *Designing Engineers* (1994) and *Engineering Philosophy* (2003) may be read as exemplifying social constructivist interpretations of engineering practice and pragmatist efforts to use philosophy in engineering, respectively.

(6) Thomist philosophy, probably the least recognized of the traditions under review here, understands itself as a continuation of Aristotelian philosophy, which it nevertheless encloses in a metaphysics of supernatural creation and a cosmological vision of Platonic inspiration. In the first half of the 20th century Etienne Gilson and Jacques Maritain cut Thomism loose from many scholastic encrustations, especially in metaphysics and epistemology; in the last half of the century Alasdair MacIntyre did much the same in ethics. Thomism typically defends a realist approach to science while, as in the work of Bernard Lonergan, occasionally adapting and incorporating elements from both Kantian and phenomenological traditions.

Although it is primarily a treatise in realist epistemology, Lonergan's study of *Insight: A Study of Human Understanding* (1957) adumbrates in the margins what might be described as a realist, Aristotelian-based philosophical interpretation of engineering. For Lonergan, insight is a heuristic movement from intuition to explicit cognition and operates in both science (knowing) and technology (making), the latter of which becomes engineering through the process of conscious elaboration. Thus it is that Thomism has adopted an epistemological approach symptomatic of modern philosophical tendencies. More generally, however, a full bodied Aristotelian-Thomistic philosophy of engineering would attempt to understand engineering in relation to all the fundamental branches of philosophy as Aristotle himself began to articulate them: epistemology, metaphysics, and ethics.

5.3 Toward a Linguistic Philosophy of Engineering

Having itemized six possible types of or approaches to the philosophy of engineering and offered quick references for each, it is now appropriate to take up the challenge suggested by our comment regarding the underdevelopment of a linguistic philosophy of engineering. Let us attempt to map out some potentials for this neglected approach. In the process it may be possible to indicate more fully some necessary aspects of any philosophy of engineering.

To talk about something called "linguistic philosophy" may appear to reference an anachronism. Certainly twenty-five years after his effort to define "the linguistic turn," Richard Rorty (1992) declared linguistic philosophy to be a distinction without a difference from analytic philosophy – if not dead. Yet what continues to be called an analytic tradition emphasizes a need to reflect critically on the ways of talking about topics of philosophical interest (see, e.g., Losonsky, 2006). Even if the slogan that "the problems of philosophy are problems of language" no longer has the naive appeal it once did, it is useful to consider in what ways a reflection on language within a regionalized field of human practice might contribute to advancing a philosophy of that practice.

Our task here has, however, become more problematic than was initially imagined. As with many projects in philosophy, what began with an initially plausible (it seemed to us) intuition, turned progressively difficult – if not confusing. Yet even though we are reduced to a somewhat episodic set of comments, and disagreements, with disagreements among ourselves regarding their perspicacity, we continue to believe in the viability of the effort. Indeed, even the difficulties we experienced have provided us insight into issues in the philosophy of engineering for philosophers, if not for engineers. Consider, then, three comments on possibilities for a linguistic approach to the philosophy of engineering.

As a first comment, it should be noted that regional or specialized philosophies such as the philosophy of science, the philosophy of art, or the philosophy of religion typically include analyses of their subjects from the perspectives of the main branches of philosophy – that is, epistemology, metaphysics, and ethics. To appreciate what a linguistic philosophy of engineering might look like, one might therefore consider how epistemology, metaphysics, and ethics have been manifested in linguistic philosophy, and then see if the methods of linguistically oriented epistemology, metaphysics, and ethics might be projected into engineering. This may be a somewhat pedestrian, but not for that reason inappropriate, approach to a linguistic philosophy of engineering.

A second comment is that any examination of what linguistic philosophy may have achieved in epistemology, metaphysics, and ethics, will depend on some understanding of how linguistic philosophy – sometimes called ordinary language philosophy – arose as a movement in England following World War II. It originated in opposition to such other philosophical schools as Hegelianism and logical positivism, and was at one point closely associated with the thought of the later Wittgenstein, especially his posthumously published *Philosophical Investigations* (1953). Other major practitioners have included Gilbert Ryle, J.L. Austin, and P.F. Strawson.

One practice common to these philosophers is an attempt to pay careful attention to linguistic usage on the grounds that "the meaning of a word is its use in the language" (*Philosophical Investigations* I, §43). Language is understood as including a number of "language games," so that learning how to correctly use words in any of those games is to learn their meaning. It is argued that philosophical problems about the meaning of knowledge (epistemology), reality (metaphysics), or goodness (ethics) arise when one incorrectly plays the corresponding language game. Philosophy thus functions, as it were, like an umpire in the games of language, able to resolve if not solve disputes among players.

Thus one linguistic philosophical approach to the philosophy of engineering would be to think of engineering as a particular language game. More specifically, one may note that philosophy of engineering – like virtually all other specializations of philosophy – might well begin with a definition of engineering. But what engineering is might be better determined by how the word "engineering" and its cognates and associated terms (such as invention, innovation, design, technology, science, etc.) are used, especially in relation to each other. From a linguistic philosophical perspective, it would be appropriate to begin not so much with our experiences of engineering but with the words we use to talk about such experiences.

This view has been interestingly advocated by Andrew Light and David Roberts (2000). In their interpretation of Wittgenstein's project, what is central is a "descriptivist thesis": the method of describing or giving an account not so much of things themselves as our diverse descriptions of them. They suggest that one way to avoid the too quick fall into normativity that they argue has vitiated so much philosophy of technology is to call up with greater self-consciousness the manifold "forms-of-life and descriptive grammars bound up with various families of technologies" (p. 139). Surely what Light and Roberts would practice with regard to technology might be as beneficially prosecuted with regard to engineering. Adopting their tactic of introducing suggestive substitutions into a Wittgenstein text would yield, for instance, the following linguistic effort to appreciate yet philosophize engineering complexity:

> And for instance the kinds [of engineering] form a family in the same way. Why do we call something ["engineering"]? Well, perhaps because it has a—distinct—relationship with several things that have hitherto been called [engineering]: and this can be said to give it an indirect relationship to other things we call by the same name. And we extend our concept of [engineering] as in spinning a thread we twist fibre on fibre. And the strength of the thread does not reside in the fact that some one fibre runs through its whole length, but in the overlapping of many fibres (see *Philosophical Investigations* I, §67).

From this perspective, engineering is not some one language game – the game of efficiency, as Lyotard (1984) has termed it – but many.

At this point, however, the descriptivist project presents a certain conundrum. For Wittgenstein, seeking linguistic clarity aims to rid philosophy of its confusions.

> For the clarity we are seeking is indeed complete clarity. But this simply means that the philosophical problems should completely disappear (*Philosophical Investigations* I, §133).

Yet for philosophical problems to disappear they must first have appeared. In other regionalizations of philosophy problems have appeared within non-philosophical practices, and it is their appearance that gives rise to regionalized philosophy. In religion, for instance, the belief in a non-empirical God gives rise to such questions as "How can I know that God exists?" or "How can I know God?" The philosophy of religion attempts to address such questions in ways different from those in religion itself. In art, the question of the nature of art itself is posed by such artistic schools as surrealism and dada – again feeding into that religionalization of philosophy known as the philosophy of art. In science, relativity theory and quantum physics likewise present both epistemological and ontological paradoxes that readily engender questions for the philosophy of science. But what are the questions within engineering that could give rise to a philosophy of engineering? It sometimes seems that philosophers have to go hunting for such problems and are alone in talking about them.

Third comment: Ian Hacking observed in *Why Does Language Matter to Philosophy?* (1975) that there are two common positive responses to his question that present linguistic philosophy as operative across all philosophical schools both synchronically and chronologically. One response is that any philosophy worthy of the name must pursue linguistic clarity in all philosophers from Plato and Aristotle to the present, through a refinement of common speech; thus one finds efforts to clarify linguistic usage by the construction of definitions that avoid ambiguity, equivocation, contradiction, and paradox and thereby to create a technical language for philosophy. Another, contrasting response, criticizes technical languages and appeals to common speech, maintaining that the path to clarity is one of sensitive and subtle reflective appreciation of the inherent richness of common speech. As Hacking summarizes:

> there are two well-known minor ways in which language has mattered to philosophy. On the one hand there is a belief that if only we produce good definitions, often marking out different senses of words that are confused in common speech, we will avoid the conceptual traps that ensnared [others]. On the other hand is the belief that if only we attend sufficiently closely to our mother tongue and make explicit the distinctions there implicit, we shall avoid the conceptual traps. One or the other of these curiously contrary beliefs may... be most often thought of as an answer to the question Why does language matter to philosophy? (p. 7)

Hacking himself, however, thinks these are minor if not trivial answers to the question, and in an analytic review of the development of that special form of philosophy known as the philosophy of language – from what he calls "the heyday of ideas" (in the 17th century) through "the heyday of meanings" (20th century) to "the heyday of sentences" (a parallel development in the 20th century) – proposes the emergence of what he terms a "lingualism" in which language itself has become the primary phenomenon if not reality. On this basis it might be possible to examine engineering language – that is, the technical language of engineering – as its own special phenomenon.

Such a lingualist approach to the philosophy of engineering would consider the kinds of words used and the ways they are used within engineering. At the same time, any attempt to reflect critically on language use within engineering needs to consider what such reflection could add over and above the technical use itself. This last is in fact a question that has been raised about linguistic philosophy as a whole.

5.4 Conclusion

A linguistic philosophy of engineering is only one possible approach to a philosophical engagement with engineering, but it is an underdeveloped approach with serious promise. At the same time, it is not an approach that we would recommend to the exclusion of others, including approaches not mentioned here. Instead, as indicated at the outset, we wish to argue for pluralism in the philosophy of engineering – a pluralism that might well help transform engineering.

As part of an argument for pluralism in the philosophy of engineering it may thus be appropriate to indicate briefly why we think engineering deserves to be transformed. There are at least two quite different reasons. First, engineers often complain that they do not receive proper respect and/or that engineering does not attract sufficient interest among students, especially women and minorities. Second, non-engineers have criticize engineering as insufficiently well developed as a profession – as not as professionally mature as, say, medicine or law. A philosophy of engineering may offer a path to the transformation of engineering that would constitute a response to such complaints and criticisms. But this would only be most likely, we suggest, if the philosophy of engineering eschewed the ostensible narrowness of engineering itself by the practice of pluralism.

Let us conclude, then, with three basic arguments for pluralism in the philosophy of engineering – a pluralism that may at the same time contribute to a measured transformation in engineering itself. The three arguments are from philosophy, from interdisciplinarity, and from responsibility.

First, as we have already argued, the linguistic approach is not the only possible approach, and there are undoubtedly strengths and weaknesses in any approach. The most robust engagement of philosophy with engineering will, it is thus reasonable to propose, entail engagement from more than one philosophical perspective. This is likely for a couple of reasons. Since philosophy itself is not some one thing, philosophy *tout court* can engage engineering only through the more specific engagements of its distinctive traditions. Because philosophers themselves represent different schools as much as they represent philosophy, the rich possibilities for a philosophy of engineering will only be realized through different philosophies of engineering; the more philosophies the better.

Second, traditions or schools of philosophy are somewhat like disciplines. As is often argued today, problems that need to be addressed through the use of disciplinary knowledge do not themselves come with disciplinary boundaries surrounding them. More often than not problems can be successfully addressed only by marshaling knowledge from more than one discipline, that is, inter- or multidisciplinarily. In like manner, the problem of creating a philosophy of engineering would surely benefit from drawing on different disciplinary-like approaches to philosophy.

Third, one of the major challenges facing engineers and non-engineers alike concerns figuring out what constitutes the ethical responsibility of those who practice and those who benefit from engineering. But ethics itself involves critical reflection from more than one perspective. So even and especially in this branch of philosophy – which must surely be part of the philosophy of engineering in a conventionally pluralistic sense – there is reason to argue for pluralism in a more robust sense. This more robust pluralism in the philosophy of engineering is one that would be open to contributions from different schools of philosophy.

What might be the result of such a pluralistic philosophy of engineering, in which linguistic philosophy of engineering would play a significant role? How might this lead not just to a philosophical understanding of engineering but to changing it. Perhaps it would be more accurate to say that we aim to change engineering by attempting to understand it philosophically, that is, by introducing engineering into philosophy and therefore, however indirectly, by insinuating a measure of philosophy into engineering. At the same time, what is most remarkable with regard to the relation between engineering and philosophy is the absence of engineering in philosophy. In no major introduction to the philosophy of science and in only the most limited number of studies in the philosophy of technology does engineering play any significant role. To include engineering in philosophy may thus have some implications for philosophy as well.

But what, it remains reasonable to ask, might be the kind of changes that philosophy could introduce into engineering? As one possible response, consider the analytic and proto-linguistic philosopher Bertrand Russell's concluding defense of philosophy in *The Problems of Philosophy* (1912). According to Russell, philosophy raises more than it solves problems.

> As soon as we begin to philosophize . . . we find . . . that even the most everyday things lead to problems to which only very incomplete answers can be given. Philosophy, though unable to tell us with certainty what is the true answer to the doubts which it raises, is able to suggest many possibilities which enlarge our thoughts and free them from the tyranny of custom. Thus, while diminishing our feeling of certainty as to what things are, it greatly increases our knowledge as to what they may be; it removes the somewhat arrogant dogmatism of those who have never traveled into the region of liberating doubt, and it keeps alive our sense of wonder by showing familiar things in an unfamiliar aspect. (p. 157)

The philosophy of engineering, insofar as it is able to highlight problems within the customary ways of thinking both within and about engineering may introduce into engineering a kind of liberating skepticism and wonder regarding engineering that could be especially beneficial to a world such as ours which is increasingly dependent on and identified with engineering. This in turn might even make engineering more attractive to some who have shied away from undertaking it while mollifying to some degree others who have criticized it.

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Chapter 6
Focussing Philosophy of Engineering: Analyses of Technical Functions and Beyond

Pieter E. Vermaas

Abstract In this chapter I elaborate on the problematic status of philosophical research on the conceptual, methodological and epistemological questions posed by engineering, and comment on the current efforts to develop this research by means of a philosophy of engineering consisting of collaboration between philosophers and engineers. I describe how recent conceptual analysis of technical functions, leading to the ICE theory of technical functions, has evolved as part of discussions in the philosophy of biology. Attempts to analyse technical functions in collaboration with engineers proved to be difficult by the engineering criteria of effectiveness and efficiency. These criteria provide room for straightforward analyses of technical functions but less so for analyses that contain philosophical detail. The ICE theory, for instance, is of limited use to engineers; a simplification of it, which I present and call the Fiat account of technical functions, is more suited to engineering but is in turn of less interest to philosophy. I conclude that profitable collaboration between philosophers and engineers is difficult and that research on conceptual, methodological and epistemological issues of engineering may better be developed by making it relevant to existing research in philosophy of technology. Philosophy of technology harbours on-going research on, for instance, ethical, social and political questions posed by engineering, and can also harbour on-going research on conceptual, methodological and epistemological questions. The current efforts to establish a philosophy of engineering should in my opinion therefore be aimed at creating an active link to philosophy of technology.

6.1 Introduction

Engineering is a rich source for philosophical analysis and it is a source that has been tapped unevenly. Engineers design and create many of the entities we are living with and as such engineering amounts to all sorts of ethical, social, political,

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phenomenological, anthropological, ontological and metaphysical questions. Many of these questions concern our way of living in a fairly direct and clear way. Possibly for this reason these questions made their way to philosophy, defining by now well-established and self-propelling lines of research that, under the heading of philosophy of technology, range from phenomenology of technology to engineering ethics. Engineering is, however, not only about entity design and creation; engineers also produce the technological tools, methods and knowledge that are used for the designing and creating. This second aspect of engineering amounts again to all sorts of philosophical questions, now conceptual, methodological and epistemological ones. Yet, even though some of these further questions made their way to philosophy, research on them seems not to be developing into self-contained research lines. In a recent encyclopaedic overview of philosophy of technology, Carl Mitcham observes, for instance, that "[e]pistemology has often been treated as a stepchild in the philosophy of technology family of philosophical interests."[1] One reason for this position is according to Mitcham that analyses of technological knowledge have regularly been conducted as part of discussions of the relation between technology and science. And even though the topic is gradually emancipating itself from philosophy of science, Mitcham describes the characterisation of basic epistemic criteria of engineering, such as effectiveness and efficiency, as a challenge rather than as something that has already been achieved. Finally the relevance of epistemological analyses of technological knowledge to ethics and politics of technology is still problematic.[2]

In this contribution I elaborate on this problematic status of philosophical research on the conceptual, methodological and epistemological questions posed by engineering, and comment on the current efforts to develop this research by means of a philosophy of engineering that consists of collaboration between philosophers and engineers. I do not consider research on technological knowledge but describe how recent conceptual analysis of technical functions at the Delft University of Technology has evolved. This analysis may be taken as a clear example of philosophical research on engineering. Yet, amplifying Mitcham's observations, I argue that it again has been conducted as part of discussions of a topic outside of engineering. Attempts to analyse technical functions in collaboration with engineers, specifically design methodologists and engineering ontologists, proved to be difficult. Precisely the engineering criteria of effectiveness and efficiency provide room for rather straightforward analyses of technical functions only and prevent mutual profitable collaboration: philosophical conceptual sophistication becomes for engineers quite quickly unproductive hair-splitting, and engineering pragmatism may become for philosophy conceptual shallowness. The analyses of technical functions, which led to the ICE theory of technical functions, was therefore primarily conducted by contrasting technical functions with biological functions. The conclusion I draw from these experiences is that if conceptual analysis is to emancipate itself and to evolve into a viable research line, then engineers are not the best partners to focus on. This analysis better connects up with existing research in philosophy of technology. The analysis of technical functions can be made relevant to, for instance, ethical research on technology, thus opening up a large research community to this analysis, a community which is moreover susceptible to conceptual sophistication. Generalising this conclusion, I conjecture that research on conceptual, methodological and epistemological issues of engineering may best be developed by making it relevant to existing research in philosophy of technology. Philosophy of technology harbours on-going research on the ethical, social, political, phenomenological, anthropological, ontological and metaphysical questions posed by engineering, and can also harbour on-going research on the remaining questions posed by engineering. The current efforts to establish a philosophy of engineering should in my opinion therefore be aimed at creating an active link to philosophy of technology.

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[1] Mitcham (2006, p. 548).

[2] Mitcham (2006, p. 549).

In Section 6.2 I introduce the Delft analysis of technical functions and present the resulting ICE theory. In Section 6.3 the limited use of the ICE theory to engineering is sketched. It is argued that the ICE theory can be simplified to an account, which I will call the *Fiat account* of technical functions, that is more useful to engineering. Yet, this Fiat account is philosophically less interesting and thus rather a step away from a philosophy of engineering. In Section 6.4 I end with sketching ways in which conceptual, methodological and epistemological research on engineering may be established more successfully within philosophy of technology.

6.2 The Eccentric Development of the ICE Theory

The development of the ICE theory of technical functions at the Delft University of Technology may count as a research effort that falls squarely within the field of philosophy of engineering. The starting point of this effort was the *dual nature of technical artefacts*, as laid down in a research program with the same name (Kroes et al. 1999; Kroes and Meijers 2002, 2006). Technical artefacts are in this program taken as entities with a conceptually dual nature since proper descriptions of technical artefacts as "(*i*) designed physical structures, which realize (*ii*) functions, which refer to human intentionality,"[3] combine both structural and intentional concepts. The concept of technical function was taken as playing a central role in connecting the structural and intentional natures of technical artefacts, and together with the program's plea to an empirical turn to conduct philosophy with a close focus on engineering practices (see also Kroes and Meijers 2000), the goal was set to come up with an analysis of technical functions based on engineering sources. Hence, the effort, to be conducted by Wybo Houkes and myself, was defined by a philosophical question about technical artefacts and positioned at the interface of philosophy and engineering. Carrying it out led us however quickly outside of engineering and inside of the philosophical analysis of functions in biology and the philosophy of mind. The main reason for this "eccentric" move away from the engineering core to topics that may be taken as peripheral to engineering and philosophy of engineering, was a general lack of consensus within engineering on how to define the concept of technical functions; existing philosophical research on specifically biological functions provided a better starting point for analysing technical functions.

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[3] Kroes and Meijers (2006, p. 2).

In the engineering literature and specifically in the engineering design methodology literature one can find multiple sources in which definitions of technical functions are given. The precision of these definitions may vary from quite loose to more detailed, but more problematic for a philosophical analysis of technical functions is that the meanings that these definitions single out are quite diverse: authors may take functions as purposes (e.g., Gero 1990; Modarres and Cheon 1999), as intended parts of behaviour (e.g., Chandrasekaran and Josephson 2000; Bell et al. 2007) or as behaviour that contributes to satisfying needs (e.g., Stone and Wood 2000). This lack of engineering consensus is already noted by the design methodologists themselves (e.g., Umeda and Tomiyama 1997; Chittaro and Kumar 1998; Hubka and Eder 2001) but seems also a situation that they accept: they observe that the co-existence of different meanings of the term function complicates the communicating and archiving of functional descriptions of artefacts, yet individual design methodologists hardly argue that the meanings they propose are the only right ones. The engineering position seems rather to be that this co-existence of different meanings should be managed, say, by accommodating them all into overarching engineering ontologies, such that functional descriptions using one meaning can be translated into functional descriptions employing other meanings.[4]

In the philosophical literature there are also analyses of technical functions to be found. Again positions vary but by having a common starting point in the work by especially Robert Cummins (1975) and Larry Wright (1973), authors more or less are agreeing that functions are in general to be taken as capacities or dispositions of the items concerned. This philosophical literature does not focus on engineering. Typically authors (e.g., Cummins 1975; Neander 1991a,b; Millikan 1984, 1989, 1993; Searle 1995; Preston 1998) come up with accounts of a general concept of functions that they applied to and defended for the domains of biology, psychology or social reality; they apply these accounts also to the domain of engineering but typically only "in passing" and typically without spending much time on proving the tenability of the results.

Given these findings, a natural first step towards a proper analysis of technical functions was to ignore the multitude of definitions given by engineers – developing an account of technical functions on the basis of this multitude would mean merely making a choice between the different options – and to arrive at an account of technical functions on the basis of philosophical analyses of functions that is tenable by engineering standards. The first task therefore became to define these engineering standards. Such standards could not consist of a requirement that an account of technical functions reproduces the definitions of technical functions that engineers put forward: by the multitude of engineering definitions such standards would be meaningless. What was needed were standards that capture general features of technical functions independently of specific positions in engineering. In (Vermaas and Houkes 2003) a first formulation of such standards were given and used to argue that the in philosophy popular etiological approach towards functions cannot provide for a tenable account of technical functions. These standards were presented as desiderata and formulated quite liberally in order to make them as reasonable as possible; arriving at an account of technical functions on the basis of a set of standards that engineers and philosophers do not accept in the first place, would not to work.[5] The desiderata are the following:[6]

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[4] I return to engineering ontologies in Section 6.4 since despite their "neutral" use for translating different types of functional descriptions, they also contain new definitions of functions that are sometimes put forward as more fundamental. Compare, for instance, Kitamura et al. (2005/2006) with Kitamura et al. (2007): in the first paper the emphasis is on a separate ontological definition of function relative to which existing meanings can be positioned, and in the second the focus is on the conversion of functional descriptions based on different meanings without singling out a privileged one.

The proper-accidental desideratum:
  A theory of artefacts should allow that artefacts have both a few enduring proper functions and an unlimited number of more transient accidental functions.
The malfunctioning desideratum:
  A theory of artefacts should introduce a concept of a proper function that allows malfunctioning.
The support desideratum:
  A theory of artefacts should bring about that there exists a measure of support for ascribing a function to an artefact, even if the artefact is dysfunctional or if it has a function only transiently.
The innovation desideratum:
  A theory of artefacts should be able to ascribe intuitively correct functions to innovative artefacts.

Having rejected by means of these desiderata the etiological approach towards functions, the second task became to give an account of technical functions that does meet them. This account was presented in Houkes and Vermaas (2004), now linking it to another philosophy project, namely the metaphysical project of defining artefact kinds by means of their technical functions. Our account is called the ICE theory and is one which deals primarily with agents ascribing technical functions to artefacts:[7]

An agent a justifiably ascribes the physicochemical capacity to ϕ as a function to an artefact x, relative to a use plan p for x and relative to an account A, iff:
I. a believes that x has the capacity to ϕ; and
a believes that p leads to its goals due to, in part, x's capacity to ϕ; and
C. a can on the basis of A justify these beliefs; and
E. a communicated p and testified these beliefs to other agents, or
a received p and testimony that the designer d believes these beliefs.

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[5] This strategy worked in part. In a response Preston (2003) argued for giving up the innovation desideratum within her etiological account of functions.

[6] The formulations originate from Houkes and Vermaas (2009) and are at points different to the ones in Vermaas and Houkes (2003).

[7] The formulation originates from Houkes and Vermaas (2009) and is at points different to the ones given in Houkes and Vermaas (2004) and Vermaas and Houkes (2006).

The notion of a use plan that is part of this definition is one we developed in (Houkes et al. 2002) as part of an action-theoretical characterisation of the acts of designing and of using technical artefacts. A use plan *p* of an artefact *x* is a series of considered actions that includes at least one action that can be taken as a manipulation of *x*. Using *x* can be described as the carrying out of a use plan *p* for *x* for achieving the goal associated with the plan, and designing can be described as the development of such a use plan, including the description of how to create the artefact *x* if it does not yet exist, and as the communication of the plan to the prospective users.

When the above definition is applied to expert designers, the first E-condition applies and the account *A* consists typically of experiential, scientific and technological knowledge. For knowledgeable users the second E-condition applies and *A* consists again of experiential, scientific and technological knowledge. For general users the second E-condition applies and the account *A* typically consists of experiential knowledge and testimony provided by the designers of the plans *p*.

With the ICE theory in place we could after the eccentric detour via peripheral topics, return to the original dual-nature question and propose how the concept of technical function relates the two natures of technical artefacts. Paraphrasing (Vermaas and Houkes 2006), technical functions may be taken as *highlighting* the structural physicochemical capacities of technical artefacts that play a role within the intentional plans by which users can attain goals. Function ascriptions may, however, also *cloak* one of these natures by allowing agents to ignore one description in favour of the other. Engineers may, for instance, focus only on the physicochemical description of artefacts by pointing out that some of their physicochemical capacities are their functions; in doing this, they highlight the capacities of the artefacts relative to a use plan that is left implicit. Users, if they ascribe functions to artefacts, may focus only on the intentional descriptions of these artefacts; by ascribing functions they describe the artefacts as having specific roles in use plans by virtue of their physicochemical make-up but ignore the explanation of how this make-up enables the artefacts to play these roles. The concept of technical functions thus connects the structural and intentional natures of technical artefacts, but also allows for separating them.

Hence, given this return to the original question about technical artefacts, one can indeed argue that the ICE theory falls within philosophy of engineering. Yet, by the eccentric detour by which it was developed, research on this account of technical functions counts more as function theory as it is done in philosophy of biology and philosophy of mind, or even as action theory or metaphysics.

6.3 The Limited Use of the ICE Theory in Engineering

Accepting the eccentric genesis of the ICE theory, one may take the position that its future development can take place with a more definite focus on engineering, thus establishing research that does count as a philosophy of engineering in which philosophers and engineers collaborate. Against this position it can unfortunately be argued that the ICE theory will be of limited use to engineering. Because of the co-existence of different meanings of technical function in engineering, the ICE theory will count for engineering as just another analysis for understanding technical functions. And because of the engineering criteria of effectiveness and efficiency that Mitcham (2006) mentioned in his discussion of epistemology research on technology (see above in the introductory section), incorporation of the ICE theory by engineering in their current spectrum of options, makes sense only if it has clear benefits. It may be said that the ICE theory has the benefit of conceptual precision, and it may be the philosopher's hope that that is for that reason also appreciated in engineering, for instance, for the development of the already mentioned engineering ontologies. What, however, counts against incorporating the ICE theory in engineering, including engineering ontologies, is the wealth of additional concepts it analyses functions with, such as use plans, justifications of beliefs and communication between agents. Hence, if one rejects a strongly revisionary position that its use is that it tells engineers how they actually (ought to) understand technical functions, the ICE theory is merely one duck in the engineering pond, and one that has strange feathers. And by these strange feathers, it may be doubted that engineers will be tempted to adopt the ICE theory; by the wealth of additional concepts it introduces compared to existing accounts of technical functions, engineers will arguably more effectively and efficiently design and create technical artefacts when they stick to one of the existing accounts.

To some extent the ICE theory can be stripped from its strange feathers. As sketched at the end of the last section, engineers can cloak the intentional part of the description of technical artefacts and highlight with functional descriptions their relevant capacities while leaving their use plans implicit. The use plan for a series of components c, c', c'', ... of artefacts, for instance, may have the following form: compose c, c', c'', ... in configuration k in order to obtain an artefact x with the capacity to ψ. This plan is, more precisely, a use plan for designers that have the goal of obtaining an artefact x with the capacity to ψ. Consider now an engineer e that applies this component use plan as part of his or her designing. This engineer can now ascribe the capacity to ϕ as an ICE function to c relative to the component use plan. Substituting this use plan in the ICE definition and suppressing the goal orientedness of the use of the components, yields the following result:[8]

> An engineer e justifiably ascribes the physicochemical capacity to ϕ as a function to the component c, relative to the composition of c, c', c'', ... in configuration k of an artefact x with the physicochemical capacity to ψ, and relative to scientific and technological knowledge, iff:
> I. e believes that c has the capacity to ϕ; and
> e believes that x has the capacity to ψ due to, in part, c's capacity to ϕ; and
> C. e can on the basis of scientific and technological knowledge justify these beliefs.

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[8] Vermaas (2006); the current formulation originates from Houkes and Vermaas (2009).

Notions such as use plans and communication between agents are cloaked in this formulation; only justifications of beliefs and the knowledge used for these justifications are mentioned.

Still this formulation is much too complicated to make the theory suitable for adoption in, say, engineering ontologies (van Renssen et al. 2007). In order to be applicable in engineering, it seems that more needs to be suppressed in the ICE theory, like the type of knowledge used for justifying the beliefs about the capacities of artefacts and their components, and possibly also that engineers *are* justifying these beliefs: one can take the position that engineers have the relevant scientific and technological justifications by default.

If one proceeds in this way, one ends up with an account of technical functions that may be called the *Fiat account*. By this account it are the engineers themselves who *by decision* determine technical functions, since as experts in technology and science their decisions are implying the right justified beliefs. Return to the above components. If engineers indeed compose the components c, c', c'', ... for obtaining an artefact x with the capacity to ψ, because c has the capacity to ϕ, c' has the capacity to ϕ', et cetera, then one may argue that the I and C-conditions in the above engineering version of the ICE theory are satisfied, and that c thus can be ascribed to ϕ as a technical function, c' can be ascribed to ϕ' as a technical function, et cetera. Generalising this to artefacts as a whole and taking engineering ascriptions of technical functions as statements that artefacts *have* functions, the Fiat account becomes:

> An artefact x has the physicochemical capacity to ϕ as a function iff engineers decide that x has to ϕ as a technologically useful physicochemical capacity, and lay down this decision in engineering documentation such as design documents, patents and technical handbooks.

This Fiat account is a clear *intentionalist* account of technical functions: the beliefs of engineers about technical artefacts fix their technical functions. The reference to engineering documentation is now added to avoid a well-known problem for intentionalist accounts, posed by beliefs of would-be, crackpot engineers: in order to rule out unrealistic function ascriptions, say, perpetual motion machines that get the function to provide infinite energy, it is required that the decisions that ground function ascriptions are laid down in engineering documentation and thus are meeting the standards that apply to such documentation. The Fiat account is thus also a *social-expert* account of technical functions: the beliefs of engineers fix technical functions only if these beliefs are accepted within the professional discipline of engineering.

This Fiat account lacks the philosophical subtleties part of the ICE theory. With the Fiat account the dual-nature question of how technical functions are connecting the structural and intentional natures of technical artefacts cannot anymore be answered straightforwardly: it becomes, for instance, unclear in the Fiat account how technical functions are related to the goals for which users manipulate technical artefacts. Yet, it fares relatively well when evaluated against the four desiderata given in the previous section. If within the Fiat account the proper functions of artefacts are taken as the technologically useful physicochemical capacities of those artefacts that engineers “canonise” for longer periods by laying them down in their more enduring patents and handbooks, and if accidental functions are taken as the technologically useful physicochemical capacities that engineers occasionally lay down in their design documentation but do not canonise for longer periods, then the proper-accidental desideratum is by and large met. The Fiat account allows also for malfunctioning: if engineers decide that an artefact x has to ϕ as a technologically useful physicochemical capacity and lay this decision down in their documentation, then the artefact has to ϕ as its (proper) technical function in the Fiat account, even if it (temporarily) does not have to ϕ as an actual capacity. The account provides support for the ascriptions of technical functions, since engineers have the status of technological and scientific experts. Only with respect to the innovation desideratum one can raise some doubts. The Fiat account ascribes intuitively correct functions to innovative artefacts in so far engineers have themselves come up with the innovation: such functions are laid down in the design documents about the innovative artefacts. Yet, users can also come up with innovation, say when using artefacts in ways that are not anticipated by engineers, or not accepted by engineers. Such innovation may be captured in terms of technical functions as well, say, when cars are described as having the function to let crying infants fall asleep and coins as having the function to open tins. Such innovative functions typically will not make it to engineering documentation, and thus do not count as technical functions in the Fiat account. Whether engineers mind that such innovative user functions cannot be taken as true technical functions, may be doubted.[9]

The upshot of this digression is that the ICE theory may be stripped from its wealth of concepts – use plans, justifications of beliefs, communication between agents – in order to make is more useful for engineering. The Fiat account one then may end up with is acceptable within limits, and may be used to, for instance, develop engineering ontologies: the Fiat account suggests including functions in such ontologies as physicochemical capacities that are reported in engineering documentation as technologically useful capacities of technical artefacts. Yet, this stripping can hardly be taken as a development of the ICE theory or as furthering philosophy of engineering. Assuming that the ICE theory does meet the four desiderata for accounts of technical functions[10] and given that the Fiat account cannot answer straightforwardly the dual-nature question about technical artefacts, the transition to the Fiat account seems rather a step backwards. The for engineering less useful concepts part of the ICE theory, which may be taken as due to its origin in philosophy of biology and action-theory, are rather elements to hold on to in a philosophy of engineering.

6.4 Focussing the ICE Theory on Philosophy of Technology

The above discussion of experiences with developing the ICE theory suggest that philosophical research on conceptual, methodological and epistemological questions can better not be established with a focus on engineers. In this final section I briefly elaborate on this suggestion and end with conjecturing that a focus on existing research in the philosophy of technology is for now the best way to proceed.

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[9] Examples of functions that are determined by users only, may also be used to argue that the Fiat account does not fully meet the proper-accidental desideratum.

[10] See Houkes and Vermaas (2009).

It may be argued that my negative conclusion about doing philosophy of engineering in interaction with engineers is due to a focus on the existing engineering community at large. Doing interesting philosophy of engineering in collaborating with mainstream design methodologists or engineering ontologists may indeed be difficult, but that does not rule out that individual engineers are willing to consider philosophical subtleties without an immediate demand to technological usefulness. Walter G. Vincenti's (1990) book on technological knowledge in aeronautical engineering, for instance, and the work by Louis L. Bucciarelli (1994) and Billy V. Koen (2003), prove that such engineers exist.

This response is valid and one indeed can argue that within engineering a less pragmatic interest in philosophy is present and may be growing. Firstly, returning to the ICE theory and engineering ontologies, it may be argued that engineers have to eventually become interested in more elaborate accounts of technical functions as provided by philosophy. As said in Section 6.2, engineering ontologies may on first sight be aimed at translating different types of engineering functional descriptions into one another, yet, in order to achieve that, engineering ontologies themselves have to incorporate a precise notion of technical function. Kitamura et al. (2005/2006), for instance, are introducing such a precise notion. Secondly, in a recent assessment of the state of the field, Kees Dorst (2008) argued that design methodology has up to now been concerned mainly with the design *process*, and ignored three other aspects of designing, being the *object* of this designing, the *designer* itself and the *context* of design. Moreover, research on the design process makes, according to Dorst, often a too quick jump from description to prescription, ignoring the, in Dorst's view, intermediate phase in which (the courses of) design processes are explained. Dorst announces a Kuhnian revolution in design methodology that will transform it to a field in which all four aspects are studied in a more encompassing and analytic way. Clearly, when such new research emerges in engineering, it will provide ample means for collaboration between philosophers and engineers. Yet, Dorst calls this revolution also *a-revolution-waiting-to-happen*. Hence, despite the promises that may exist for a philosophy of engineering that focuses on engineering, the current state is still that there exists in engineering only a limited number of points of contact for philosophical research on conceptual, methodological and epistemological questions. For propelling this research one better can look – also – at other partners in academia.

In my view these other partners can be found in existing research on topics that traditionally have been subsumed under the heading of philosophy of technology. Ethics seems to me a prime candidate. In the ethics of technology the design process is increasingly becoming part of the analysis as a locus at which ethical considerations are at play and should be made manifest, as is, for instance, exemplified in the emerging interest in the notion of value-sensitive designing (e.g., Friedman 1997; van de Poel 2001). An ethical analysis of the design process presupposes understanding how this process in carried out by engineers and this defines a common interest with research on the conceptual, methodological and epistemological questions of engineering. Moreover, collaboration with the ethicists in research on engineering may be expected to lead to further conceptual, methodological and epistemological questions about engineering and thus to broadening and deepening this research rather than to simplifying matters. Finally, collaboration would immediately make clear the relevance of this research. In this volume on philosophy of engineering a first example of what such an interaction may result in is given by the chapter by Auke Pols, in which parts of the ICE theory of technical functions are used to consider the ethical responsibilities of engineers. Another example could be research on the first conceptual phase of design, in which engineers are by a number of design methodologies, advised to analyse their design tasks in terms of functional requirements. The required overall functions of the product-to-be are in this conceptual phase to be decomposed into series of subfunctions, instead of to be immediately linked to existing design solutions for the overall functions, in order to increase the innovation and flexibility of the design. Analysing the ethical values in play in this first conceptual phase defines a joint research effort of both ethicists and philosophers of engineering.

Beyond collaboration with ethicists of technology one can also envisages a convergence of research on conceptual, methodological and epistemological questions and of research on the politics of technology. Technical artefacts are increasingly analysed as parts of socio-technical systems, which are amalgams of artefacts, agents and social objects. The understanding of such socio-technical systems poses all kinds of new conceptual questions for a philosophy of engineering, an understanding that at some point may contribute to more political studies of technology as exemplified by Langdon Winner's (1980) analysis of the politics of technical artefacts.

To sum up: engineering is a rich source for philosophical analysis, and a source that can establish a self-contained and viable philosophy of engineering if it is tapped with a focus on existing ethical and political research in philosophy of technology. Developing philosophy of engineering with a focus on engineering and in collaboration with engineers may at this point hamper its viability because of the current engineering interests in research that is fairly immediately useful. A direct focus on engineering may prove viable in the (near) future; for now the future of philosophy of engineering lies, to my mind, within the discipline of philosophy of technology.

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Chapter 7
Philosophy, Engineering, and the Sciences

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Abstract Philosophers aim for universal truths, but in that effort, when the empirical details are ignored, the philosophical story may end up missing the mark. Here it is argued that when attention is applied to the details, the Old Story that engineering is applied science falls apart. It is further argued that attempts to establish some kind of epistemic authority for science over engineering are simply misguided.

7.1 Introduction; Problems with the Old Story

Philosophers don't like details when it comes to facts. They are perfectly happy to worry to death the myriad meanings of "meaning". But when it comes to working though the factual components of what are fundamentally empirical claims the work is slim. And because some of what looks like a philosophical claim, but for what is really an empirical claim, the results of not finding out what is really the case can result in some philosophical claims appearing rather stupid. One I have in mind concerns the relation between science and technology, or more specifically between science and engineering.[1] In this chapter I look at something that has not been looked at by philosophers: the real world interaction between doing science and engineering. What I argue is that contemporary science cannot be conducted until some serious engineering is already in place. This may not be news to scientists and engineers, but it is news to philosophers, especially to a distinct group of philosophers of science who tend to think of science in isolation from the real world. These philosophers are concerned with such issues as the logical structure

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[1] Talking about "technology" as if it is a thing in itself is unhelpful. I argue this case in my 2000 book. Likewise for "science". In that work I argue for the need to look at some category of practitioners comparable to scientists if we are to learn anything of value. I lay out some criteria that lead me to identify engineers as the technological counterpart to scientists.

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of explanation or the role of probability in the logic of confirmation. But the results have nothing to do with understanding how science really works, meaning by that how scientists go about their research.

We all know the *old* story: the scientists do basic research and technologists (for our purpose here, specifically engineers) apply it. This is a troublesome account because something about it doesn't ring true. In particular, *how* does the move from basic science to applications take place? The results of basic scientific research are published (when they can be published[2]) in very specialized venues using very specialized language not readily accessible to most mere mortals. I not even suggesting that engineers can't read this literature, but simply asking if, given their other responsibilities, can they find the time to do so? It is not clear to me that having made some discovery or other that the scientist picks up the phone and tells his engineering colleague "now you can do this or that". Nor is it clear that engineers keep close track of the burgeoning scientific literature to find out what's new and have immediate "ah, ha!" moments, or even later, "duh" moments. There is also the complex problem of intellectual property rights, finding interested investors, manufacturers, distribution routes, etc. So, in the end, the old story is not only a false story, but highly misleading. I want to tell a different story. The point is this: if the technological infrastructure of science is, in part, the product of engineering research and hands on design and inspection, and the research that makes it possible to build both labs and instruments comes out of engineering research, then engineering research is just as fundamental as scientific research. But there is more, for the result of looking at the relation between science and engineering through these lens results in seeing that conceptualizing the issue in terms of who is subservient to who, science or engineering, is wrong from the start.

Although he hasn't said this explicitly, the argument I am proposing is congenial to the views Peter Galison develops in his *Image and Logic* (Galison 1997). In particular, I have in mind his distinction between the inner and outer lab, especially the outer lab. I take Galison's outer lab to be amenable to the notion I introduced in my *Thinking About Technology*, the technological infrastructure of science. What the technological infrastructure idea is supposed to capture is the range of things that make the doing of science possible: funding agencies, universities, private corporations, technicians, labs, graduate students, etc. I will proceed by returning to my motivating issue, which is whether or not it is correct to think of the relationship been science and engineering as one of subservience. I am going to begin by looking at a couple of examples and argue for a more encompassing view.

7.2 Examples of Applied Science

Some cases are easier to understand than others – i.e., some discoveries more readily suggest applications than others. This can happen is many ways, but looking at two examples will yield the general idea. In the first case a scientist can be looking to achieve a specific end which itself is an application. Thus, consider a microbiologist working on transmission of micro-organisms through ground water, who sets out to construct a bug that will eat oil. Let's say he started on this project after hearing of a particular disruptive oil spill when a tanker went aground. After successfully creating the oil eating bug, he sets up his own company, rents some space at the Virginia Tech Corporate Research Center, hires some graduate students to make the things, contacted oil companies to inform them of the product and is now making money hand over fist.[3] What is missing from this picture is an engineer. Moreover, while a close examination of the process employed to create the bug deeply resembles a classic engineering design process, complete with feedback loops, our researcher is a biologist, not an engineer. In this case, the line between scientist and engineer is clearly blurred, given the old story. But, the positive result of this new story is that it opens up the possibility that in some cases, the so-called scientific method is more like an engineering design process than some idealized and false view of how scientists do their work. Here we started with a product in mind and after considering the restricting parameters – the end product must be inexpensive to produce, must pose no danger to the environment, must be easy to transport, etc. – proceeded to propose a mechanism, test it, refine it, retest, etc.

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[2] Restrictions on the dissemination of research results often are found when scientific research is conducted for the military or by private laboratories funded by industrial or pharmaceutical companies.

A second example of how scientists connect to applications is the "opps!" case. This occurs when a mistake is made or an accident occurs in a lab and an unintended result comes up that has immediate applications because of the result itself. The process by which this discovery makes its way into the public domain may or may not involve engineers down the road, but the awareness of its applicability does not. For example consider the case of penicillin. The following account is from the Discovery Channel web site.

> Alexander Fleming discovered penicillin in 1928. Of course he wasn't actually looking for it at the time- he was researching the 'flu. He noticed that one of his petri dishes had become contaminated with mould. Other scientists may have recoiled in horror at this result of shoddy work practice, but not Alexander. He chose to investigate.
>
> Whatever this intruder was, it was killing off the Staphylococcus bug - a bug causing everything from boils to toxic shock syndrome. Eventually he identified it as the fungus Penicillium notatum and it put the knife into Staph by means of a chemical that destroyed its ability to build cell walls. Being a scientist, he thought long and hard about what to call this new chemical, a chemical released from the fungus Penicillium notatum.
>
> That's right he called it penicillin. Nice one Alex. Unfortunately naturally occurring penicillin isn't very stable and thus not very useful. Fleming had found a wonder drug, but couldn't do much with it. Luckily just three years later two Oxford researchers created a stable form and today it's one of our most important tools in the fight against disease.

Consider now an example of a discovery that was delayed in its application and why.

This account is taken from Wikipedia – thereby acknowledging all my student's resources.

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[3] This description is based on a real episode.

> In 1968, Dr. Spencer Silver, a scientist also at 3 M in the United States, developed a "low-tack", reusable pressure sensitive adhesive. For five years, Silver promoted his invention within 3 M, both informally and through seminars, but without much success. In 1974, a colleague of his, Arthur Fry, who in a church choir in North St. Paul, Minnesota, was frustrated that his bookmarks kept falling out of his hymnal. He had attended one of Silver's seminars, and, while listening to a sermon in church, he came up with the idea of using the adhesive to anchor his bookmarks.[1] He then developed the idea by taking advantage of 3 M's officially sanctioned bootlegging policy. 3 M launched the product in 1977 but it failed as consumers had not tried the product. A year later 3 M issued free samples to residents of Boise, Idaho, United States. 90% of people who tried them said that they would buy the product. By 1980 the product was sold nationwide in the US and a year later they were launched in Canada and Europe[2]. Post-It Notes are produced exclusively at the 3 M plant in Cynthiana, KY. In 2003, the company came out with Post-it Super Sticky notes, with a stronger glue that adheres better to vertical and non-smooth surfaces.

The point of these two examples is to suggest that to understand the move from scientific discovery to practical application needs more than hand waving at science and technology as such. We have already observed that the process of going from a discovery to a practical application is more complicated that the standard story would lead us to believe. While complicated, it nevertheless seems possible to spell it out using the standard story. However, I want to argue that even doing so will still give us a skewed picture.

7.3 A Transcendental Argument for Engineering Priority

The picture is skewed because it starts with the scientist. It suggests that the scientist does research and comes up with discoveries, but it does not fill out the picture as to what is entailed by saying the scientist does research. To resolve this we need to pursue a classic Kantian transcendental argument: what does the scientist need in order to do what he or she does?

In order for a scientist to conduct research, he or she generally needs a lab. It can be as simple as a computer, or as complicated as a radio telescope, but to say a scientist conducts research entails that there is a context in which that research is done, even field scientists who study the behavior of the great apes treat the environment in which the apes live as their lab. Once we open that door, the entire picture changes.

In *Thinking About Technology* I introduced the notion of *the technological infrastructure of science* as "an historically determined set of mutually supporting artifacts and structures that enable human activity and provide the means for its development" (Pitt 2000, p. 129). As noted above, parts of this complex are the labs, graduate students, technicians, instruments, universities, and funding agencies that make modern science possible.

Consider what is involved in hiring a new scientist at a typical American university. I am not talking about the hiring process, i.e., the means by which the individual hired is selected – but rather the rest of the process that must be completed before the offer is accepted: the support package offered to the new potential hire as an enticement to accept the offer. No active researcher would think of accepting a position without being guaranteed a lab, i.e., a particular space and start up money to equip the lab with the appropriate equipment needed to conduct his or her research, to hire a technician or two or three and to support at least a couple of graduate students. The typical "start-up package" at my university for a new Ph.D. in one of the sciences or in one of the areas of engineering, coming out of school and off a two year post-doc is approximately $400,000. It obviously gets way more expensive for senior researchers.

Now let us unpack this a bit further. Laboratory space is expensive. Depending on the research to be done, there will be a water supply and sinks, exhaust hoods, computers, isolation spaces, etc., all housed in buildings meeting more stringent building codes (meaning costing more to build) than your typical classroom building. The differential here just for the costs of the buildings is $50/square foot for a classroom building versus $150/square foot for an unequipped laboratory building. Doing science is expensive.

Second, part of the start-up package involves the money needed to fund the research. But it is also money that provides the time for the researcher to develop a research program and to write grant proposals to support further research once the start-up monies run out. That means there have to be sources for that funding. I would argue that the sources of funding, like the United States' National Science Foundation and the National Institutes of Health on the public side and various foundations on the private side also constitute part of the technological infrastructure of science. They are enabling systems.[4] Moreover, by virtue of having the money and issuing calls for proposals in certain research areas on certain topics, they not only enable scientific research, but to a large extent they control its direction. In the United States, under the G.W. Bush administration, federal sources of research funding could not fund stem cell research on strains of stem cells recently developed. This had an interesting effect in two directions. 1. It is forced certain kinds of research to be suspended or terminated for lack of funds. 2. It also pushed individual states like California to appropriate the funds themselves for such research, thereby putting them in the position to attract researchers in these areas away from states where they cannot do their work and making the universities and research centers in California a major force in this area. So funding sources make a difference in how science is done and what kinds of scientific research will be done and where it will be done. The picture of how scientific research is done and why is getting messy.

Let us return to the lab – for convenience sake let's make it a university lab. The picture sketched above is too simple – we don't just give the new researcher a lab and some money. The buildings have to be designed, built, and inspected to meet building codes and certain specifications. Instruments have to be designed and built. In short, not only are the funding agencies needed, the engineers who translate architects' designs into buildings and who make sure they meet building codes, as well as the engineers who design and oversee the building of instruments are essential infrastructure components for scientific research. The materials that are used in the buildings are the product of engineering research for the most part, and that research requires the same kind of support as scientific research does – labs, technicians, graduate students, funding agencies, etc.

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[4] See Fink (2004) for some hard data on these issues.

To be even a bit more specific, the spaces where scientific research is done do not simply appear out of nowhere. It is designed space. And then it is built space. I am deliberately making a distinction here between designing the space and building it. It actually needs to be a threefold distinction: designing the space, figuring out how to build it, and building it. Architects, if they figure into this process at all in a significant way, work in the first part, designing the space. For the most part, the most significant part of the work involves figuring out how to make the proposed design work – and that is an engineering job. Architects are notorious for drawing lines that appear to connect and leave it up to engineers and builders to figure out how to actually make them connect. It is of no small note that the most successful architectural firms today - what are called full service firms –involve both architects and engineers in the process of getting a building from plan to fact, sometimes they also supply the builders. So, the very spaces in which scientific research is conducted is heavily influenced by engineers. But there is more, for the materials used to build these spaces are constantly being improved thanks to engineering research into materials. And that research is conducted in much the same way scientific research is – in specially designed spaces, and so the cycle spirals upward and beyond. Peter Galison's account of laboratory design in *Image and Logic* speaks directly to this point (Galison 1997).

What engineers do and how they do it, to coin a phrase, is fundamental to what scientists do and how they do it. So far I have only addressed the spaces where scientific research occurs; if you will, the building of the spaces. But if we also look inside the science lab, we find the footprints of the engineers all over the place. Maybe not in labs of the gorilla researchers, but in the labs in the buildings we have been discussing we find instruments. Sometimes instruments are designed and built by scientists. If you will allow the anachronistic use of the term "scientist", when we consider Galileo the scientist, then we also have to contend with Galileo the instrument maker. One of the sources of income he relied on was the sale of instruments he not only invented, or made popular, but also built and sold, such as his military compass and his telescope (Drake 1978).

And it is well known that many contemporary scientists build their own experimental apparatus, pulling this and that off the shelf, which is one of the things that makes replication of experimental results so difficult.

Nevertheless, when it comes to buying equipment from commercial suppliers to equip your science lab, engineers are involved up to their elbows. For in the production of standardized lab equipment engineers play a major role, for these instruments are their provenance (See Baird 2004). In short, the contemporary scientist could not do her job without the engineer. There would be no appropriate space in which to work. The development of quality materials would be greatly delayed. If anything, there would be fewer and more poorly made instruments as well as whatever else is needed to fill out a functioning lab, instruments needed to conduct that work without engineers working independently.

This is not to say that from the beginning of time, engineers were central to the doing of science. The thesis I am reaching for is this: *modern* science relies on this technological infrastructure, in which large components involve work in which engineers play a major role. As historical backdrop it would be an interesting doctoral thesis to trace the historical development of the split of *scientia* into science and engineering. Something obviously happened in the 16th–17th century. The *media scientia* were already recognized as doing something applied – both Da Vinci and Galileo were often employed as what we would today call engineers working on military fortifications while doing multiple other things, like painting and writing music, etc. But to talk that way may be too simplistic. Why should we assume that there was a split into something like science and engineering from something like the *media scientia?* Maybe things don't happen that neatly. If you are looking to draw straight lines ignoring what is actually going on, you can probably do so. But straight lines are boring.

7.4 Conclusion

So the bottom line here is that simple generalizations about the relation of this to that need a more nuanced historical analysis that goes deeply behind the surface to uncover what really is going on. I hope I have provided a schematic for the kinds of details that need to be examined – it is not presented as the full story by any means. There are a couple of problem areas here that we need to be sensitized to: (1) the reification of human activities – i.e., science as somehow something that doesn't take place in a time and place being done by people; (2) Galison's idea of how science changes, not all at once, but different parts changing at there own pace, works here; (3) the politics of priority – this has not been addressed in the current chapter, but it is worth raising, even in passing: as any sociology undergraduate major will tell you, there is a competition in society among groups for some kind of social recognition. In our story it is alleged to be between science and engineering. But that just may be the wrong way to frame the discussion. It assumes there are these *things* that are called *science* and *engineering*, when if fact they are complexes of great complexity. Simplifying the rhetoric makes it easier to present a case for superiority or priority, but presenting the case does not make the case. It is one thing to talk about the miracles of scientific discovery, and quite another to address the particulars of research into the biochemical structure of stem cells. There is much to be said about the rhetoric employed in the politics of the funding world. And we should make no mistake about it, it is all about money when the fancy language is put aside. In the end questions of priority and subservience seem to boil down to who gets the money to fund their favorite research projects. And what people do and say to get that money is a topic of endless fascination. That is one reason why we should address the particulars, the people and what they do. The other is that science and engineering simply don't do anything, people do.

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Chapter 8
Engineering Science as a "Discipline of the Particular"? Types of Generalization in Engineering Sciences

Marc J. de Vries

Abstract Literature suggests that in engineering sciences the possibilities to generalize knowledge are more limited than in natural sciences. This is related to the action-oriented nature of engineering sciences and to the role of values. I will discuss the contributions of abstraction and idealization to generalization and then describe four case studies in engineering sciences to illustrate that different types of generalization can be distinguished. I will then analyze the nature of these types of generalization.

8.1 Sciences of the Particular: A Contradiction in Terms?

In a 1975 article on medical fallibility, Samuel Gorowitz and Alasdair MacIntyre argued that the use of medical sciences can easily lead to failures when the knowledge generated by these sciences is of too high a level of generality. Therefore they made a plea for medical sciences to be "sciences of the particular". They were well aware that this goes against a longstanding bias, going back as far as the time of Plato and Aristotle, towards sciences as being focused on generalization. The natural sciences with their highly generalized knowledge have served as the model for all sciences for a long time. But as Gorowitz and MacIntyre showed, general laws in medical sciences do not necessarily give an accurate description of an individual patient. They claimed that knowledge of particulars should be accepted as truly scientific knowledge, no less than generalized knowledge. Clearly, the need to be modest in generalizing knowledge in medical sciences is related to the nature of these sciences: application to practical situations is the main aim for developing such knowledge. This raises the question if the same concern about generalization also applies to other sciences that are developed primarily for practical purposes. Engineering sciences are an example of such sciences. These sciences

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are mentioned by Ladislav Tondl in an article on the limitations to generalization in certain sciences, among which he reckons what he calls "sciences of artifacts" (Tondl 1998). It is evident that engineering sciences to a large extent develop knowledge that is somehow related to (technical) artifacts. Rather than using the term "application-orientation", he wrote about "action-orientation". Another author that used the term "science of the particular" is John Meurig Thomas (cited by Ball 2006). He used the term for industrial chemistry, again a science that can be regarded to be an engineering science.

Gorowitz's and MacIntyre's idea of a "science of particulars" is supported by the distinction, introduced by Windelband and later by Rickert, between nomothetic and ideographic sciences. These authors showed that there are sciences that differ in nature from natural sciences, and yet are considered to be genuine sciences. Historical sciences are an example of that. Historians do not necessarily seek "general laws" in history. Rather, they aim at providing an accurate and observer-independent description of individual persons or occurrences. Windelband and Rickert, no doubt, were too naïve when they equated the distinction between nomothetic versus ideographic sciences and the distinction between natural versus cultural and human sciences. But the idea of some sciences aiming at general laws and others at describing particulars has been widely accepted now. This raises a question concerning the nature of engineering sciences: are they primarily "sciences of the general" like the natural sciences to which they are so closely related, or do they differ from natural sciences in their generalization claims? If they are different and more aimed at knowledge of particulars than natural sciences are, then, of course, they still must have some tendency towards generalization in order to be a science. How does that work for engineering sciences?

Before I move on and focus entirely on engineering sciences, I want to point out that the term "science of the particulars" was also used by James Ogilvy (1976) to characterize the science of aesthetics. He claimed that this was related to the values that feature in aesthetics. Values differ between people and this sets limits to the possibilities to generalize knowledge claims in aesthetics. This provides a second motive for investigating if the same limitations appear in engineering sciences, apart from the action-oriented nature of certain sciences, as values also feature strongly in engineering sciences. In Gregory Cooper's article on the limited generalizability of knowledge of ecology both aspects come together (Cooper 1998): ecology is a science that primarily is developed to be applied in practice, and values feature strongly in it.

This chapter will not yet answer the question as to which are the boundaries for generalizing in engineering sciences. What I will do here as a first step towards answering that question is to investigate how generalizations are made in engineering sciences. What types of generalization can be distinguished? Do they match with typologies for generalization in sciences that others have developed? These are the questions that will be the focus for this chapter.

8.2 Generalization, Abstraction and Idealization

How is knowledge generalized in sciences? There are at least two ways that can lead to generalizations. In the first place there is abstraction. I will use the term abstraction for abstaining from certain aspects of reality in order to get a deeper understanding of the remaining aspect(s) (from the Latin abstrahere, which means something like: peeling of). The physicist when observing a cat falling from a roof, abstains from describing the fact that the cat is a living object, for whom the owner maybe paid money, and whom (s)he dearly loves, to describe only the motion of the falling cat in the language of mathematics. By doing that, the scientist can generalize the outcomes of studying the cat's motion to the motion of any other object, irrespective whether it lives or not, whether or not it is natural or artificial, whether or not it costed money, and so on. Likewise the engineering scientist leaves out certain aspects of the artifacts (s)he studies in order to be able to generalize from one particular artifact to a broader set of artifacts. But usually the focus of the engineering scientist is less narrow than that of a natural scientist. Although a description of the physics of the artifact is important for the engineering scientist, dealing with that only would mean reducing engineering to science, and as both history and philosophy of technology have shown is an inappropriate reduction. In engineering sciences several different aspects of reality must be kept in focus to make the outcome useful for the designer or maker of artifacts. To reduce the artifact to "just a matter of nuts and bolts" or "just a matter of money" would not result in a valuable understanding of the artifact. Still, a certain degree of abstraction does take place in the engineering sciences otherwise engineering research would be as complex as reality itself.

A second "mechanism" that can lead to generalization is idealization. According to Mark Shephard (1990) it is a "fundamental part" of the design process. But according to Sven Ove Hansson (2007) in engineering science the possibilities for idealization are more limited than in natural sciences. This supports my earlier claim that literature suggests that generalization in engineering sciences is different from that in natural sciences. I will use the term in the following way: by replacing a complicated detail of reality by a simplified version of that detail (e.g. by presenting a rough surface as if it were smooth) possibilities for generalizing knowledge claims emerge. By developing knowledge about a completely frictionless surface, the physicist can make claims that hold for a variety of more or less smooth surfaces, at least as an approximation. The difference with abstraction is that the outcome is not knowledge that is limited (because aspects of reality have been left out) but inaccurate (because an approximation has been made). Abstraction does not change the description of reality but only limits it; idealization describes reality is a (slightly) different way than it is. Here, too, engineering sciences meet more limitations than natural sciences. If the knowledge generated by engineering sciences is to be applied to real artifacts, it can not be too much "distorted" by idealization to be useable. Walther Vincenti has already pointed out that the use of knowledge from natural sciences in engineering requires a transformation because of the gap between the idealized description of reality in the natural science theory and the actual artifact (Vincenti 1990).

It would seem that these two "mechanisms" for generalization lead to the two types of generalization as distinguished by Bailer-Jones (2003). She wrote about construct idealization and causal idealization. In construct idealization, the conceptual representation is only simplified, so that there is no necessary loss of truthfulness. It is just that only part of the truth is told. In causal idealization, the phenomenon representation is simplified, such that the resulting representation (model) may not be true for the original phenomenon. Generalization by abstraction is of Bailer-Jones' construct idealization type, because it only selects part of the aspects through which an artifact can be studied. Generalization by idealization (in my terms) is of Bailer-Jones' causal idealization type, because we make an "as if" representation of reality. Later I will show that for engineering sciences it can be useful to define generalization types not based on either abstraction or idealization, like in Bailer-Jones' typology, but having types that allow for combinations of the abstraction and idealization "mechanisms".

8.3 Taking an Empirical Turn

Although the considerations above give us a first impression of what limits the generalizability of knowledge and theories in engineering sciences, the picture is still rather vague. Paraphrasing on Vincenti's example of "stable but not too stable" as the pilots' vague way of expressing their needs to the designers of aircraft, we could say that knowledge in engineering sciences should be "general, but not too general". That, of course, is not satisfactory and we would like to gain further insight into the different ways in which knowledge in engineering sciences can be generalized and what limits this. For that purpose I will use a case study approach. This fits well with what Kroes and Meijers (2000) have called the "empirical turn" in the philosophy of technology. This does not mean to turn philosophy into an empirical science, but to make it an empirically informed science. Philosophy of technology, in particular analytical philosophy of technology, then becomes systematic reflection on the practice of technology and engineering.

In my case, I will use case studies from the history of the Philips Natuurkundig Laboratorium (in English: Philips Physics Laboratory). Since its initiation in 1914 this has been the main research facility in the Philips Electronics company, a multinational company that produces a great variety of artifacts, such as consumer electronics, household equipment and medical equipment. In my book on the history of this lab, I have shown that a corporate industrial research laboratory can be seen as a contributor to engineering sciences, because the knowledge generated in it is often published in academic journals (De Vries 2005). Therefore examples from work done in the Philips Natuurkundig Laboratorium can be used to illustrate how knowledge in engineering sciences can be developed. The researchers in the lab were called "scientists" by themselves as well as by others. Their claim was that the knowledge they developed was truly scientific knowledge. In order to stimulate publication of this knowledge in the scientific world, the lab had it's own research journal called the Philips Technical Review. I will use material from this journal to describe four cases of the development of engineering science knowledge. If we take engineering sciences to be those sciences that develop knowledge in the context of technological problems and challenges, then the knowledge developed in the Philips Natuurkundig Laboratorium can certainly be called engineering science knowledge. The research that was conducted was always in some way or other related to the company's main activity, namely the development and improvement of new artifacts, systems and processes. Besides that, a substantial percentage of the researchers had been educated in engineering colleges or universities of technology, and therefore were engineering scientists by training.

8.4 Four Case Studies

Case 1: Microwave Oven Characteristics

My first case study is based on an article by W. Schmidt, titled "The heating of food in a microwave oven". It was published in 1960. The author worked at the development laboratory at the Valvo Ltd. radio tube factory in Hamburg, Germany. The article deals with a microwave device that had already been developed and was produced for industrial purposes (heating wood or textile products or the welding of plastics). Several type numbers are mentioned in the article, which indicates that the microwave device had already been developed in a number of variants. The author focuses on what in that time was still a relatively new application, namely the heating of food. For restaurants this seemed to be a useful application because of the speed with which the food was heated. In conventional ways of preparing food (cooking, baking) one can only heat the exterior of the food and the inside gets warm through conduction. By using electromagnetic waves of around 2400 MHz (which is in the microwave range) for dielectric heating the inside of the food was heated directly. As a result the heating took only one fourth to one eighth of the time needed for conventional heating. This would solve both the problem of the current lack of personnel in restaurants and the problem of serving great quantities of warm food (for many customers) in a short time. The author expresses the expectation that in the end the microwave oven might also be used in households, which would particularly be convenient for housewives who also had a job.

The article presents the outcomes of measurements for microwave types 7091 and 7292. These types are identical as far as the produced electromagnetic waves that are produced; the only difference between the two types is that 7091 is air-cooled and 7292 is water-cooled. The measurements concern the way the frequency and the power of the generated waves relate to the load impedance of the oven when the power generated in the resonance cavity of the microwave is taken over by a coaxial line. This relationship is presented in what is called the Rieke diagram, a polar diagram in which the curves each represent a value of the wave frequency and the combination of radius vector and azimuth represent the combination of load impedance and the generated power. Although the article does not mention this explicitly we must assume that the measurements have been done with a limited number of tokens of the two microwave types. Yet the Rieke diagram is presented for the two types in general, that is, for all tokens of these types. Early in the article the author emphasizes the need for an accurate similarity of all tokens. The microwaves must be easily replaceable because in many cases the replacement will be done by non-experts (e.g., restaurant personnel) so that tuning because of differences between the old and the new device must not be part of the act of replacement. The author's assumption is that indeed all tokens of the types are identical so that the Rieke diagram is valid for all tokens. This is a first type of generalization: conclusions based on measurements done on a limited number of tokens are assumed to be valid for all tokens of the type.

Case 2: Transmitter Pentodes

The second case study deals with transmitter pentodes. In 1937 an article on this topic by J.P. Heyboer was published in the Philips Technical Review. Heyboer was a researcher at the Philips Natuurkundig Laboratorium. The pentode was one of the most important Philips inventions of that period, made by B.D.H. Tellegen in 1926. In the triode there are three main parts for different functions: the cathode is for producing electrons, the anode is for capturing them, and there is a grid (called the control grid) for regulating the electron flow from cathode to anode. The triode's functioning was hampered by the capacity between anode and grid, which could easily result in an undesired auto-oscillation of the current in the tube. To fix this problem, in the tetrode another grid (called screen grid) was added to the design, between anode and grid, and this functioned as an electrostatic insulation. The tetrode, though, had a new problem: now electrons hitting the anode caused secondary emission of new electrons at the anode, which electrons caused other electrons coming from the control grid to be turned back. Tellegen solved this new problem by putting another additional grid (called suppressor grid) between the insulating grid and the anode. When this grid had a negative potential (approximately the same as the cathode) the electrons approaching the anode were no longer hampered by secondary emission at the anode. But this additional grid also could be used as an additional control grid. By positioning the bars in the additional grid in the electrical "shadow" of the bars in the original control grid, the secondary emission was reduced (so not only the effect of secondary emission is dealt with, but also the emission itself). Furthermore, the variation in capacity between the cathode and the control grid became very small, which suppressed practically every frequency shift when the tube was used in a wave generator circuit.

The article contains some measurements done on the Philips PE 05/15 pentode. A graph of the anode current versus the anode voltage for different voltages of the control grid and for a specified voltage of the screen grid and the suppressor grid is presented and used to explain the advantages of the pentode over the tetrode: for a long range of anode voltages the anode current is constant (contrary to tetrodes, where a fluctuation can be seen), so that an alternating current is amplified without distortions, even when the highest value of the alternating voltage is almost as high as the constant anode voltage. The type number of the tube (PE 05/15) is dropped in all conclusions, so that we must assume that the author claims that they hold for all pentodes and not just for the type that was used for the measurements. At the end of the article the author presents data concerning a different pentode type (the PC 1,5/100) and still uses the conclusions drawn from the graph that was made for the PE 05/15. Then he lists a whole range of type numbers (PC 1/50, PE 1/80, PC 3/100 and PA 12/15). Evidently, he suggests that the conclusions drawn for the PE 05/15 hold for those as well. Here we see a second type of generalization: conclusions based on measurements done on one type (of pentode) are claimed to be valid for all types of a class (of the pentodes). This can be seen as an extension of the first type of generalization.

Case 3: High-Speed Sparking Machinery Equipment

In 1982, J.L.C. Wijers, one of the researchers at the Philips Natuurkundig Laboratorium, published an article in the Philips Technical Review on applications of high-speed sparking machinery equipment. This equipment had already been developed in the late 1960s at the Philips Natuurkundig Laboratorium and since then different applications had been studied. The aim of the article is stated in the abstract: to discuss the “promise of universal applicability” of the equipment. In high-speed sparking machinery material particles on a workpiece are removed by using the spark discharge that occurs when a high-voltage electrode is moved over a conducting material. The heat of the spark causes the material to erode and the eroded material is removed with an isolating fluid. “High-speed” means that per minute some square millimeters of the material surface are sparked away. The expectation was that this type of machining would be particularly suitable for making cavities inside a workpiece and for situations where precise right corners were needed. An advantage of using the sparking technique is that there is no contact between the equipment and the workpiece and as a consequence no mechanical tensions in the material occur during the treatment.

In the article, measurements are presented concerning seven different combinations of workpiece and electrode material. All measurements were done with one machine. The results show that for the combinations of diamond-tungsten/copper, steel-steel, steel-tungsten/copper, hardened tool steel-tungsten, hardened tool steel-tungsten/copper and hardened tool steel-hardened tool steel erosion speeds of 0.59–4.10 square millimeter per minute are realized and surface roughness as low as 0.8–1.5 micrometer. Then the author continues by describing three different applications, each of which profits from these good values: (1) making a miniature bit for thermocompression bonding in integrated circuits, (2) making small spheres of monocrystalline aluminum for materials research and (3) the processing of diamond for tools. In the first two examples the very small dimensions of the tools posed a problem for conventional ways of machining, and the high-speed sparking techniques proved very suitable for such purposes. In the third case precision as needed because the tools were to be used for making optically smooth surfaces and for cutting optical fibers. As the three examples are quite different, the author concludes that the equipment can be used for all sorts of machining processes. This is a third type of generalization: conclusions based on a limited number of examples of a certain treatment are extended to all possible applications of that treatment. Now the generalization does not concern artifact characteristics, but functional characteristics. In this case the function of removing surface particles is the content of the generalization.

Case 4: An Evacuated Tubular Solar Collector with Heat Pipe

The fourth and final case study is an article by Bloem et al. (1982) on an evacuated tubular solar collector with heat pipes. The authors were not from the Philips Natuurkundig Laboratorium, but from two of Philips' Product Divisions, namely Elcoma (Electrical components and materials) and Lighting. The solar collector (with type number VTR141) had been developed by the two Product Divisions by using a technique that had been developed by the Natuurkundig Laboratorium. Solar collectors are used to transform solar energy into heat in the water in the collector. This solar radiation is absorbed by a black panel with water pipes running into it. This panel is isolated from its environment by isolation material under the panel and a covering glass panel on top of it. In a conventional solar collector there is a layer of air between the black panel and the glass cover. This causes loss of heat and therefore the Philips solar panel had the air layer removed (hence the term "evacuated"). A tubular configuration is more suitable for that than a flat configuration. The transfer of heat from the black panel to the water tubes takes place via a heat pipe. The hot black panel makes a fluid in the heat pipe evaporate, and the gas condenses near the water pipe, thereby transferring the condensation energy. The advantage of this is twofold: the heat can not flow back from the water pipes to the black panel, and the system is protected against high water pressures (due to high temperatures). Both advantages are the result of the fact that the heat transfer stops when all fluid in the heat pipe has evaporated.

The production of the solar collector requires a technique for connecting glass and metal as well as a technique for evacuating the space between the black panel and the covering glass plate. These two processes played a major role in the production of Philips' original product, namely light bulbs. To make a light bulb, the glass bulb has to be connected to the metal socket and the air has to be pumped out of the bulb. Although the process had to be adapted to this new application by the Philips factory in Turnhout, Belgium, in effect it was still the same technique. It was not the first time that this technique was transferred to a new application. This transfer played a major role in the diversification of the company's product portfolio in the pre-WWII period. The researchers in the lab then used to say that knowledge of light bulbs is knowledge of "glass and vacuum" and that the same knowledge applied to a variety of tubes, because they also were just a matter of "glass and vacuum". This enabled the lab to move from light bulbs to X-ray tubes, to radio valves and other amplification tubes (e.g., for telephony). Here we have another type of generalization: knowledge of a physical phenomenon (here: that realizes the desired connection between glass and metal) in one particular artifact (a light bulb) is generalized to all artifacts in which the same physical connection is needed.

8.5 Analysis of the Types of Generalization in the Case Studies

I will now analyze more precisely the nature of the different types of generalization that we encountered in the case studies. Thereby I will make use of the dual nature approach for conceptualizing technical artifacts, as it has been developed at the Delft University of Technology in the Netherlands (in De Vries 2003 I have shown how different types of engineering knowledge can be derived from this approach). In this approach technical artifacts are characterized by their physical nature and their functional nature. The physical nature (or "structure") is the physical/chemical and structural set-up of the artifact; the functional nature (or "function") indicates what it is for. The term "two natures" does not refer to a dualistic approach. They are two ways of describing the same artifact, not two parts of the artifact. Using this account of technical artifacts, let us now examine the case studies.

In the first case study, data on one toke of a type are used to make claims about the type. What is assumed in doing that is that all tokens of the type are identical both in their physical nature and in their functional nature. The physical nature, though, is influenced by the production process. Small differences are introduced as a result of tolerances in that process. In the generalized knowledge claim these differences are annihilated. This means that idealization is used for this type of generalization. No abstraction was made in the generalization. One can also say that the conclusions refer to the design of the microwave device, both as far as its function and physical realization are concerned. The design is as it were the model that results from the generalization.

In the second case study, data about one type are used to make claims about other types as well. These types all have the same functional nature (serving as a pentode transmitter tube), but differ in physical nature. To generalize knowledge of one type, it is not assumed that there are no differences between the types in their physical nature (the sort of idealization that was used in the first case study) but the whole physical nature is just left out of the considerations about the kind (pentodes), of which the examined type (PE 05/15) was one type. In other words: in this type of generalization abstraction is applied. In the second case study the various types (e.g., PE 05/15) within the kind (pentodes) still have several physical characteristics in common. In the third case, the differences between the physical natures of the various situations in which the sparking machinery equipment is used differ greatly. As in the second case, these differences are not eliminated in the generalized knowledge claim, but the physical nature is left out and the knowledge claims only refer to the functional nature of the artifacts. There is, though, idealization involved in this type of generalization. It is assumed that there is no malfunctioning resulting from crucial deviations from the design in the physical nature of the artifact. Another appearance of this form of generalization is the use of a systems perspective on the artifact. Such a perspective contains claims about the artifact that only concern functions (and sub-functions), and not the physical realization of the system. Here the system description is the model that results from the generalization.

In the fourth case study, not the physical nature is left out of consideration, but the functional nature is. Knowledge claims about the physical nature ("glass and vacuum") of various tubes are made irrespective of the function of the tube. So here again we have abstraction as the "mechanism" for generalization, but now of a different kind. Here the model that results from the generalization is the physical or mathematical representation of the phenomena that govern the working principles of the artifact. Here, too, we have idealizations, namely the ones that are made in the natural science perspective on the phenomena in question.

8.6 Conclusions

I have shown that literature suggests that generalization is different in engineering sciences than in natural sciences. This makes the topic of generalization in engineering sciences of interest for the philosophy of engineering. By analyzing four case studies, drawn from the history of the Philips Natuurkundig Laboratorium, I have shown that at least three types of generalization in engineering sciences can be distinguished: "artifact-token to artifact-type" generalization, based on the idealization of no production deviations being present in any token; "artifact to function" generalization, in which abstraction takes place (only the functional nature of the artifact is considered), and "artifact to artifact-structure" generalization, in which also abstraction takes place (only the physical nature is kept for study). In the latter two types idealization also takes place. In the second type of generalization any malfunctioning is replaced by proper functioning. In the third type of generalization the idealizations made in natural sciences concerning the phenomena in study are applied. The first type of generalization is of Bailer Jones' "causal idealization" type; the other three are combinations of "concept" and "causal" idealizations in Bailer-Jones' typology.

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Chapter 9
How the Models of Engineering Tell the Truth

Zachary Pirtle

Abstract Models are one of the more important ways in which scientists and engineers understand and engage with the world. Philosophers of science have analyzed how modeling idealizes the world, helps explain events and supports our understanding. I advocate the study of models and modeling practice in engineering. I analyze two classic case studies on flush riveting and control volume analysis from Walter Vincenti as well as a set of models used in the evaluation of levee failures in New Orleans after Hurricane Katrina. Engineers use a variety of different kinds of models and understanding how each model is used to guide understanding is worthwhile. Among the questions raised are how models guide processes of testing and design; what sorts of idealizations do engineers include in their models; and how do engineers use independent models to try to generate robust agreement between model results.

9.1 Introduction

Since Aristotle at least, philosophers have privileged abstract theoretical knowledge over practical knowledge, but today this assumption is generally regarded as far too simple (Bechtel and Hamilton 2006). Philosophers of science are paying more attention to the rich detail and complexity of scientific knowledge by asking new questions about explanation, styles of reasoning, and idealizations (Wimsatt 2007). Engineering, which integrates scientific principles in its design and analysis of artifacts, has long been neglected as a result of this bias toward theoretical knowledge, but it offers a goldmine for philosophical work on explanation and idealization. Engineers often engage with the world using a variety of conceptual and mathematical models, which in turn represent the world through idealizations and are used to explain events and designs. In particular, engineering is philosophically interesting

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because of the ways it differs from and is similar to a long-cherished philosopher's conception of what scientific theorizing and explanation looks like.

The central focus of this chapter is the use of models to explain events and solve problems in engineering. How are models used? What epistemic constraints do they reveal on the part of the engineers who build them? What connections are there between models and the world? What differentiates a good model from a bad one? What inferences do models of engineering license, and how? In what ways do models of engineering tell the truth? Notice that these are current questions in the philosophy of science and are not peculiar to engineering. The answers offered by careful attention to engineering, however, may be.

I will not even attempt to answer all of these questions here. My aims instead are first to show through examination of cases that engineering is ripe for such inquiry and secondly to argue that any plausible account of model-based epistemology in engineering will have to deal with multiple varied and diverse kinds of models in multiple contexts.

In what follows, I will briefly discuss three models which are typical of broader trends of model usage in engineering. First, engineers learning how to flush rivet in the 1930s had in mind a conceptual model of what types of rivet designs are plausible. Using trial-and-error analysis, this conceptual model of rivet design was used to guide the testing process and eventually explain optimum design standards.

Second, control volume analysis (CVA) is an instance where engineering scientists took a theoretical model from physics, and adapted it to better fit the problems that engineers face. It represents situations in which everyday engineering knowledge reflects the physical problems that engineers face, and shows how engineers idealize and focus on parts of a system needed to solve problems.

Finally, I will discuss numerical and physical models used in the Interagency Performance Evaluation Taskforce's failure analysis of the levees in New Orleans after Hurricane Katrina. In this case, models are being used to explain why the levees failed, and they collectively employ independent lines of analysis to reach greater confidence in that explanation. These three cases show a diversity in the kinds of models engineers used as well as in the epistemic strategies by which they try to understand the world.

A word of caution is in order before moving on to cases. My survey of engineering's diversity of model kinds and uses is situated within a broader context. Two of my examples are taken from rich case studies in Walter Vincenti's *What Engineers Know and How They Know It,*a landmark in the history and philosophy of engineering. Vincenti, an aeronautical engineering professor at Stanford University, used his case studies to generate a framework to describe engineering knowledge. I will build on his analysis and focus on the roles models play, but I wish to remain agnostic about a central theme in Vincenti's analysis. Vincenti is of the view that "treating science and technology as separate spheres of knowledge" (Vincenti 1990, p. 4, quote of Wise) is advisable.

My main work here is to point to interesting epistemological questions raised by models in engineering, to show their diversity, and begin a conversation about how models work in these cases and others like them. The extent and ways in which they are similar and different from the models and model-based epistemic strategies in "science" seems to me to be a question that is well worth taking up, but only after we have a good understanding of models as they are used in engineering. I will not argue this thesis directly here, but the cases below point to some difficulties in drawing lines between "scientific" and "technological" uses of models and their attendant epistemologies. Whether "scientific" and "technological" models should be treated differently from an epistemic perspective is therefore best left as an open question, as is the issue of what the distinction comes to in these cases.

9.2 Theoretical Background on Explanation, Laws and Models

Some philosophical accounts of science and engineering have focused on explanation as a central intellectual activity in science and engineering (Woodward 2003; Pitt 1999). The best known and most influential account of explanation is the deductive-nomological (DN) account of explanation, which was established in Hempel and Oppenheim (1948). The DN model holds that events are explained if their occurrence could have been logically derived from a set of fundamental scientific laws along with observations about the past or present state of the system of interest. This emphasis on laws was highly influential for early accounts of scientific theory, as well as in rare accounts of technological theory (such as Bunge 1972). In the 1970s and 1980s, many philosophers began to reject the strict characterization of theory as axiomatic laws, thus casting the DN account into doubt (Suppe 1974; Cartwright 1983). Scientific explanation today is an area of ongoing research, with no consensus view yet established. To date, the only prominent account of explanation in technology and engineering, Pitt (1999), still focuses on a DN-based account of explanation.

Given recent critical accounts undermining the importance of scientific laws, some philosophers have focused on models as the cornerstone of scientific theory (Giere 1988; Cartwright 1983, 1999; Lloyd 1994; Woodward 2003). No model (much less a law) ever completely represents the world, as it always leaves out, or idealizes away, some aspects of the world. As it seems impossible for models to have an exactly matching correspondence with real systems, how do models relate to the world? Some philosophers, like Ronald Giere, hold that models are neither true nor false, as they think models do not directly represent the world at all. Instead of using truth as a criterion to evaluate a model's relationship with the world, Giere holds that communities of experts judge them to be *similar*to the world. In Giere's similarity based account, the degree to which a model is successful in representing the world is based upon conventions within fields of research. This approach seems fruitful (and has even been applied to engineering theory in Cuevas-Badallo (2005)), but some find similarity-based accounts to be problematic, in part due to the vagaries of using a subjective criterion such as similarity (Callender and Cohen 2006).

There are competing philosophical accounts that still place a heavy emphasis on scientific truth. Nancy Cartwright has long been a harsh and influential critic of traditional conceptions of scientific law. Cartwright (1983) argues that the laws of physics “lie” because they work by idealizing away all the confounding factors that we know to be operating in the real world. They are therefore only true of the sanitized world of the scientists’ imagination, rather than true of the world as we find it. Laws can be made true, of course, by relaxing their idealizing assumptions, but then, according to Cartwright, laws lose their explanatory power. Focusing on how general accounts are made to accurately describe specific situations in the world provides an illuminating way of thinking about what engineers do, and how they come to know, explain, and intervene on the world. Engineers idealize, but do their idealizations lie?

The following three cases showcase different instances of idealization and explanation surrounding models used in engineering. Following from a particular notion of truth, each case suggests the different ways in which engineering models can be said to lie and to tell the truth.

9.3 Paradigm Cases of Engineering

9.3.1 Flush Riveting

Engineering is intimately connected with design, but it is not encompassed by it. Whereas design might have a purely instrumental and aesthetic approach, engineers push the boundaries of their designs with scientific analysis about how the world works. A prominent and, ultimately, scientific dimension of that analysis involves the use of trial and error testing, where different designs are tested and evaluated. Even in highly developed fields like aeronautical engineering, trial-and-error analysis is an intimate part of the design process, as is illustrated by Vincenti’s analysis of flush rivets. While Vincenti does not claim this, I think the work done by these engineers can be interpreted as being guided by the use of conceptual models, or mental conceptions of what the rivet should be like and how it will perform. Engineers here used these conceptual models of what flush rivet designs should look like, which guided the testing process and served to bound ultimate explanations of what the best designs should be.

Flush rivets – or rivets that are flatly embedded on a metallic surface – arose in the aeronautical industry between 1930 and 1950 (Vincenti 1990, pp. 170–199). Generally, riveting joins together two pieces of metal by way of a metal rivet placed between matching holes; the rivet is sealed in by upsetting- or depressing- the rivet on one side. This can leave a protrusion extending beyond the plate surface. A flush rivet has this protrusion removed, making its surface continuous with that of the plate.

Flush riveting existed before the 1930s, having had a history in ships and land-based structures since the 1830s. This history, however, provided little insight for aeronautical work (p. 175) as the application of flush riveting to aircraft was a more difficult process as a result of the thin light-weight plates being used in the wings of aircraft, which were too fragile to be riveted using the normal methods. The motivation for flush riveting in aircraft was obvious from the start: protruding rivets caused unnecessary drag. As speed advancements were implemented on aircraft, the small speed increase that flush riveting offered became viewed as necessary for aircraft development and research quickly commenced.

Three corporations kept written records of their research inquiries into flush riveting: Douglas Aircraft Company, Curtis-Wright Corporation, and Bell Aircraft. All three developed approaches which dimpled the sheet around the rivet, but each company came to different conclusions about what type of riveting process to use. Each test was judged by a multitude of criteria, ranging from whether or not the rivet is successfully placed, ability to work with differently sized plates, cost, ease of installation, and strength. The process of determining and explaining why one design was better than another was complex. For example, all three corporations began by using a 78° head angle for their rivets, but Douglas Aircraft's testing found that the 78° rivets were too steep for their purposes because they caused the sheet to become too brittle. As part of its alternative, Douglas adopted a 100° head angle rivet. However, Curtis-Wright saw the same problem with the 78° head angle, but they attempted to keep the same head angle but counter act increased brittleness using a different process for flush riveting, the machine counter-sink. They reduced the size of the rivet head and altered the positioning of the shaft, and were able to gain secure results with the smaller head angle. Bell Aircraft eventually tested and tried both methods but found problems with both; they instead opted to go for much larger 120° rivets. There were further complications that made it difficult to decide upon optimum rivet designs. Airplane designers, when trying to assess the strength of the different kinds of flush rivets and their ability to handle the loads across plates on the surface of the aircraft, were unable to find an analytical answer. According to Vincenti, designers' knowledge of rivet strength "came entirely from experiment" (p. 189).

Each of these corporations worked for several years using their particular method, with each being generally satisfied in their results. The industry converged on a 100° head angle over the course of the 1940s, but not because one method clearly showed itself to be the best – aerospace industry associations wanted unified standards, so as to cut down on the number of costly rivet assembly tools needed for manufacturing (p. 192). Despite the lack of a conclusive best practice, the 100° rivet was deemed acceptable. Even today, Vincenti says that "flush riveting today is still not a closed book," which emphasizes that the level of detail required to manage various problems in dealing with rivets was and still is complex, and cutting edge aerospace techniques have still not removed the need for rigorous trial-and-error testing (p. 193).

The flush riveting example holds numerous lessons for a philosophy of engineering. There are first the lessons that Vincenti himself draws. As many (but not all!) engineers often have to do, these aeronautical engineers had to create optimum design standards for a new type of rivet, without direct guidance from any physical or theoretical "first principles." Further, each company's development of a different rivet standard shows that design choices are not always determined on the basis of testing results. The eventual convergence of the industry on the 100° rivet shows both how technological development can go in unexpected directions, as well as how design decisions are affected by engineering needs such as low cost, standardization and ease of manufacturability.

Beyond Vincenti, the nature of trial-and error testing obviously can be an efficient strategy for attempting to justify and explain the value of particular designs. However, designs are not constructed *de novo:*existing precedents provide a context for every level of the engineer's approach. For example, engineers often stick with previously existing tools; here, the existing prominence and ease of riveting in aerospace and other industries makes it an efficient basis for new designs. Similarly, the design and interpretation of tests is also theoretically determined; basic stress theory and mathematics can describe how stresses on the wing will propagate, and how much stress each rivet might be forced to go. From theory, engineers thus define tentative initial goal for what a successful test should look like. Trial-and-error based analysis clearly is not simple or derivative, but is always bounded by a context. Its success in many fields indicates the value of trial and error testing as a general epistemic strategy.

In part due to this context that surrounds both design and trial and error testing, I suggest that we think of engineers as utilizing a conceptual model to guide the design and testing processes. The key here is that the testing described above was not a random process: context, existing tools and practices and basic understanding play a guiding role. I label this guiding context a conceptual model. While Giere's model-based view of theories might likewise claim engineers use conceptual models, he does not think about how such models guide the search for acceptable rivet designs and, perhaps more importantly, guide away from unacceptable testing and design practices. As noted above, the liberal use of the term model to describe general conceptual knowledge is not without objection (Godfrey-Smith 2005), but it may prove a useful way for examining the role and nature of an engineer's knowledge.

For example, what connection does an engineer's conceptual model have to the justification of the final design? Is there any sense in which an engineer's testing and conceptual knowledge can *explain* the choice of rivet head angle? Explanation, conceived in a model-dependent sense, could result from a set of testing that is guided from the beginning by a model which tries to understand the effect of different design choices on the model. In this way, a model establishes what the meaning of an observed test result is, and gives a predetermined sense of what a plausible design should look like. This complex process to explain a design would not exist in the more linear DN account of explanation.

James Woodward (2003) has given an account of causal explanation based on the idea of manipulability: once one understands how a given manipulation of a "cause" will manipulate its corresponding effect, you can claim to have explained the event. This notion of explanation is highly interventionist, and perhaps for design engineers explanation is achieved when the designers understand how changing the design would affect its tangible behavior in the field. In this explanatory context, it does not matter if the engineer can describe the scientific details underlying the cause and effect so long as they know how to produce the desired effect.

9.3.2 Control Volume Analysis

Outside of the design process and close to areas traditionally associated with scientific experience, engineers can characterize scientific principles differently than do traditional scientists. To illustrate this, Vincenti focuses on the exclusive use of the method of control volume analysis (CVA) by engineers (112–136). CVA begins from simple equations that define the conservation of mass, momentum, energy and entropy of a system, and focuses on how to apply these equations to arbitrarily established control volumes (Fox et al. 2004, pp. 99–152). CVA uses the equations of conservation to derive new equations that describe the change of various properties within the control volume over time. Often employed in fluid mechanics problems such as the one shown in Fig. 9.1, control volumes are usually placed around systems of interest, such as the inside of a piston or the interior of a pipe where fluid flow occurs. The engineer, with previously derived equations for CVA, can calculate incoming, outgoing and stored properties within a variety of possible control volumes.

Vincenti argues that engineers exclusively use CVA, while physicists rarely apply the tool. The counterpart in physics to CVA is control mass analysis. This form of analysis doesn't track a specific area, but instead follows a group of mass particles as they move. Applying control mass analysis to fluid mechanics problems often confronts huge problems in complexity as a group of particles can be dispersed beyond the ability to track easily using mathematics. For the physicist, analyzing such complex motion could be highly desirable, but engineers often are highly constrained by budget and time constraints on their projects. Solving altered equations of conservation across a control volume is easier and more efficient than tracking the path of particles as they move. Further, as Vincenti also points out, engineering problems concerned with fluid flow are often focused on the overall results, as opposed to a detailed description of events throughout the volume of fluid motion.

CVA represents one area where the epistemic demands of a working engineer affect the type of analysis the engineer uses. Vincenti's historical account of the development of CVA shows how the need for fast, accessible analysis led to the refinement by academic engineers of the CVA tool. Famous academic engineers like Ludwig Prandtl and Theodore von Karman refined the concept, and it was later

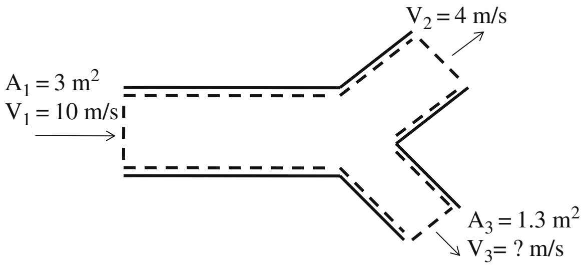

Fig. 9.1 Example of fluid flow in a pipe, where CVA can be used to calculate an unknown variable based on known areas and volumes and the conservation of mass

picked up by American academic engineers who wrote the technique into engineering textbooks, partly due to the ease with which it could be learned by engineering students. Similar economic and educational constraints are capable of affecting how engineers use and develop other conceptual tools.

CVA also raises issues regarding idealizations in engineering. In this sense, the idealizations comes from: defining the boundaries of the system, excluding some parts which obviously in fact exist; and from only examining the properties inside the control volume that are related to the conservation equations, making irrelevant to the model any actual behavior (such as turbulence) which might actually occur. Control volumes and the equations of CVA clearly serve as a model of a system, and highlight the aspects of a system that can be ignored by the engineer. By removing some features of a physical system, a control volume model allows for the application of knowledge from physics and thermodynamics to determine property changes in the volume. This idealization clearly favors the general over the particular, and as long as the relevant assumptions of the CVA analysis (such as that the generation of energy inside the volume is known, or that the flux of mass and energy leaving the system is accurately known) are realistic enough, then the model's predictions about property changes over time will be realistic enough. Some scientists and philosophers have written about tradeoffs between generality, precision and realism that occur in other scientific models (Levins 1966; Wimsatt 2007). Examining engineering models and the way that tradeoffs between these desiderata could provide a way to continue to analyze how economic and problem-driven concerns have an effect on ways engineers approach and understand the world.

9.3.3 Numerical and Physical Models Used in the Failure Analysis of the New Orleans Levees

Engineering does not occur in a vacuum. In the wake of Hurricane Katrina and the tremendous failure of the levees in New Orleans, the Interagency Performance Evaluation Taskforce (IPET) systematically analyzed the numerous levee and floodwall failures using a set of models (IPET 2007). Whereas some levees failed after being overtopped by flooding water, some of the most lethal failures occurred before the levees were overtopped, at water levels that the levees were designed to withstand. One such failure occurred at the 17th St. Canal, where the breech flooded 85% of the downtown area and has been estimated to have caused half of the fatalities that occurred during Katrina (Seed et al. 2006). The social and ethical dimensions underpinning the Katrina disaster are likely the most important ones to address to prevent future failures, but it is vitally important that IPET and the Army Corps of Engineers have as accurate as possible an understanding of the technical failure of an event like the canal failure.

Katrina emphasizes how engineers can be called upon to explain failures and to try to prevent them in the future. In some cases of failure, such as with the levees, it is impossible to replicate the original conditions of failure and investigating engineers have to make the most of an initially limited set of data. As is common practice in engineering, IPET engineers used multiple models to interpret incomplete information and to explain the cause of the levee failures. The levees models here are particularly interesting because they present both a set of questions for future analysis and a way for philosophical reflection to lead to better engineering practice. The IPET engineers, given post-failure information collected from the site along with rough knowledge of floodwater height at the time of failure, used a variety of models that are in some ways independent.

Understanding the forms and degrees of independence between the models is a conceptual question that relates to the physical first principles, idealizations and data sets used by the models, and it has a direct bearing on the level of confidence engineers should have in the accuracy of their model projections. As is clear in the levee models, they are based on different principles, and the importance of questioning the scope of agreement between these models is established by subsequent criticism of the IPET analysis.

The different modeling tools employed to analyze many of the Katrina levee failures are discussed here, with relevant diagrams from the 17th St. Canal analysis.

9.3.3.1 Finite Element Analysis Models (IPET 2007, V-45-V-52)

Finite element analysis is a commonly used practice in engineering that subdivides an object into discrete "elements," which are then subjected to forces or energy fluxes that are balanced across the elements. Elements are typically one dimensional beams or interfaces or two dimensional blocks (three-dimensional bricks are also available but are rarely used in practice). Finite element analysis in some ways is merely a method of solving differential equations of force equilibrium, conservation of mass, and continuity of displacement collectively across the domain being modeled for the specified boundary conditions, thus allowing for FEA to solve problems such settlement of an embankment or seepage through an earth dam. The accuracy of a FEA is highly dependent upon the grid resolution employed to model an observed system, and results of an analysis depends upon both the boundary conditions and the inputs to (demands upon) the system. FEA can generate detailed information on stresses and strains in each part of the system and can model the response of the system over time.

FEA models were used to generate factor-of-safety values, which are the calculated maximum yield strengths of the soil divided by the stresses calculated in the FEA model for the flood conditions along an assumed failure surface. The factors of safety in FEM analyses conducted by the IPET team were all above one, indicating that failure would not occur, except for models which assumed the creation of a gap in between the flood wall and the canal embankment. Because the assumption of a gap between the wall and soil was the only way to predict a failure prior to overtopping for the 17th St. Canal (a possibility likewise supported by the subsequent models), the IPET team has concluded that that gap formation contributed to the failure, which the model also predicted to occur in a clay layer beneath the levee.

9.3.3.2 Limit Equilibrium Assessment Model (IPET 2007, V-41-V-43)

Limit equilibrium analysis (LEA) is a relatively old method of analysis of the stability of slopes and embankments developed by civil engineers, which is valued for its simplicity, accuracy, and ease of computation (Duncan and Wright 2005). LEA analyzes possible failure along a slope by positing a failure plane (here a circular plane). Given the known loads caused by the weight of the water and of the soil, moment and force equilibrium are applied to establish the forces along the postulated shear plane. A shear strength is assigned to each portion of the postulated failure surface based upon assumed strength parameters and the applied normal forces. A factor of safety is calculated as either the resisting moment about the center of rotation due to the shear strength divided by the driving moment due to the induced shear forces or, for sliding block failures, the integrated resisting shear strength divided by the integrated applied shear stress. In a LEA analysis, all possible ("kinematically admissible") failure surfaces must be evaluated to find the surface with the lowest factor of safety. By definition, a factor of safety less than one on any surface means that the applied shear stress along that surface is great enough to exceed the shear strength along that surface and cause slippage across that LEA failure plane.

Analysis of failure was done by examining what conditions would generate a factor of safety less than one. The LEA model indicated that for the factor of safety to decrease below 1, it was necessary for a gap to emerge between the floodwall and the canal side soil, failure was more likely to occur at the flood-level heights seen during Katrina.

9.3.3.3 Centrifuge Models (IPET 2007, V-43-V-45)

Physical centrifuge models attempt to replicate at a small scale the performance of geotechnical systems, e.g. flooding of the levee. Because of difficulties in physical modeling of the in situ geometry and properties of the ground, the strength of centrifuge testing lies primarily in identification of mechanisms of failure, as well as in calibration and validation of numerical models, i.e. by numerically modeling the centrifuge test. The spinning of a centrifuge models the gravity-induced body stresses in the soil mass (which govern its shear strength) and causes the water to exert stresses roughly approximate to the stresses experienced during flooding. In a centrifuge model test, physical dimensions in the model scale according to the centrifugal acceleration, i.e. at an acceleration of 30 times gravity (30 g's) lengths in the model are scaled by a factor of 30 with respect to the prototype. The capacity of the centrifuge (in terms of g's and payload weight) determines the size of the physical model that can be tested based upon this similarity relationship.

A centrifuge model test, of an idealized levee system was conducted by the IPET team (IPET V-43). As with the FEA and LEA models, the centrifuge model also suggested a gap between the floodwall and the canal side soil was necessary for failure. The model likewise suggested that the location of failure was along a layer of clay at the bottom of the structure.

To synthesize the results of the three studies cited above: the levee breach was analyzed by IPET using three different models. However, each of the models used initial conditions (levee cross section size, soil properties, etc.) based upon observed data from the field, and thus, in a certain sense, each model is based upon roughly similar initial conditions. The underlying analytical principles behind each model are significantly different. The principles for the models at hand are:

- FEA models solve equations of stress and strain (which incorporate more physical phenomena than the LEA static equilibrium analysis) across small elements throughout the levee.
- LEA solves static equilibrium equations over an aggregated plane where failure is assumed to occur, determining a factor of safety for a given load.
- Centrifuge models are idealized physical models subjected to similar loading as experienced in the field, with the experiment results used to identify the governing mechanisms of behavior in the field.

The physical model is perhaps fundamentally different from the mathematical models. The LEA model solves broad equations of static equilibrium along assumed failure slopes, which thus avoids calculations of strains (and only calculates stress on the postulated failure surface) and does not attempt to understanding the integrated system behavior throughout the levee. The FEA model includes static equilibrium equations, but is more comprehensive in its stress analysis; however, given its greater resolution and more detailed input soil property requirements, it is subject to errors in soil strength calculations.

No set of models can be completely independent of one another, but the differences between these models is enough to warrant increased epistemic confidence as a result of a robust agreement between what are largely independent means. Within theoretical ecology, Richard Levins (1966) described robustness as applying to truths lying at the "intersection of independent lies." This is a provocative phrasing, but what he showed was how different models, each with their own inadequacies and idealizations, significantly increase one's confidence in model results when there are independent models in agreement with one another. The metaphor of an intersection of independent lies helps to characterize how independent models, all of which have their own flaws and inaccuracies, can attempt to agree on what's happening in physical systems.

Each model suggested a gap was necessary, but understanding whether the model results were in agreement was not simple. In response to early drafts of the IPET report, some engineers questioned the scope of the agreement between the different models. The National Research Council, focusing on the two numerical models, is largely complimentary: "The IPET has used two independent analysis methods for evaluating mechanisms of failure at the breach sites" (NRC 2006, p. 11). With the limit equilibrium method, however, they assess the breadth of the analysis used and argue that "It is not clear why the IPET calculations have been restricted to circular arc failure mechanisms, which apparently are not the critical mechanisms associated with levee breaching as they are inconsistent with Finite Element analyses and physical model tests the IPET has conducted ... The IPET team has not reported on analyses for planar and other alternative sliding surfaces and has thus opened itself to criticisms of its conclusions" (ibid).

In the early IPET draft, were the FEA and LEA models really in agreement with one another in explaining the 17th St. Canal failure? Both models concluded that the soil underneath the levee was the location of failure, though it is apparently less clear as to what the exact mechanism was. The limited equilibrium analysis focused on circular arc failure mechanisms, which, as noted by the above NAE quote, were inconsistent with the finite element analysis model. The IPET team later did this analysis, but the point remains that understanding agreement can be difficult even amongst highly trained engineers.

Levin's discussion of robustness provides a way to characterize this example. Given two largely independent methods of analysis, there was a clear agreement about the location of the failure, but there might not have been a similar "intersection" as to the exact causal mechanism of the failure. These independent models agreed a gap formation contributed to the failure, making that conclusion robust. The NRC call for better integrating the different model outputs would serve to change the nature and robustness of the models' agreement.

This strikes me as an area in which philosophers, working in partnership with engineers, can help to generate conceptual clarity that can lead to better failure analyses, which in turn can help design safer levees.

9.4 Conclusion: How the Models of Engineering Tell the Truth

The examples used in this chapter serve as a rough sketch of a taxonomy of models that are relevant in engineering: conceptual models (used in flush riveting), analytical models (CVA), numerical models (FEA and LEA) and physical models (centrifuge). These models are used for diverse purposes, and they help guide the engineer's search for understanding. These different models may be fundamentally different from one another (what commonality does a conceptual model share with a physical model or a numerical model?), but possible differences do not undermine the proposed research examining how each kind of model is used to understand and represent the world (Godfrey-Smith 2005). My examples were chosen from traditionally recognized engineering practice, and analyzing those raises questions about whether there is any meaningful distinction between models and theory in science and models and theory used in engineering. The point remains that what engineers do has been philosophically underexamined, and here I have tried to present a range of kinds of models in context in an effort to show that philosophers' neglect for engineering is not well founded. Indeed, the question of whether engineering and science are different enough that we require separate understandings of them should turn importantly on how we understand model use in both areas of study.

Nancy Cartwright, in her 1983 book, *How the Laws of Physics Lie*, helped provoke a sea change in thinking about scientific laws, truth, and explanation. Part of this lying comes in the form of idealizing assumptions – of describing a world that we can track rather than the world as it presents itself to us. Models, of course, very often are only tractable if we make similarly heroic assumptions. Levins, who was mentioned in the last section, was motivated in part by noticing that his models contain so many assumptions that they were literally false. In this engineering is no different. However, the epistemic and efficiency constraints on engineers may force them to do a better job of telling the truth, and it may thus be the case that engineering, despite its having been neglected and dismissed as unscientific, may well describe and explain the world more accurately than science properly so called. Whether this is the case we won't know until we understand engineering models and how they work in epistemic and practical contexts.

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Chapter 10
Limits to Systems Engineering

Maarten M. Ottens

Abstract In this chapter I will analyze the concept of boundary and the rationale behind considering elements part of a system in three key systems engineering texts. Using examples of electric power systems in Europe being sociotechnical systems, I will argue three points. (1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the 'missing' elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing even just the technical part of sociotechnical systems.

In the night of September 23, 2003, around 3 AM, a power line collapsed on the Swiss-Italian border. Just over half an hour later over 50 million people in the whole of Italy were left without electricity. On November 4, 2006, around 10 PM on a Saturday evening, a planned action to switch off a line was followed by a cascade of tripping lines and blackouts throughout Europe, even affecting countries in North-Africa. In both cases the problems happened at times of a relatively low use of electricity. The subsequent reports traced the train of technical events leading up to and following the initial incidents meticulously. Besides analyzing the technical aspects, both reports also point to a change in use of the network, a change that contributed to high loads on power lines during off-peak hours, a change in use following a change in governance of the electric power system in Europe.

The European electric power system is an example of a so-called sociotechnical system. In these systems technical and non-technical elements are strongly

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interconnected and are both essential for the systems to function the way they do. They are hybrid systems, containing elements of a different nature. With a rapid development of technology in the last century, both in scale and complexity, the interdependence of technical and non-technical elements (e.g. humans, legislation) has increased. In the above examples changes in legislation concerning the governance of electric power systems affected the physical flow of electricity. Such sociotechnical systems bring new challenges to the field of engineering. These challenges are addressed in a discipline of engineering specifically focusing on systems: the systems engineering discipline. However, despite the claim made in key systems engineering texts that systems engineering is applicable to large, complex systems (and to human and social systems) (INCOSE 2004, p. 14), and that the approach is adequate for any man-made system (ISO 2002, p. 1), I will argue that the current conceptual framework used in systems engineering is not fit for the practice of designing and managing sociotechnical systems such as the current electric power system in Europe.[1]

I will focus in particular on the rationale for considering specific elements part of the system by analyzing the use of the concept of *boundary* in three key systems engineering texts: two systems engineering standards by "the world's largest developer and publisher of International Standards", the ISO[2] and by "the world's leading professional association for the advancement of technology" the IEEE,[3] and a systems engineering handbook by INCOSE,[4] "the world's authoritative systems engineering professional society."[5]

Throughout this analysis I will refer to examples of electric power systems in Europe. I focus on electric power systems for two reasons. (1) First because these systems are paramount examples of engineering ingenuity. Unlike many other sociotechnical systems like, for example, transportation systems and communication systems, the existence of electric power systems does not predate the discipline of engineering. Engineers have been deeply involved in the development of these systems from the start. The fast growth of these systems and their increased reliability points to a successful engineering effort. (2) The second reason to focus on electric power systems is because in Europe (and in North America) these systems faced a major shift in mode of governance in the last decades. This shift in governance affected the physical flow of electricity through the network, raising questions to the status of policy and legislation in a practice of modeling, designing and managing such systems. This shift emphasizes the sociotechnical character of these systems.

By focusing on the concept of boundary, and the rationales behind the decision to take certain aspects into account and not others, I will argue three points.

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[1] Similar remarks can be made about electric power systems elsewhere, but I will focus on the European system.

[2] International Organization for Standardization (ISO 2002).

[3] IEEE (2005).

[4] International Council on Systems Engineering (INCOSE 2004).

[5] The three quotes come from the respective websites of the organizations: www.iso.org, www.ieee.org and www.incose.org (Accessed March 27, 2008).

(1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the "missing" elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing even just the technical part of sociotechnical systems.

I will start outlining some physical, technical, historical and organizational characteristics of electric power systems in Europe, to provide a background for my analysis.

10.1 Electricity and Electric Power Systems

The convenience that comes with electricity, our daily use, is perhaps most apparent when it fails. In the European electric power system failures leading to outages are rare. Nevertheless outages do happen and provide challenges to an engineering practice concerned with improving electricity supply. With the changes of governance of the electric power systems over the last decades came a change in the physical flow of electricity on the network, playing a role in recent outages of the network. To understand this role I will highlight a few characteristics of electricity and give a short history of the development of electric power systems in Europe.

10.1.1 Physical and Technical Characteristics

(1) Electricity flows at near light-speed velocities. (2) It follows the path of least resistance.[6] And (3) electricity is hard to store. In order to keep the output at the outlet within the small range of voltage and frequency that our electric appliances need to operate, and given above three characteristics, a continuous and near-perfect balance of supply and demand of electricity needs to be maintained. Managing the balance is only possible because the flow of electricity is highly predictable. It will *always* follow the path of least resistance and because we can make a fair estimate of this path given our knowledge of the physical characteristics of the grid, we do have functioning electric power systems of the current scale.

Unfortunately there are some complicating factors in transporting electricity that add to the volatility of the system. (1) The nowadays continent-wide system in Europe has hundreds of millions of individual users switching their appliances on and off following their own intentions. While the general patterns of electricity use are predictable, the precise demand is unknown. (2) Electricity needs a conductor to flow. In most electric power systems networks of power lines (e.g. metal cables) are used as conductors. These cables have a limited capacity for electricity transport and their resistance will vary with the load on the cable. In order to transport electricity and overcome the resistance, so-called *reactive power*[7] is needed, with can be generated alongside the so-called real power that we pay for. Power lines both produce and consume reactive power while transporting real power, depending on the technical characteristics of the lines and the size of the load. Because of this both the relative and absolute locations of generation and consumption of electricity need to be taken into account when balancing the network. With a change in governance, location became a more important factor.

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[6] Technically speaking this should be called impedance, but I will use the term resistance instead for the purpose of clarity.

10.1.2 History and Governance

In less than a century electric power systems developed from local small-scale systems to city-scale and from interconnected cities to nationwide, international and even intercontinental systems (Schot et al. 2003; Liscouski et al. 2004). The initial isolated systems had a relatively simple balance to maintain in terms of the amount of suppliers and clients. Over time engineers built more reliable power plants for generation, more reliable networks and on the demand side a wide variety of artifacts using electricity. They developed tight control mechanisms to govern the balance of the system. Since the task of maintaining the balance is very much contingent on the state of the technology used, these technological advances made it possible to scale up the networks, while simultaneously improving the balance.

The systems were initially governed by vertically integrated utility companies, who generated electricity, distributed it using the network, and sold it to the clients. The electric power systems were controlled from supply to demand by one authority.[8] The utility governed networks were interconnected to be able to draw upon generation capacity from other utility companies in case of local failures. Following an increase in interconnections between networks and between countries, a call for a free market for electricity grew and translated to electricity policy in large parts of Europe and North America. The vertically integrated utility companies were broken up in separate companies for generation, transmission and resale. Subsequently generation and resale did no longer necessarily happen in the same geographically region. This change in governance adds a complicating factor to maintaining the balance.

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[7] "Elements of AC systems supply (or produce) and consume (or absorb or lose) two kinds of power: real power and reactive" (O'Neill et al. 2005, p. 17). Already terminology wise this is puzzling, since reactive power is not less real than "real power". I will not explain the difference between this real and reactive power here (you can read (O'Neill et al. 2005) or search the internet for a good explanation). For my analysis it is only important to understand that both these kinds of power are needed to keep electricity power systems up and running, but that we (as consumers) only get billed for the use of real power. Reactive power is needed, for example, to transmit high amounts of real power over long distances. It can be generated, just as real power can be generated, and it can be provided or absorbed locally by respectively capacitors and inductors. Generation, however, is the main source of reactive power.

[8] "For almost a century, electricity policy and practice were geared to the vertically integrated utility. Tradeoffs between generation and transmission investments were largely internal company decisions and, for the most part, out of the public view" (O'Neill et al. 2005, p. 21).

I argued before that an electric power system needs a near-perfect balance of supply and demand and that demand is unpredictable. When governed by the utility companies both the network and the supply were controlled by one organization, which also signed the contracts with the clients. The companies were in control of the flow of electricity in their local region. Interregional connections functioned as "a backbone for the security of supply" (UCTE Investigation Committee 2004, p. 3). Under new governance, generation, transportation and re-sale became separated entities and trade is internationalized. With this so-called unbundling of the electric power systems, keeping the balance became, virtually overnight, more complicated. Apart from an unknown demand, the unbundling can theoretically lead to an unknown supply as well,[9] because the manager in charge of keeping the balance, i.e. the network manager, is no longer in charge of the power generation. Furthermore, international trade increased long-distance electricity transport, with its earlier mentioned complications concerning real and reactive power. The very cross-border power lines that were built to improve stability functioning as a back-up system were used to first argue for and then practice international trade of electricity.

10.2 The Concept of Boundary in Systems Engineering

The problems that occurred in the European electric power system are not unique to Europe. In the same year when the blackout hit Italy, a similar power outage happened in North America.[10] A couple of years prior to these events, a series of rolling blackouts hit California, just after a change in governance to a deregulated market (Roe et al. 2002). Reports were written analyzing the cascade of technical failures in the different incidents. Next to providing a meticulously mapped out sequence of events, the reports emphasized the role of non-technical aspects in the failures. In the California case, management decisions to withhold generation capacity from the market, seriously and negatively affected the stability of the grid. Following the two incidents in Europe mentioned in the introduction, the respective reports emphasized the importance of the governance of the system for the overall functioning of the system, while simultaneously drawing boundaries around engineering practice: "Although it is not strictly an UCTE[11] competence, clearly, market rules and incentives tending towards better adequacy are essential" (UCTE Investigation Committee 2004, p. 100). This demarcation of the engineering job, focusing on the technical aspects only, is reflected in the conceptual representation of systems in systems engineering. To understand the rationale for taking certain aspects into account in the systems engineering approach and not others, I will turn to (the use of) the concept of boundary in systems engineering literature. I will use my analysis of the concept of boundary to show the limits of systems engineering with regard to modeling, designing, managing and/or implementing sociotechnical systems like electric power systems.

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[9] I say "theoretically" here, but during the California energy crisis in 2000, suppliers intentionally turned of power plants in order to drive up electricity prices, indeed creating an "unknown" on the supply side.

[10] "On August 14, 2003, large portions of the Midwest and Northeast United States and Ontario, Canada, experienced an electric power blackout. The outage affected an area with an estimated 50 million people and 61,800 megawatts (MW) of electric load" (Liscouski et al. 2004, p. 1).

[11] Union for the Co-ordination of Transmission of Electricity.

10.2.1 Boundary in Systems Engineering Literature; Three Distinctions

Sociotechnical systems, I argued, consist of technical and non-technical elements. Most technical elements are composed of matter; they are concrete.[12] Following an argument made by Bunge (1979) that every concrete system is a subsystem of a greater system, with the exception of the universe as a whole, sociotechnical systems are open systems (Bertalanffy 1968). They are in interaction with an environment. An important question raised in systems engineering literature is the question how to demarcate the system from this environment, or where to draw or find its boundary.[13]

While the concept of boundary and the question where to find or draw it are considered important, the systems engineering texts are rather vague in their characterization of the concept of boundary. Following my analysis of the texts I came up with three distinctions with regard to the characterization of boundary in systems engineering: (1) a distinction between physical and metaphorical boundaries, (2) a distinction between demarcating the actual systems from their environment and demarcating possible solutions from impossible "solutions" (the design space), and (3) a distinction between system models and implemented systems.

I will use these three distinctions to point out the rationale behind the choices to consider certain elements (and relations) part of the system or certain solutions part of the design space for the system.

10.2.1.1 Two Kinds of Boundaries

(I) In our everyday life we frequently encounter *physical* boundaries. Usually they refer to things we set up ourselves, like fences, walls or even chalk lines, or they can refer to natural obstacles, like rivers and mountains. These boundaries are for example used to spatially delineate areas. We can talk meaningful about what is on one side and what is on the other side of these boundaries. While objects can be on the boundary as well, even that is, although sometimes in dispute, fairly obvious.

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[12] Here I use an understanding of technical element that excludes rules on their own, like an algorithm used in software. In order to be a technical element, I argue, these algorithms need to be encoded in concrete, and they need to be executed. In this understanding procedures, prescribing human behavior, can only be considered technical if executed.

[13] ". . . the challenge is to understand the boundary of the system, . . . and the relationships and interfaces between this system and other systems" (IEEE 2005).

(II) We also encounter *metaphorical* boundaries. An example is boundaries to what you deem socially acceptable. If someone "crosses the line" with regard to their behavior to you, they cross a metaphorical boundary. Talking in terms of locating this boundary is problematic, since "locating" refers to a spatial framing. Rather we talk about what we think is socially acceptable and what is not, about our understanding of different kinds of behavior.

When it comes to electric power systems we see both understandings of boundary surface. The European electric power system spans different spatially delineated jurisdictions. Within and between these areas we can find physical boundaries, like rivers, mountains and seas. With regard to the resale of electricity we set metaphorical boundaries for the amounts that can be sold between different places. Electricity, however, being physical, cannot be bound by metaphorical boundaries. While electricity became theoretically free to trade on an international level, it is impossible to earmark generated electricity to be delivered to specific clients following specific paths. In practice "[i]t is not unusual that in a highly meshed network, physical flows significantly differ from the exchange programs." (UCTE Investigation Committee 2007, p. 16). To be able to translate a governance based on "free" trade of electricity to a balanced network, the "metaphorical" contractual limits need to match the physical capacity of the network. The metaphorical and physical boundaries to electricity trade and transport are indirectly related.

The question of boundary in systems engineering, I will argue next, concerns primarily metaphorical boundaries, boundaries to what is (or can be) and what is not (or cannot be) part of the system under consideration. Certain elements and relations are explicitly or implicitly considered part of the system or not part of the system.

10.2.1.2 Two Uses of Boundary in Systems Engineering

Within the studied systems engineering texts, explicit references are made to the concept of boundary in two different uses, (I) as system boundaries and (II) as design constraints. This dual use of the term boundary relates to a dual understanding of systems engineering. As argued in (Ottens et al. 2005) systems engineering is understood both as "engineering of (complex) systems" and as a "systems approach to engineering". With this duality of the concept of systems engineering, a similar, and related, dual understanding of the term boundary surfaces in the systems engineering texts.

(I) In an understanding of "*the boundaries of the system*" (INCOSE 2004, p. 200) there is a "(complex) system" or "system under design" that is delineated from an environment by a boundary. Such boundaries manifest on two levels. First we need to address the question what *kinds* of elements can or should be taken as part of the system and which ones as part of the environment? In answering this question we draw metaphorical boundaries. We give a rationale for including or not including certain aspects. I will discuss this rationale in the last chapter, arguing that this rationale limits the kinds of systems that can be modeled and designed using systems engineering not including sociotechnical systems. Secondly we face the question what *particular* elements make up a system. In the case of sociotechnical systems, given their hybrid character, the boundaries of these systems cannot be solely physical. Whether we talk about the system as a conceptual representation or as the actual system it represents, in both cases we encounter metaphorical boundaries.

(II) The second use of boundary can be found in the concept of *design constraints*[14] (sometimes also called external constraints (IEEE 2005, p. 39)). These "boundaries" constrain a "design space". A design space contains solutions to a design problem. Not all solutions are feasible, or legal. Engineers look at what is technically feasible, given economical and knowledge constraints, and they look at what is legally possible, given legislative constraints.[15] The boundaries found here are boundaries to a set of solutions rather than a system. However, in limiting the solutions they can effectively constrain both what kinds of elements and what particular elements can be part of a system.

In my analysis I am mainly interested in the boundaries to the conceptual representation of a system, and the rationale behind drawing these "metaphorical" boundaries. In part, however, the answer to this question is embedded in the understanding of design constraints. I will come back to this after I introduce a third distinction between two uses of the term system (as object of (re)design) in systems engineering, referring to (I) either an (idealized) system model or (II) an existing, already implemented, system.

10.2.1.3 Two Understandings of System in Systems Engineering

The third and last distinction is a distinction between systems that are not yet designed (system models) and already existing systems. This distinction is reflected in the characterization of boundaries in the systems engineering texts. There is a mention of *defining* boundaries (INCOSE 2004, p. 105), which is used next to (or instead of) *identifying* boundaries (INCOSE 2004, p. 200).

(I) The focus in systems engineering is on designing rather than redesigning. Given that systems engineering focuses on both the engineering of systems and on a systems approach to engineering, where in the latter understanding products are engineered, it is understandable that there is a strong focus on design. The question of boundaries in this focus is geared towards including that what we need for the product to fulfill the function we have in mind for it, meanwhile protecting it from relations with an existing environment that we cannot control. These are the boundaries of a system model.

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[14] "*Design Constraints*. The boundary conditions within which the developer must remain while allocating performance requirements and/or synthesizing system elements" (INCOSE 2004, p. 278). "The project identifies and defines external constraints that impact design solutions" (IEEE 2005, p. 40).

[15] "These constraints constitute the sociopolitical climate under which commercial or industrial activities are regulated and include environmental protection regulations, safety regulations, technological constraints, and other regulations established by federal and local government agencies to protect the interests of consumers. Additionally, international, government, and industry standards and general specifications constrain enterprise and project activities and design options" (IEEE 2005, p. 69).

(II) However, the small products that systems engineering in this understanding caters for contrast with the large sociotechnical systems I introduced in this chapter. These systems have a long history, very specific local implementations, and strong mutual links with their environment. The question of boundary cannot be solely answered by focusing on the proposed, intended or designed function for the system. For one it is unclear what the function of a sociotechnical system is and secondly we cannot shield such a system from its environment. In part the existing implementation follows from decisions about boundaries taken before in designing the system model. But over time new aspects from "outside" the original design came to influence the functioning of the system. By merely resorting to *defining* system boundaries we can overlook influences that do not fit in the original system model.

This distinction and tension between the original system design and its latter use is recognized in the report that was made following the blackout in Italy:

> It must be emphasised that the original function of the interconnected systems is to form a backbone for the security of supply. To this aim the system has been developed in the past 50 years with a view to assure mutual assistance between national subsystems. This includes common use of reserve capacities and, to some extent, optimising the use of energy resources by allowing exchanges between these systems. Today's market development with its high level of cross-border exchanges was out of the scope of the original system design. (UCTE Investigation Committee 2004, p. 3)

The original focus on a robust system laid the groundwork for governance allowing international trade. A management approach sticking to an initial system model fails in the long term for sociotechnical systems. In dealing with sociotechnical systems, we need to understand what aspects play a role besides what, from an engineering perspective, we think should be system elements.

Like the first two distinctions, this distinction between these system models and implemented systems is not sharp. Not one product is designed in complete isolation from previous or other products that are already implemented in a society. However, even in that case the products are designed. When it comes to sociotechnical systems of the magnitude discussed, we do not, or hardly ever, design such systems in its entirety. The question that I will address here is whether a rationale for drawing boundaries "around" a 'system that is not yet designed' holds in the face of these changing sociotechnical systems, in specific whether it includes all elements essential for its functioning and if not whether it leaves room for such an inclusion.

10.3 Function, Control and Design, and the Limits of Systems Engineering

By focusing on the concept of boundary and the rationales behind the decision to take certain aspects into account and not others I will argue three points.

(1) First, I will argue that the systems engineering approach excludes certain elements from its conceptual representation of systems that are essential for the functioning of sociotechnical systems. (2) Secondly I will argue that the rationale behind this exclusion is based on an understanding of the behavior of its elements and their relations that leaves no space for the 'missing' elements. Therefore simply adding the elements is not an option. (3) And thirdly I will argue that because those left-out elements have a vital impact on (the functioning of) the system, a systems engineering methodology that does not and cannot take this vital impact into account is not fit for the practice of designing and managing sociotechnical systems or even just the technical part of such systems.

(1) Legislation, pictured as legislative design constraints, is seen as constraining the design space, limiting possible solutions. With this understanding of legislation it is excluded from being an element of the system under design. Nevertheless in the European electric power system changes in legislation pose a serious problem to the technical functioning of these systems. Given the scale and longevity of these systems an approach that merely understands legislation as external overlooks the mutual relation between legislation and technology. An approach to the design of systems with this conceptual understanding of legislation in mind cannot factor in the changes in legislation that might follow from technical implementations and will leave as the only option a redesign of the system after the fact, following suit. As is clear in the case of the electric power systems, this development worries the UCTE. In order to maintain a balance on the network, technical and non-technical elements need to be aligned. The changes in governance put stress on this balance.

In response to this problem (and to my argument) one may include those elements that mutually relate to the technical make-up of the system, elements that are currently not part of the possible system make-up. However, as I will argue next, the rationale behind this decision is based in an understanding of the behavior of its elements and their relations that leaves no space for the "missing" elements. Therefore simply adding these elements is not an option.

(2) To understand the rationale for delineating a system or system approach in systems engineering I turn to the understanding of three key concepts use when drawing boundaries: function,[16] control and design.[17]

10.3.1 Function

Function is a key concept in systems engineering literature. In the INCOSE handbook 42 pages are dedicated to functional analysis, which "establishes what the system must do" (INCOSE 2004, p. 5). In the IEEE standard functional analysis and functional verification make up two of the eight steps of the systems engineering process. And in the ISO standard the first two steps of the Requirements Analysis Process are "Define the functional boundary of the system" and "Define each function that the system is required to perform" (ISO 2002, p. 27). In the three texts the concept of function relates the different elements in the system. In a functional analysis, the overall system function is hierarchically split up in sub-functions. These sub-functions are in turn translated into specific solutions. The process of functional decomposition as systems engineering understands it hinges on the idea of function as a causal, predictable input-output relation, "expressed in quantitative terms" (ISO 2002, p. 26).

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[16] "Define the functional boundary of the system" (ISO 2002, p. 27).

[17] Regarding a rationale for drawing boundaries the IEEE standard brings up the question: "Which system elements are under design control of the project and which fall outside their control" (IEEE 2005, p. 40).

Such an understanding of function leaves little room for, for example, relations involving affection, expectations, reflection and intentionality, human characteristics that are not conceptualized in the systems engineering understanding of humans. Understanding such relations is essential for understanding the functioning of, for example, legislation.

10.3.2 Control

The conceptualization of function as a causal and predictable input-output relation testifies to the focus of the systems engineering approach on controlling the output of their designs. The conceptualization of function as an input-output relation works very well for the modeling and designing of purely technical artifacts where there is a relatively high level of predictability of output given a certain input. The pathways of mechanical devices, their reactions to actions follow laws of nature, and our approximations of these laws give credible predictions. The input-output model works, we can predict very complex technical situations given such models.

The sheer existence of electric power systems is only possible because of a high level of control of the processes involved in producing, transmitting and using electricity. The unknown factors in this process of control come from humans interacting with the system, humans that are "highly complex, with behaviour that is frequently difficult to predict" (ISO 2002, p. 53) and, as became apparent, from changing policies.

In the systems engineering literature it is recognized that humans can be "simultaneously or sequentially, a user and an element of a system" (ISO 2002, p. 52). Whereas in the vertically integrated electric power systems the only "unpredictable" humans were the end-users of the electricity, in the current unbundled system a new unknown factor to the stability of the network is introduced on the supply side. The operators of the power plants can theoretically withhold supply, and during the California energy crisis the operators involved actually did so. They are, however, unlike the users, seen as elements of the system that can be, at least partially, controlled through training and instructions. Instructions for their actions can be designed, like technical artifacts, using the same functional input-output models. The ISO standard correctly remarks that all humans, whether users or operators can be difficult to predict. The difference between humans in their roles of users and humans in their roles of operators is the means available for controlling their behavior.

This relates directly to the second “unknown” factor in the electric power systems, the changing policies and legislation. An understanding of control based on a law-like predictability fails for predicting the “outcome” of policies. Neither can the policies and legislation be controlled in this matter, nor can their effect on human behavior be modeled in such an understanding.

This understanding of control and function forms the rationale for exclusion of users and legislation from the “system under design”.

10.3.3 Design

Given that functional analysis in above understanding of function is central to the systems engineering design approach, it becomes clear that whether something is considered designable, is limited to whether it can be controlled. The emphasis in the systems engineering texts is on design of technology. However, if design is understood broader as “do or plan (something) with a specific purpose or intention in mind”,[18] legislation can be designed as well.[19] While it maybe a different kind of design, it does involve intentional creation. Following the UCTE’s concern about the engineering tasks, we cannot argue that we should do something that we cannot do. However, this does not mean that we can ignore it.

The understanding of the behavior of system elements following predictable input-output patterns, related through output to input based in a strict understanding of function and aiming to control all elements in the system leaves no room for adding elements that cannot be controlled in such a rigid manner. Elements whose function cannot be mapped in input–output relations that fit into technical functional decompositions. Such elements, in the light of this rationale, cannot be designed. A systems engineering approach using this rationale for drawing its system boundaries cannot include the “missing” elements.

(3) Given that in the current conceptual representation of systems in systems engineering the relation between the “missing” elements *is not* (my first argument) and *cannot* (my second argument) be taken into account, I will now argue that the use of the systems engineering approach is inadequate for the modeling, design and management of even only the “technical part” of the system.

Going back to the example, clearly the developments in the electric power system in Europe were not foreseen when the first cross-border connections were made. The influence, however, of this decision to improve the technical stability of the system by growing the network on the new policies are unmistakable. In a system as complex as the European electric power system, an approach focusing on designing only the technical elements is no guarantee for even just an adequate technical functioning of the system if potential vital impacts of non-technical elements cannot be taken into account.

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[18] An Oxford English Dictionary definition.

[19] In “A Functional Legal Design for Reliable Electricity Supply” Knops argues for an inclusion of legislation in the design of electric power systems. Legislation, as Knops (2007) argues is both designed and fulfills a function. However, to be able to argue this he stretches the understanding of these concepts beyond the understanding used in systems engineering.

While the aspects that are beyond their expertise are not completely ignored in the systems engineering conceptual representation of systems, they are relegated to the environment, the representation lacks an adequate understanding of the characteristics of these elements. And with that lack of understanding of the characteristics comes a lack of understanding of the possible relations between the excluded aspects and the elements that are part of the system. Even if the elements themselves are not considered part of the system, their impact on the system needs to be taken into account if that impact affects the technical functioning of the system, which it does in above examples of electric power systems. In the current conceptual representation this "taking into account" can only happen after the facts, following changes in the environment, not including them. This representation focuses on system models rather than existing systems with boundaries to those system based on a rationale of including the known and controllable.

Given the scale and longevity of sociotechnical systems and their hybrid character the current systems engineering approach as laid out in the central texts from the IEEE, ISO and INCOSE organizations is not adequate for the modeling, design and management of sociotechnical systems like the discussed electric power systems, despite their claims to be adequate. Furthermore the perceived limits to the engineers job in the practice of maintaining the electric power system in Europe indicates that despite a difference between engineering theory and practice[20] the limit to the conceptual representation of systems in systems engineering is, at least in this instance, limiting practice as well.

In more comprehensive continuing research I analyze different sociotechnical systems and give a more detailed analysis of systems engineering methodology, extending my argument beyond the case of electric power systems and the concept of boundary.

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[20] Engineering theory is prescriptive, it will give guidelines for the behavior of engineers, analyzing, modeling, designing and managing systems. Engineering practice deals with real-life problems, concrete situations that might or might not fit the conceptual representation at the basis of the prescriptive guidelines. Engineers can and do deviate from theory, taking approaches different from what the theory prescribes.

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Part II
Ethics

Chapter 11
Integrity and the Ethical Responsibilities of Engineers

Alastair S. Gunn

Abstract Engineering is a unique profession in many ways. It is the oldest professional activities whose practitioners can be held to account for their failures, according to publicly promulgated standards. This is partly because engineering is such a pervasive profession, but also because engineering "failures" are usually highly visible and sometimes spectacular. Engineers go to enormous lengths to avoid "failure". However, the public has little understanding of what engineers do, because they do not understand the nature of risk or the limited extent to which individual engineers are responsible for the construction, use and maintenance of their designs. Integrity is explained in this chapter as not so much a virtue but rather as a coherence or synthesis of the virtues, including an unwillingness to compromise ones values for gain. Professional integrity requires a commitment to the goals and values of the profession, and a person of integrity will not take up such a profession unless they can do so without compromising their personal values and ideals. Because of the complex nature of engineering as a profession, engineering integrity is also complex, and engineering education should emphasize this.

> A person of integrity lurks somewhere inside each of us: a person we feel we can trust to do right, to play by the rules, to keep commitments. (Carter 1996, p. 8)

11.1 Introduction

Integrity is often considered to be a virtue. As Cox et al. (2005) note, "Integrity is one of the most important and oft-cited of virtue terms. It is also perhaps the most puzzling." In the popular literature, lack of integrity is sometimes identified with

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Parts of this chapter that deal with the concept of integrity will appear in a monograph on integrity to be published by the Centre for Civilisational Dialogue, University of Malaya, in 2008.

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generally unethical behaviour, especially financial dishonesty and misuse of organizational facilities (e.g. Kay 2005). However, if having integrity means no more than acting virtuously, for instance displaying courage, loyalty, commitment, honesty etc., then there seems little point in discussing it as a separate topic. In this section, I examine a number of different accounts of integrity. I am sympathetic to the idea that it is in fact a "cluster concept" (Cox et al. 2005).

If integrity is indeed a virtue, then it is a special one. It seems to me that it is not so much a way of behaving as what holds together the commitment one has to certain ways of behaving. Everyone should have integrity. For engineers, this presents a particular challenge, because of the very nature of the profession.

11.2 Engineers and How They are Perceived

Engineering is the oldest profession. As an activity practiced for gain – a job or business – it may not be older than what is commonly referred to as "the oldest profession" – there is no way to know. However, it is the oldest skilled and paid activity for which there are publicly promulgated standards: the Code of Hammurabi. This is often referred to as a Code of Ethics, and admired for predating the earliest document on medical ethics, the Hippocratic Oath by about a thousand years. The relevant sections of the Code deal with structural engineering: they require competence and ascribe responsibility (and penalties) for failure.

The Code is an astonishingly modern document for its time. The predominant world view of the day was what we would call supernatural – events happened because that was what the gods decided. Thus was especially true in the case of crucial events such as rainfall (a matter of life or death in Babylon), the fortunes of war, and disease. The Greeks are usually held to have invented secular explanations of phenomena (i.e. science) and philosophy around the time of Thales, some 2600 years ago. However, the Code implies a basically mechanistic world view. It requires structural engineers to behave in a responsible way towards both clients and members of the public. This is taken for granted today but I imagine was not in 1750 BCE. The Hippocratic Oath, in contrast, discusses only responsibilities to clients and fellow doctors and even modern medical codes are oriented predominantly towards clients.

Engineering is the most pervasive profession. Engineers transform the environment. They drain swamps, create dams and divert watercourses; they create infrastructure such as roads, ports, railroads and airports; they devise ways of extracting resources such as minerals and energy sources, and they develop ways of generating, transmitting and using energy. They provide us with transport and communications and technology in every area from weaponry to cooking, video games to space travel. All of this is totally obvious to every engineer, but not to the public.

Engineering is the most interdisciplinary or multidisciplinary profession. At least in universities in the Western tradition, including former European colonies and countries such as Japan, an engineering education is characterized by teamwork and cooperation, with students working together to design and build projects as a team.

Engineers see themselves as pragmatic, inventive, creative problem solvers: Samuel Florman's famous *The Existential Pleasures of Engineering* (1976) is still the best account of why engineers love their work. They are primarily interested in making the world a materially better place and therefore tend to be utilitarians. They tend not to be closely involved in politics (Beder 1998; Wiewiora 2005) – according to one of the many jokes about engineers, "Real Engineers' politics run towards acquiring a parking space with their name on it and an office with a window" (Professions Jokes website). Only one of member of the US House of Representatives, and no senator, is an engineer, whereas 170 representatives are lawyers (Greenberg 2008). There is also evidence that they are more conservative and religious than average (Gambetta and Hertog 2007).

Engineers believe, correctly, that of all the professions they are both the most useful and the most misunderstood. According to one US government study, "Despite decades of social change, the general perception remains that IT workers, scientists and engineers are unusually intelligent, socially inept and absent-minded 'geeks' or 'nerds'" (Kowalenko 2000). A 2005 AAES Harris poll documented that "most of the public see engineers as creating economic growth (69% vs. 25% for scientists); preserving national security (59% vs. 29%); and making strong leaders (56% vs. 32%). However, scientists are seen more prominently as discovering the natural world (92% vs. 6%); saving lives (82% vs. 14%); and protecting the natural environment (77% vs. 17%). Science is seen as improving the quality of life more than engineering (71% vs. 22%); as caring more about the community than engineers (51% vs. 37%); and as being more inclusive of women and minorities (54% vs. 26%)" (McCarter 2005). Some of these figures are quite bizarre, especially those on "saving lives" and "improving the quality of life".

The comparison on "caring about the community" is interesting because I suspect that engineers are probably more concerned with what engineers usually call "social responsibility" than scientists. While there was much debate in the 1970 s and into the 1980 s about whether engineers have any responsibilities at all other than technical excellence and doing the best for one's client the engineering literature tends to reflect a recognition that technical and social considerations are inseparable, because technology both shapes society and is shaped by it; indeed, it is sometimes argued that, because of their expertise and knowledge of risks, engineers have a duty to be "moral heroes" (Alpert 1982). Moreover, especially in Australia and New Zealand, engineers are increasingly aware of their environmental responsibilities (Gunn and Vesilind 2005).

Perhaps one reason why the public is so ignorant about what engineers do is that it has very limited knowledge of risk. In relation to transportation, for instance, most people probably consider that flying is probably the most inherently risky. However, consider these figures: In 2005, 45 636 people died in transportation accidents in the US, almost all (43 443) on the nation's highways. Of the 616 aviation fatalities, only 22 were on airlines. Rail accidents claimed 789 deaths and 769 died in marine accidents (almost all in recreational boating incidents); 785 cyclists were killed in accidents (National Transportation Safety Board 2008, Bicycle Helmet Safety Institute 2007). It would be interesting to survey the public perception of the relative safety of these modes of transport. Media coverage is probably largely to blame. Incidents where a number (even quite a small number) of people die, such as the Minneapolis bridge collapse on 1 August 2007 (13 deaths) are treated as "disasters". Moreover, they are also treated as engineering failures, even though the engineers who designed and built the bridge had absolutely no control over its use and maintenance.

11.3 Engineering: The Unique Profession

The thesis of this section is that engineering is a uniquely demanding profession, for three reasons.

First, it is the most public profession and all engineering projects are supposed to be 100% successful. Anything that goes wrong is perceived as a "failure". Of course, all engineering structures will fail eventually but they should not fail when in I ot. trolled by engineers, which t arely is. ail eventually but they should not fail when i use, and they rarely do if their use and maintenance is controlled by engineers, which it often is not. If a plane crashes or a ship sinks, a bridge or building collapses, a life support system stops working, a brownout occurs, or, horrors, a nuclear meltdown occurs, everyone knows about it, and everyone knows who to blame. In contrast,

- Lawyers negotiate in secret, and of the cases that go to trial, on average they lose half of them.
- Doctors are expected to "lose" some patients and can bury their mistakes.
- The "helping professions" – social workers, priests, counselors, psychologists and psychiatrists operate under confidentiality and "the client has to want to change" so if s/he doesn't, it's not the professional's fault.

Secondly, professionals such as lawyers, doctors, dentists, architects and the "helping" professions":

- Mostly operate one on one, which engineers rarely do.
- Have far fewer constraints on their practice than do engineers.
- Do not run a high risk of "indirect" harm, i.e. harm to third parties as a result of their professional services to their clients, unlike engineers.
- Are therefore expected to devote themselves entirely to their clients' interests, whereas engineers have to take account of the interests of others likely to be affected.

Thirdly, the attribution of responsibility in other professions is often relatively straightforward, because those professionals are often in control of the whole process (the client's cooperation excepted). Paradigm cases include the dentist who fills your teeth, the accountant who files your tax return, the doctor or midwife who delivers your child, the surgeon who locates and removes your diseased appendix and sews you up, the lawyer who takes your case. Note that these professional services are carried out in isolation; their providers do not form a “team” and nothing that, say, the accountant does for a client has any impact on the services provided by the dentist. The attribution of responsibility in engineering is much more difficult, because, as noted, engineers, whether operating individually or as a team, are responsible for whole projects. Moreover,

- Engineering failures often have multiple and/or unknown causes.
- Engineers operate under financial and institutional constraints. All engineers are familiar with the story of the astronaut who was asked how he felt about his first flight and replied, “How would you feel if you if you were out in space and sitting on 20 000 parts each of which was purchased from the lowest bidder?”
- Engineers who design structures don’t build them, nor, as noted, do they have any control over the use and maintenance of those structures.

Thus, whatever professional integrity might turn out to be, it will likely be more complicated in engineering than in other professions.

11.4 What is Integrity?

> By “integrated life” I mean a life in which various aspects are in harmony; for example, one’s plans and policies cohere with one’s values and ideals, one’s deeds cohere with one’s words, and the whole pattern of one’s “inner” and “outer” choices cohere over time not only with each other but with others’ in a larger moral community. (Hill 1991, pp. 77–78)

As Cox et al. (2005) note, “Integrity is one of the most important and oft-cited of virtue terms. It is also perhaps the most puzzling.” In the popular literature, lack of integrity is sometimes identified with generally unethical behaviour, especially financial dishonesty and misuse of organizational facilities (e.g. Kay 2005). However, if having integrity means no more than acting virtuously, for instance displaying courage, loyalty, commitment, honesty etc, then there seems little point in discussing it as a separate topic. In this section, I examine a number of different accounts of integrity. I am sympathetic to the idea that it is in fact a “cluster concept” (Cox et al. 2005).

While this chapter is not primarily concerned with ethical theory, it is worth noting that virtue ethics theorists disagree on what exactly integrity is, or indeed on whether it is a virtue at all. Robert Solomon, a professor at the University of Texas who specializes in virtue ethics in business states,

> Integrity is not itself a virtue so much as it is a synthesis of the virtues, working together to form a coherent whole. This is what we call, in the real sense, *character*. (Solomon 1999)

In many contexts, integrity refers to a wholeness, with the implication that an object, organization, natural or human made system is intact and not damaged or corrupted, and is thus functioning properly. Integral parts or features are those that are necessary to proper functioning. Typically, the term has strong normative overtones, as is evident from the contrast with damage and corruption. Obviously, everything constructed by engineers has to have integrity in this sense.

Analogous to this is the idea of the integrated self:

> [I]ntegrity is seen as a matter of persons integrating various parts of their personality into a harmonious, intact whole. Understood in this way, the integrity of persons is analogous to the intactness of things: integrity is primarily a matter of keeping the self intact and uncorrupted. (Cox et al. 2005)

One may also speak of a whole person in a psychological sense, as if a person who is suffering from a mental illness or personality disorder, or lacks cognitive abilities, is incomplete. In another chapter at this conference, it was noted that cluster bombs are often weapons in pursuit of a policy of encouraging depopulation of a strategically important area. A proportion of the bomblets that make up a cluster bomb are deliberately designed to "fail", that is, not to explode on impact. They are also small and brightly coloured and thus attractive to children, who tend to pick them up and have their arms blown off. When this happens, whole communities will move away. An otherwise normal engineer who works on such projects would need to be able to compartmentalize his or her life to the point of not being a "whole person".

In a moral sense, a person is said to have integrity if they are true to their values and refuse to compromise them. Consider the following case:

> Chris is Chief Engineer for a local authority. He is required to represent the authority at an Environment Court hearing on a proposed expressway. Chris is not in favour of the routing of the expressway, because it will cut in half a low income housing area and destroy a local park; this conflicts with his strong personal commitment to social justice and equity.

If Chris is to be true to his personal values, it is difficult to see how he can advocate for the expressway.

There is a sense in which only I can know whether I am acting with integrity, because only I know what standards I strive to meet. As Eugene Torisky (Undated) puts it,

> There is no set of necessary and sufficient conditions accessible from outside, from a third person perspective, determining whether a person is living with integrity.

However, if a person has publicly committed herself or himself to a set of values, their reputation will suffer if they are perceived to act contrary to those values. Consider the following example, based on a real case from New Zealand:

> Kiri (name changed), a consulting engineer, is asked by the Minister of Conservation to be a member of a panel that is hearing an application under the Resource Management Act 1991 from a meat works to continue to discharge wastes into the ocean via a pipline; she believes that she will be able to persuade the rest of the panel that pre-treatment of the effluent must be improved, thus reducing the degree of water pollution, but for cultural reasons she is strongly opposed to any marine disposal of organic wastes

Kiri was (and is) a prominent member of the Maori community and advocate for traditional Maori values being incorporated into decision making and policy. Maori believe that human waste must never be discharged directly into waterways.

As well as being a sound public health policy, this practice has a spiritual basis: wastes can be purified only by being first passed through the body of the Earth-Mother, Papatuanuku.

It is often noted that we can greatly admire people with whom we disagree because they have integrity, even if we disagree with them. University of San Diego philosopher Lawrence Hinman (Undated), who calls this “personal integrity” gives the example of former Arizona Senator and 1964 Republican presidential nominee Barry Goldwater (1909–1998).

> Personally, I disagree with almost everything that Goldwater has said over the years. However, I always trusted Barry Goldwater to be Barry Goldwater, to stick by his beliefs, no matter how unpopular they were at any given moment. Goldwater didn’t change his beliefs in order to gain votes ... he always stood for something ... he fought hard for what he believed in, but he also fought fairly. And we admired him for it . . .

However,

> Because we find ourselves with so many commitments, of so many different kinds, and because commitments inevitably clash and change over time, it will not do to define integrity merely in terms of remaining steadfastly true to one’s commitments. It matters which commitments we expect a person of integrity to remain steadfastly true to. (Cox et al. 2005)

Hinman (Undated) compares Goldwater with the Unabomber, whose terrorist activities were, he claimed, designed to draw attention to his views about the dangers of modern technology, “He has certainly remained steadfast in his commitments, and has backed up his words with actions.” However, Hinman believes that the Unabomber lacked integrity, for two reasons. First, of all the virtues, courage is most directly related to integrity. This is because “integrity involves standing up for what we believe in – and that takes courage.” The Unabomber, however, was a coward, sending parcel bombs through the mail (killing three and wounding 29) and demanding that his manifesto (Kaczynski, Undated) be published but anonymously. Secondly, Hinman states (though he doesn’t argue for it) that a person’s acting on his values is not consistent with integrity if those values are not within “the range of core values which reasonable human beings can accept”.

Many writers also refer to professional integrity, which is associated with voluntarily assumed roles. As Hinman (Undated) notes, this can be seen, and expected, at many levels, from the firefighter who risks his or her life to rescue someone from a blazing building to a parent remembering to be the Tooth Fairy.

> When we grant integrity to a person we need not approve of his or her principles or commitments, but we must at least recognize them as ones that a reasonable person might be tempted to sacrifice to some lesser yet still recognizable goods.

Professionals and other role players, unlike individuals acting in a private capacity, cannot just be guided by their private beliefs, and given the nature of their profession, engineers may be said to have special responsibilities, as the following case suggests:

> Students (“Aggies”) at Texas A & M had a tradition, beginning in 1907, of building a bonfire associated at the time of their annual football game against traditional rivals the University of Texas. Originally it no more than a trash pile, gradually evolving

> into a 20 m complex "wedding cake" structure there is an impressive photograph at http://en.wikipedia.org/wiki/Aggie_Bonfire. In 1999, the bonfire collapsed during construction, leaving 12 dead and 27 injured. The bonfire was designed and supervised by engineering students but no professional engineers were involved.

It is unclear how responsibility for this disaster should be apportioned. It was an official university event, and the university lent tools and trucks to the students, but did not exercise any supervision. Despite the huge size and complexity of the structure, it does not appear that any professors from the College of Engineering made any attempt to advise on its design and construction. Somewhat belatedly, the Texas Board of Professional Engineers stated in 2000 that "the Aggie Bonfire met the requirements to be considered a complex construction project that should be regulated by state engineering laws" (Wikipedia 2008). It is submitted that a number of persons (not just engineers) failed to exercise their professional obligations in this case and, in this sense, did not observe the requirements of integrity.

Furthermore, and perhaps more so than any other profession, there is a sense in which an engineer is always "on duty", as the following 1995 case from New Zealand illustrates:

> Fourteen people, on a college trip, died when a Department of Conservation (DOC) scenic viewing platform 40 m over a small stream, Cave Creek, collapsed. This was not exactly an engineering failure because no qualified engineer (or even builder) was involved in design, approval or construction. The platform had significant design faults, exacerbated by the fact that some of the sound designed safety features were not actually built. The Commission of Enquiry into the disaster noted that DOC had acted illegally and negligently, but emphasized that it was under-resourced and forced to "cut corners" and "forced to accept poor quality standards"

Perhaps, though the Institution of Professional Engineers in New Zealand might consider taking on a watching brief for potentially dangerous structures especially where, as in this case, no building permit was ever sought. While, as noted, no engineers were involved in this project, no doubt a number had visited it but apparently did not notice its deficiencies as a structure. But, it might be said, an engineer on vacation is just a tourist and should not be expected to be constantly on the look out for risks.

In so far as we value integrity for its own sake, we do so because people who have it in a high degree are prepared to stick to their values regardless of whether it is in their interests to do so. If we ourselves have made sacrifices for what we believe in, we are entitled to feel a modicum of pride in ourselves. But as well as intrinsic value, integrity is important because it makes the difference between merely having a theoretical commitment to virtues and following them in practice.

Finally, lack of integrity is often seen as a major reason for organizational failure. It is not that those involved do not know what they ought to do, but that they don't have, in Britspeak, the bottle to speak up. From St Peter in the Bible, who denied that he was a follower of Jesus, to the engineers who kept silent about the Challengers' O-rings, people have failed to do what they knew to be right; have exhibited what

Aristotle termed *akrasia*, moral weakness. Carter (1996, p. 8), who believes it to be "the first among the virtues": puts it well:

> Indeed one reason to focus on integrity as perhaps the first among the virtues that makes for good character is that it is in some sense prior to everything else: the rest of what we think matters very little if we lack basic integrity, the courage of our convictions, the willingness to act and speak in behalf of what we know to be right.

For professionals, this ideal means that their professional and personal values and behaviour coincide. But professional life is immeasurably more complicated than personal life, and, as I have argued, engineering professional life is more complicated than that of other professions. Probably, it requires more compromises. It certainly requires more education.

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Chapter 12
Prioritising People: Outline of an Aspirational Engineering Ethic

W. Richard Bowen

Abstract One of the greatest challenges for engineering is the development of an aspirational ethical foundation in the profession that redresses the present imbalanced prioritisation of technical ingenuity over helping people. This article presents an analysis that seeks to provide a basis for such reprioritisation. It begins with a brief account of ethical analyses that have traditionally been applied to engineering. Some salient aspects of medical ethics and business ethics are then considered. An aspirational engineering ethic needs to overcome the limitations of the traditional ethical views and to learn from the analysis of ethics in these other professions. The present outline is based on two philosophical sources. Firstly, writings that lie somewhat outside what is conventionally regarded as the mainstream of ethics, especially those of Buber and Levinas, but which contain profound ethical insights that can provide an important balance to prevailing views. Secondly, recent writings that build on the philosophical mainstream in especially imaginative and useful ways, especially MacIntyre's concept of a *practice*. Specific outcomes of the proposed aspirational engineering ethic for both individual engineers and engineering institutions are identified.

12.1 Introduction

At its best, engineering changes the world for the benefit of humanity. However, the great technical successes of engineering and the enormous satisfaction that engineers can gain from the purely technical aspects of their work lead to a danger – that engineers forget that technical ingenuity in itself is not the goal of engineering. The unfortunate tendency to prioritise technical ingenuity has a pervasive presence in modern engineering, we become lost in "the labyrinth of technology". [1]

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[1] The title of a book by W.H. Vandenburg (2000) Toronto: University of Toronto Press.

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This tendency has two main types of undesirable outcome. Firstly, the development and application of complex but inappropriate technology. A very significant example is the design, manufacture and use of military equipment and weapons. Many of the weapons produced contravene international conventions and treaties as they cause indiscriminate injury and death. Almost a third of engineers in the US are reported to be employed in military related activities (Gansler 2003). Secondly, technology that could alleviate great human suffering is available but is not being applied as extensively or as rapidly as it could be. A critical example is that 1.1 billion people do not have safe drinking water and 2.4 billion people have no provision for sanitation, even though suitable engineering is readily available. As a result, 6,000 people die *every day* from water-related diseases, mostly children under the age of five (UNESCO 2003).

The current imbalanced prioritisation in engineering presents us with a particular challenge:

> The challenge for us is to develop an aspirational ethical foundation in our profession and to redress the present imbalanced prioritisation in engineering of technical ingenuity over helping people. (Royal Academy of Engineering 2007a)

That is, we need to develop a convincing and aspirational foundation for the *overall* ethical aim of our profession. The present chapter aims to contribute to such a reprioritisation. It begins with a brief account of ethical analyses that have traditionally been applied to engineering. Some salient aspects of medical ethics and business ethics are then considered. An aspirational engineering ethic needs to overcome the limitations of the traditional ethical views and to learn from the analysis of ethics in these other professions. The present outline is based on two philosophical sources. Firstly, writings that lie somewhat outside what is conventionally regarded as the mainstream of ethics, but which contain profound ethical insights that can provide an important balance to prevailing views. Secondly, recent writings that build on the philosophical mainstream in especially imaginative and practical ways.

12.2 Ethical Viewpoints

Ethical analysis of engineering has tended to adopt consequentialism as a default position, due to its apparent simplicity and quasi-empirical basis combined with an inadequate appreciation of its philosophical limitations. These limitations include the incommensurability of consequences, the contingency and indeterminacy of outcomes, that in principle any action is allowed, that there is no provision for justice, and that the analysis is impersonal. Contractualism has also been widely applied in engineering ethics. Some engineers would view this as a default justification of their activities: if some aspect of their work is not explicitly legally forbidden then it is regarded as acceptable. The widespread development of weapons that contravene international law shows that even this minimalist view is not always adhered to. More generally, contractualism tends to secure present arrangements rather than promoting high ethical aspirations. Furthermore, the most disadvantaged individuals and nations are often excluded from agreements. An emphasis on duty, deriving in philosophical terms from Kant, has also played a significant role in the development of engineering ethics, especially as a background to the formulation of ethical codes. The respect for persons inherent in a duty approach has much to offer engineering ethics. However, the dense argumentation often associated with this approach is a barrier to its more widespread adoption by engineers, as is the apparent lack of empirical input in its most usual formulations. Virtue based approaches have had less influence on engineering ethics.

Engineering ethics can learn from the emphasis on the person in medicine. Modern medical ethics differs in two striking ways from the generally adopted approaches to engineering ethics. Firstly, there is a great emphasis on the *individual*, the patient, affected by the doctor's actions. Secondly, the doctor is emphatically *personally* accountable for decisions (General Medical Council 2006). In contrast, engineers tend to view their work as affecting populations and engineering responsibility is often diffused within an organisation. Furthermore, a key feature of the difference between the work of doctors and engineers is *proximity*. Those affected by a doctor's work are usually in his or her immediate proximity, whereas those affected by an engineer's work are frequently distant in both place and time.

Insights from business ethics are also of great relevance to engineering, especially as engineers are frequently employed in commercial organisations. Two concerns that have become apparent in the study of business ethics need specific attention in the development of an effective approach to engineering ethics. Firstly, a tendency for employees to bracket their personal ethical values, a suppression of ethical responsibility that seems to be a feature of goal- and end- oriented work environments. Secondly, social science studies of cognitive moral development which suggest that employees often function at a level of minimally acceptable ethical behaviour rather than aspiring to the highest achievable levels (Crane and Matten 2004).

The formulation of an aspirational engineering ethic needs to take into consideration the current imbalance in engineering priorities, the limitations of the philosophical analyses previously applied to engineering ethics and the lessons arising from medical and business ethics. There is a particular need to restore the priority in engineering of helping people over technical ingenuity for its own sake. There is also a need to find a formulation and vocabulary that are less formidable than those of the traditional mainstream philosophical writings. Ideally, such a formulation would build on the personal commitment to ethical behavior that most people exhibit in their personal lives. In these contexts it is worth noting that a number of philosophers have also been concerned that the mainstream of philosophical ethics has been too abstract, "What is lacking in these theories is simply – or not so simply – the person" (Stocker 1997, p. 71), and that their emphasis on systems over people can lead to serious injustices (Anscombe 1997).

12.3 The Priority of People

The challenge for any aspirational ethic is to find ways to express and promote the sympathetic side of our nature. In the context of engineering ethics it is beneficial if such expression also provides a means of valuing technical activities. Such a means has been provided by Buber's description of human activities in terms of the "primary words" *I-It* and *I-Thou* (Buber 2004). Buber was concerned with an individual's relationship to other people and to the natural world. It is especially useful in the present context that he develops a philosophical approach to these relationships that is based on everyday experience of dealing with others and the physical world.

The world of *I-It* is that of *experiencing* and *using* with the aim of "sustaining, relieving and equipping of human life" (Buber 2004, p. 36). This includes the world in which the engineer usually would be seen as carrying out his or her professional tasks, the world of mathematical analysis and physical exploitation of materials and processes. The world of *I-It* is where a man or woman:

> . . .works, negotiates, bears influence, undertakes, concurs, organises, conducts business, officiates . . . the tolerably well-ordered and to some extent harmonious structure, in which, with the manifold help of men's brains and hands, the process of affairs is fulfilled. (Buber 2004, p. 39)

Buber observes that both in the life of an individual and with the progress of history there is a progressive augmentation of the world of *It*, "the world of objects in every culture is more extensive than that in its predecessor" (Buber 2004, p. 35). Indeed, the world of knowledge is structured around *It*, and this is essential to our existence: "You cannot hold on to life without it, its reliability sustains you" (Buber 2004, p. 31). However, in Buber's analysis the world of *I-It* is severely limited, "he who lives in *It* alone is not a man" (Buber 2004, p. 32) and indeed holds inherent dangers: "If a man lets it have the mastery, the continually growing world of *It* overruns him and robs him of the reality of his own I" (Buber 2004, p. 41) for, "The primary word *I-It* can never be spoken with the whole being" (Buber 2004, p. 11). That is, fulfilment in life, living a fully human life, comprises more than just experiencing and using.

The world of *I-Thou*[2] is characterised by *meeting.*Buber's writing is more poetic than is usual in philosophical works, and he illustrates his core meaning in the following progression:

> Consider a tree. . . I can look on it as a picture. . . I can perceive it as movement. . . I can classify it in a species and study it as a type. . . I can subdue its actual presence and form so sternly that I recognise it only as an expression of law. . . I can dissipate it and perpetuate it in a number. . . In all this the tree remains my object. . . It can, however, also come about, if I have both will and grace, that in considering the tree I become bound up in relation to it. The tree is now no longer an *It*, I have been seized by the power of its exclusiveness. (Buber 2004, p. 14)

What is significant here is the possibility of a close relationship engendering *care* for the other. Buber chooses a tree, an inanimate object, as his primary example. In the case of a person the relationship is more intimate for the response of the other may be explicit.

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[2] "Thou" corresponds to "Du" in the original German or to "Tu" in French. Its use has fallen out of modern English. However, just as the corresponding words in modern German and French, it was earlier used to indicate a close relationship with the person addressed.

Further, Buber notes that, “The relation to the *Thou* is direct. No system of ideas, no foreknowledge, and no fancy intervene between *I* and *Thou*” (Buber 2004, p. 17). Most importantly, “The primary word *I-Thou* can be spoken only with the whole being” (Buber 2004, p. 17). This is the essence of a fully human way of being. However, vigilance is always necessary and especially so in highly technological societies, *for the development of experiencing and using comes about mostly through the decrease of an individual’s power to enter into relation*. Even when relation has been fulfilled there remains the danger that the *Thou* will degenerate to an *It*.

Buber’s unconventional writing style makes demands for imaginative reflection on the part of the reader. However, it provides a number of insights of value in the development of an aspirational engineering ethic. It is clear that Buber has provided a vocabulary and approach that enables a discussion of important aspects of human life. The *I-It* world would be recognised by engineers as a description of the conditions under which they commonly carry out their professional activities. Buber rightly emphasises the importance of technical knowledge and technical activities. The development of the *I-It* concept also provides an account of the unease that engineers may feel about being restricted to technical aspects alone in the course of their employment. *His description of the progressive augmentation of the world of It is a means of expressing the danger of becoming lost in the labyrinth of technology.*

Buber’s description of *I-Thou* interactions has the exceptional advantage of encompassing both person/person and person/natural world (environmental) relationships. Engineers would certainly recognise *I-Thou* experiences in their interpersonal relationships and most likely in their interaction with the natural world. However, they may not have considered such *I-Thou* experiences as being part of their engineering activities. This vocabulary and approach should encourage engineers to re-evaluate their attitudes to the ethics of their professional activities. This could occur through the *I-Thou* relation providing a conceptual grounding for desirable goals. For example, the *I-Thou* concept can express concern for the individual persons affected by engineering activities, rather than the statistical concern of consequentialism and contractualism or the impersonal concern of duty. Furthermore, such a vocabulary can raise the sensitivity of engineers to the environmental consequences of their activities.

An even stronger formulation of our responsibilities has been provided by Levinas, who reverses the philosophical tradition that has seen ethics as arising initially out of self-interest by instead prioritising the demands that an other can make on us, which he designates by the strikingly visual notion of *the face*. He describes an ethical act as being defined by “a response to the being who in a face speaks to the subject and tolerates only a personal response” (Levinas 1969, p. 219). This view is based on the proximity of others generating a sensibility that leads to their needs taking priority. He even writes of the needs of others making us hostages, that we are above all responsible for others, indeed summoned to responsibility, even to the extent of substituting their needs for ours (Levinas 1981, pp. 117 and 184). Levinas does not develop his philosophical arguments in a conventional way but his message is nevertheless clear. In simple terms, and changing the metaphor, we need to hear the voice of others saying, “It’s me here, please help me!” According to Levinas the individual response should be, “here I am for the others” (Levinas 1981, p. 185).

It may be considered that Buber’s notion of *I-Thou* relationships demands too much for an engineering ethic. It assumes a close proximity and there is certainly a limit on the number of such relationships that an individual can maintain. However, it has been proposed that a third type of interaction, an *I-You* relationship, may be an appropriate description of many encounters in modern society (Cox 1965, p. 61), especially in modern urban life. Such an *I-You* relationship recognises the uniqueness and integrity of the person encountered but acknowledges that the interaction may be brief and lacking intimacy. There is a great variety of such relationships, but in all there is an aspiration to ensure that the person is not used in a way that leads to degeneration to an *I-It* interaction. Simply put, other people have names. In some cases reciprocity may be maintained, such as in simple commercial exchanges. In others one of the parties may make a response *beyond reciprocity*, for example in helping another in difficulty. In both cases, spatial proximity is experienced, but only for a short time.

It may be proposed that the articulation of an aspirational engineering ethic can be facilitated by extending the *I-You* vocabulary *beyond proximity*, to include a relationship with people who may be distant in place and/or distant in time. Thus, the task of the engineer may be viewed as the development of technical knowledge and technical activities, the world of *I-It*, in response to an *I-You* concern for those benefiting from the technical advance. The people affected by the activities may be located far from the place where the engineering work is conceived and planned. In some cases, they may be far from the place where the engineering artefacts are constructed or even far from the place where the completed, engineered artefacts are located. Again, people may be affected at some future time, perhaps at some distant time. Otherwise expressed, and extending Levinas’ notion, the engineer must visualise *the face* of those affected by his or her activities even if they are not physically present. This visualisation of *the face* should be accompanied by the internal hearing of the voice who says, “It’s me here, please help me!”.

12.4 The Practice of Engineering

There has been a tendency for published accounts of engineering ethics to focus on ethical dilemmas, leading to what could be termed a “quandary” view, or even a “catastrophe” view. Alternatively, it might be proposed that the key ethical features of an individual’s life are not responses to quandaries, but rather the adoption of a positive way of living the very nature of which helps to minimise the occurrence of such difficult situations. Such a virtue approach to ethics requires careful consideration in the development of an aspirational engineering ethic.

A focus on virtues is certainly a way of expressing and promoting the sympathetic side of our nature, of cultivating the sensitivity envisaged by Buber and Levinas. MacIntyre (1985) has traced the historical development of the philosophical discussion of virtues. Like Buber and Levinas, he has argued that other traditional approaches have placed too little emphasis on persons, and further that such approaches also placed too little emphasis on the contexts of these persons' lives. However, there is one feature of virtue ethics that requires special attention if it is to be successfully applied: that the various proponents of this approach provide different listings and prioritisations of qualities considered to be virtues.

MacIntyre's interpretation of these differing accounts is that virtues can only be fully identified in the context of what he terms a *practice*. He gives a very specific definition of what he means by a practice:

> . . .any coherent and complex form of socially established cooperative human activity through which goods internal to that form of activity are realised in the course of trying to achieve those standards of excellence which are appropriate to, and partially derivative 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. (MacIntyre 1985, p. 187)

Among his examples of a practice are the game of football, chess, architecture, farming, and the enquiries of physics, chemistry, biology and history. MacIntyre makes a distinction between *internal goods* and *external goods*. *Internal goods* need a practice for specification and can only be fully understood by participation in that practice. In the context of a game of chess these might be particular kinds of analytical skill, strategic imagination and competitive intensity. The achievement of such goods involves standards of excellence and obedience to rules. *External goods* are contingently attached to activities and could be achieved in other ways. Examples include prestige, status and money.

This analysis allows MacIntyre to postulate a new definition of virtue:

> A virtue is an acquired human quality the possession and exercise of which tends to enable us to achieve those goods which are internal to practices and the lack of which effectively prevents us from achieving any such goods. (MacIntyre 1985, p. 191)

He regards such virtues as defining the relationships between people who share the purposes and standards of a practice. He further regards truthfulness, justice and courage as being prerequisite virtues for any practice. The inclusion here of courage appears at first surprising. However, it has special relevance in the present context following from the explanation, "We hold courage to be a virtue because the care and concern for individuals, communities and causes which is so crucial to so much in practices requires the existence of such a virtue" (MacIntyre 1985, p. 192).

MacIntyre draws attention to several key features of his analysis. Firstly, that a practice is more than just a set of technical skills. Secondly, that no practices can survive for an extended time unless they are sustained by *institutions*, of which he gives clubs, laboratories and universities as examples. He regards institutions as characteristically concerned with external goods. They also give practices an historical dimension. Thirdly, as is clear from the initial definition, practices have an aspirational aspect. Their goals are subject to continuous extension. Fourthly, that if the pursuit of external good were to become dominant, the concept of the virtues would suffer attrition and even total effacement. That is, the nature of the world is such that unbridled pursuit of wealth, fame or power leads to loss of truthfulness, justice, courage and other desirable qualities.

MacIntyre considers architecture as a practice, and though engineering is not mentioned in *After Virtue* it seems clear that it fulfils the requirements of his definition. There are specific *internal goods* in the profession of engineering, in particular those associated with the accurate and rigorous application of scientific knowledge combined with imagination, reason, judgement and experience. These give personal satisfaction as well as providing a framework of excellence on which further activities can be based. The *external goods* of engineering particularly include technological artefacts. Further, considerable economic benefits are generated for the broader societies in which engineering activities take place. The various forms of *institution* that provide continuity and coherence to the practice of engineering include professional engineering associations, universities and commercial enterprises. These institutions can play a key role in promoting the aspirations of individual engineers, in *systematically extending* their practice.

Though *ends* are mentioned in the definition of a practice, it is curious that MacIntyre subsequently writes very little about them. This is maybe because the examples that he develops, such as chess and portrait painting, do not have ends providing substantial physical benefits to the broader community. *The end of engineering may be described as the promotion of human flourishing through contribution to material wellbeing.* Here a cautionary note should also be sounded. MacIntyre noted the dangers of too great a focus on external goods such as wealth, fame or power. In the case of engineering there is also a danger of focussing too greatly on the external goods of ingenious technological artefacts. In MacIntyre's terminology, technological artefacts should be considered as contingent products, external goods, in the pursuit of the end of human flourishing. *Hence, the present imbalanced prioritisation in engineering of technical ingenuity over helping people may be considered as arising from mistaking the external goods of the practice for the real end of the practice.*

It is also pertinent to inquire about which virtues are appropriate for the practice of engineering. MacIntyre defined virtues in terms of the enabling of achievement of goods internal to practices. In the case of engineering this definition would benefit by being broadened to include the enabling of the achievement of ends. MacIntyre has suggested that truthfulness, justice and courage are prerequisite virtues for any practice. An authoritative statement of the further virtues is given in the UK Royal Academy of Engineering's *Statement of Ethical Principles* (Royal Academy of Engineering 2007b). Though the Academy refers to them as principles, they clearly merit consideration as virtues on the understanding presented here:

> *Accuracy and Rigour* Professional engineers have a duty to ensure that they acquire and use wisely and faithfully the knowledge that is relevant to the engineering skills needed in their work in the service of others.
>
> *Honesty and Integrity* Professional engineers should adopt the highest standards of professional conduct, openness, fairness and honesty.

> *Respect for Life, Law and the Public* Good Professional Engineers should give due weight to all relevant law, facts and published guidance, and the wider public interest.
>
> *Responsible Leadership: Listening and Informing* Professional Engineers should aspire to high standards of leadership in the exploitation and the management of technology. They hold a privileged and trusted position in society, and are expected to demonstrate that they are seeking to serve wider society and to be sensitive to public concerns.

As part of the introduction of these principles or virtues, the *Statement* contains a cogent and challenging description of what in MacIntyre's terminology might be considered *the practice of engineering*:

> Professional engineers work to enhance the welfare, health and safety of all whilst paying due regard to the environment and the sustainability of resources. They have made personal and professional commitments to enhance the wellbeing of society through the exploitation of knowledge and the management of creative teams.

These principles or virtues and the description of the practice of engineering provide a key component in the development of an aspirational engineering ethic. What is most needed in addition is a more positive commitment to prioritising people, to work for the wellbeing of all *individuals* affected by engineering activities. There is a danger that consideration of the "welfare, health and safety of all" or the "wellbeing of society" can be interpreted in terms of a calculus of consequences or even a too narrowly defined contractualism. The terms "all" and "society" need to be interpreted both more specifically, in terms of persons, and also more generally, beyond the boundaries of nation states at which societies tend to draw their limits. *Such terms need to be understood as referring to both human collectivity and the human quality in each individual.* Here concepts such as those of Buber's *I-Thou* relationships, *I-You* relationships or Levinas' *face* can provide vocabularies encouraging sensitive engagement.

12.5 The Life of the Individual Engineer

MacIntyre's virtue based description of practices and institutions provides the basis for a coherent ethical description of engineering as a profession. A further issue that needs to be addressed is how ethical coherence can be achieved for an individual engineer. This is a topic needing specific attention due to the tendency for employees to bracket their personal ethical values while at work in goal- and end- oriented organisations. The adoption of a genuinely aspirational engineering ethic would be greatly facilitated if this susceptibility could be minimised. Here a simple observation is very pertinent – that a person who genuinely possesses a virtue would be expected to manifest it throughout the range of his or her activities, both professional and personal. This is a very important benefit of virtue-based approaches to ethics. In contrast, rules and duties tend to apply to rather specific sets of circumstances.

The suggestion is that we need to view our ethical lives as a unity. Such coherence of professional and personal affairs would give to each of us a greater consistency in ethical decisions. In developing such a viewpoint we can refer to the way that

MacIntyre and others have drawn attention to the narrative nature of human lives. In trying to understand ourselves we imagine ourselves within a story. We do not view our lives as a series of unconnected episodes, as simply a chronology. Instead we consider the intentions, situations and history of our activities. We have a degree of authorship of our lives. We can set aims and choose directions, though we are of course subject to many unpredictable occurrences including the actions of others. The narrative in which we place ourselves gives intelligibility to our lives. Our degree of authorship also makes us accountable not just for isolated events but for our overall direction and the cumulative effect of all activities in which we take part. This approach is closely related to the ancient view of ethics as having as an aim the leading of an accomplished *life*.

A narrative view of life is recognised in everyday language. The description of someone having "lost the plot" is used to indicate loss of judgement in a given situation, usually a situation of significant importance in an individual's life. We can recognise this in our own lives and in the lives of others. Indeed, recognition of the need for and the importance of a cumulative narrative in the lives of others can provide a powerful underlying support for providing care. We can become aware of other's stories. As Ricoeur has written, "We tell stories because in the last analysis human lives need and merit being narrated. This remark takes on its full force when we refer to the necessity to save the history of the defeated and the lost" (Ricoeur 1984, p. 75).

Engineering ethics has been most frequently approached as seeking an answer to questions of the type, "What should I do?" or more specifically, "Which option should I choose?". A virtue approach to engineering ethics, with the virtues defined within the context of the professional practice of engineering, indicates a further important type of question, "What underlying professional characteristics should I cultivate as an engineer?" The challenge of considering one's life as a narrative unity suggests further questions, "Of what story am I a part and how do I wish to develop this story?" However, there is another crucial way in which the approaches differ. The question "What should I do?" can lead to a further series of investigations and questions of the type, "What are the reasons for doing...?" Due to the complexity of engineering, indeed the complexity of life, there are a myriad of such investigations and questions. In the case of consequentialism, contractualism and even, to a large extent, duty based approaches to ethics such questions will in theory have an impersonal answer. However, in practice, at some point the engineer has to make a decision, to make one of the available options his or her own. Virtue ethics in a narrative context to the greatest extent makes clear that the engineer then has to be prepared to make the statement, "*I* am responsible for...".

12.6 Practical Outcomes

This article has made the case for the priority of people, for the continuity and coherence provided by a practice, and narrative unity in the development of engineering ethics. As both engineering and ethics are practical, engineering ethics should be doubly expected to have practical outcomes. Such outcomes may occur at both the institutional and individual level.

Important outcomes at the institutional level suggested by the aspirational ethic outlined include:

In education Recruitment of students and the overall tone of engineering courses should give greater emphasis to the goal of benefits in terms of the quality of life of individuals. Personal responsibility for the results of professional activities should be emphasised.

Professional associations Professional codes of national engineering associations should progressively incorporate increased degrees of compassion and generosity. The creation of an effective international engineering organisation to promote aspirational practice for all across national boundaries would be beneficial.

Industry and work practices The more widespread adoption of aspirational codes of conduct in industry should be promoted. Career development plans that bring employees into closer proximity with end-users for at least part of their working life should be encouraged.

However, the outcomes for the individual engineer are the most significant. Each and every engineer needs to take an active role in considering the ethical implications of his or her work. It is not credible to be an engineer who "does what he is told but does not know what he is doing". The special capabilities for promoting well-being which engineers possess bring special responsibilities. Buber noted the especially demanding and enhanced responsibility inherent in the asymmetric relationships which teachers and doctors have with their pupils and patients (Buber 2004, pp. 98–99 (Postscript)). Such an enhanced responsibility to provide care applies likewise to engineers. Engineers have a responsibility *for* those affected by their activities. Our aspiration as engineers should be to hear the voice in need which cries, "*It's me here!*" and to reply "*Here I am, how can I help you?*".

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Chapter 13
Ethical Principles for Engineers in a Global Environment

Heinz C. Luegenbiehl

Abstract Engineering ethics has undergone an evolutionary process from a national perspective to a recognition that global concerns matter in engineering. However, this has been an additive process which is still generally based on an American model of ethical theory as a foundation, with professional ethics as the outcome. Neither of these elements can be expected to be understood or accepted on a worldwide basis. This chapter therefore argues that a new foundation for a global engineering ethics must be established, one which derives ethical principles from the nature of engineering and the universal use among engineers of the faculty of reason. Arguments are presented why this is the appropriate approach given the contemporary work environment of engineers. A number of fundamental engineering ethics principles are derived.

13.1 Introduction

Traditional engineering practice has been relatively localized in specific cultural contexts. Ethics education for engineers, in the instances where it actually occurred, could therefore legitimately be based on the background conditions existing in a particular society and assume a general familiarity with the value structure of that society among learners. Starting in the latter part of the twentieth century, this was no longer the case. The previously existing conditions of engineering practice underwent significant changes, these including the coming to dominance of multinational corporations, the location of plants by national corporations in other countries, the increasing international mobility of engineers, and the establishment of international supplier and customer systems. While some texts on engineering ethics ignored these developments, others responded by adding one or more chapters regarding issues sometimes encountered by engineers dealing with foreign entities, such as the

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question of grease payments (Martin and Schinzinger 1983, 2005). Such responses, while a legitimate first attempt at dealing with the new international environment of engineering, did not however address the need for a fundamental evaluation of how ethics should be conceptualized if it was no longer sufficient to look at international issues from within the framework of a national perspective.

Necessary is instead a rethinking of engineering ethics at a more fundamental level, one where the global environment of engineering is the starting point for discussion, rather than a mere addition. This, in turn, requires setting aside particularized national assumptions about the practice of engineering, as well as avoiding the theoretical foundations of practical ethics which arise out of specific cultural traditions, since these will likely either be unfamiliar or unacceptable to engineers from other cultures. Only those claims which can be justified on the basis of the nature of engineering itself, or are relatively universal human characteristics, are legitimate starting points for a global discussion about the nature of engineering ethics.

The work in this chapter forms part of a larger project of the author's, one focused on integrating business ethics, engineering ethics, and cross-cultural concerns into an ethical foundation for engineers working in the contemporary environment of technology. Within that project, the current discussion focuses on the recognition that contemporary engineering operates in an international context requiring a globally acceptable foundation for an engineering ethics. I will argue that this foundation cannot be provided by either an approach of ethical theory or one of casuistry. Instead, a set of engineering ethics principles will be proposed based on the nature of engineering activity and the universal use of reason in engineering.

13.2 A Global Approach to Engineering Ethics

Given the role of engineers and engineering in the contemporary world, it is my intention to take a global approach to engineering ethics. While this may make immediate sense to younger engineers, it is in fact a departure from the tradition. Engineering ethics is a relatively new area of study which originated in the United States and has only begun becoming significant in other parts of the world, largely due to the establishment of engineering program accreditation standards in other parts of the world. Because the American model of engineering ethics was first, it has become somewhat of a global standard. The problem is that the American model carries within it some uniquely American or Western features, such as an emphasis on ethical theory and on the ideal of professions (Luegenbiehl 2004). Some of these features are not readily, or not appropriately, adaptable to other parts of the world. It is thus necessary to begin anew in the development of an appropriate engineering ethics. One could, of course, begin with a cultural perspective other than the American one, but that would raise the same issues of being too focused on one cultural perspective at the expense of others. My approach is instead to begin the development of an engineering ethics without any cultural presuppositions, but to raise questions of culture at a later stage of analysis.

In thinking about engineering ethics independently of a particular cultural background, it is instead helpful to consider engineers to be a community with a shared set of values. A bond is created among engineers based on these values, whatever their nationality or cultural background, just as there typically exists a set of common core values in other types of societies. These values provide for an element of trust among the group's members, and a legitimate defense against forces that would undermine the appropriate application of technology. In dealing with engineering ethics in a global context it will thus ultimately be necessary to describe this actually existing value structure, although that is beyond the scope of the current discussion. For now I take it as an indication that a global approach will emphasize the interplay between the descriptive and normative dimensions of ethics. That is, unlike some philosophical approaches to ethics, it holds that real-world conditions must be accounted for by developers of a global engineering ethics.

13.3 Foundations for Analysis of Ethical Issues

13.3.1 Problems of Ethical Theory

Many of the texts on engineering ethics currently available begin with a discussion of philosophical ethical theories (Martin and Schinzinger 2005; Baura 2006). Such theories have been developed over several centuries to serve as foundational principles for ethical analysis. Dealing with specific ethical issues that arise in the world has consequently become known as applied ethics, indicating that procedurally it is the ethical principles which form the basis for discussion. Recently there has begun a trend away from this form of applied ethics because of the difficulty students find in applying these general principles and because there continues to be serious disagreement among philosophers as to which principle or set of principles should be used.

When ethics is viewed on a global basis, these problems become magnified, because foundational ethical principles as the major source for ethical decision-making are a specific product of the Western philosophical tradition. Consequently, many students not familiar with that tradition have a difficult time understanding that approach in the first instance, before it even becomes a question of whether or not they agree with a particular instantiation of the approach. Courses in applied ethics in such cultures thus face the danger of becoming an introduction to Western philosophical thought at the expense of actually considering specific applied issues. Fundamental disagreements about the appropriateness of utilizing ethical theory, perhaps based on the claim that ethical theory seeks to operationalize a uniquely Western perspective and impose it on the rest of the world, also stand in the way of reaching agreement on how specific ethical issues should be resolved. This discussion, in addressing a global perspective, will therefore avoid reference to specific ethical theories or to the identification of duties based on particular religious/philosophical traditions.

13.3.2 Problems of Casuistry in a Global Context

In recent texts on applied ethics casuistry, or the building up of theoretical framework through the study of specific cases, has become an increasingly common approach (Harris et al. 2005). As a foundation for the study of ethics by those with a common cultural background this is a useful tool because it can be assumed that to a large extent learners share a common approach and a common moral outlook. However, when engineers with diverse cultural backgrounds are put together, this shared bedrock for analysis will be missing and lead to divergent interpretations and decisions. It will also be difficult to separate general social values or matters of custom from more fundamental ethical concerns. Further, fundamental problems of differing interpretations of the same vocabulary will also exist. Rather than aiding communication, the case study approach in a global environment will actually hinder the development of an ethical framework. This can be seen in the difficulty foreign engineering graduate students in America often have in adapting to local normative standards regarding such issues as plagiarism. In some cultures, for example, the process of copying another work is seen as honoring the original author rather than a form of theft. In others, it is viewed a form of teamwork with the original author which is encouraged in other engineering contexts. For practicing engineers the time and effort necessary to develop a global standard based on the method of casuistry thus is not a workable solution.

Eliminating casuistry as a basis for establishing a global framework for engineering ethics is not to suggest that cases should not be utilized in the study of the subject. Consideration of cases is important. For example, working with cases emphasizes the process of active learning and furthers engineers' ability to analyze a series of events. These are not activities which are common in all societal educational systems and thus also broader educational value beyond the study of ethics.

13.3.3 The Important Role of Reason

In a general sense, the ability to reason is a feature common to all adult human beings. It is the ability to logically think through problems. Often pointed to as features of reason are the ideas of consistency, reversibility, deliberation, disinterestedness, and universality. The ability to reason is claimed to be so central to human existence that some have identified it is the core of human identity, that which separates humans from other creatures. Whether this is true may be subject to debate and it is certainly the case that the use of reason is stressed more in some societies than in others. In some societies is may even be given a clearly secondary role in practice. Independent of a specific societal approach to reason, however, what is indisputable is that without the ability to reason, engineering, at least in its modern manifestation, could not exist. All engineers must therefore accept the premise that the use of reason is a valid decision-making instrument, independently of what thought processes they may use in other parts of their lives. While other elements of humanness are also significant, such as an emphasis on emotions for example, it is only reason which we expect to manifest itself among engineers in a uniform fashion across cultures.

It is important to notice that in advocating the universality of reason among engineers, I am not proposing a subtle reintroduction a Kantian framework into engineering ethics. Immanuel Kant is concerned with the primacy of basic principles of reason, such as the principle of non-contradiction, while I am advocating reason in its broader, more colloquial sense, of using logic and evidence in support of a conclusion, that is, that decisions should be "reasonable." Given this interpretation, it is then justified to expect that reason as a tool for establishing a cross-cultural and global foundation for the development of ethical principles should be understandable and acceptable to engineers from all cultural backgrounds.

13.3.4 Role Responsibilities and Engineers

A further foundation for establishing a global engineering ethics is the idea of "role responsibilities." Role responsibilities, as the name indicates, are duties associated with a particular position that we hold in life. All of us have many roles, and different duties may be associated with each of these, arising out of the nature of the role itself rather than out of a more general principle. For instance, parents have a special responsibility to nourish and support their children, much beyond the responsibility that strangers or the state might have. Teachers have special responsibility to ensure students learn. Physicians have a special responsibility for the physical health of their patients.

In making a list of one's own roles, it will quickly be discovered that these will be numerous. An engineer might also be a parent, a golfer, a sibling, a student, a lunch room customer, a driver, and on and on. Once we identify our own roles, two things need to occur. We need to decide what special duties are associated with our roles, or at least to be informed by others what these should be, and we need to prioritize the relationships among our many roles. It is part of the aim this chapter to identify the responsibilities associated with being an engineer, based on the nature of engineering itself. As for the process of prioritizing among different roles, that is a vital task, but one beyond the scope of this chapter. It should at least be noted, however, that the role of individuals as engineers will in practice not automatically supersede all other roles of the individual, as is assumed by most current engineering codes of ethics.

A second reason why we need to specifically consider the idea of role responsibilities is that engineers are in fact different from the general public. They have specialized knowledge and skills which are only acquirable through long periods of intensive study. Their knowledge is the equivalent of a black box to the public. What goes on inside that box is a mystery. The public thus exists in a relationship of dependency to engineers. It must trust the work that engineers do on its behalf. Through an establishment of ethical constraints in their activities, engineers can help assure the public that they are worthy of this trust.

13.4 Foundation for Principles of Engineering Ethics

Traditional moral theory seeks to develop one or a very few moral principles on which to base all ethical judgments. My approach differs from this in that I begin at the more concrete level of engineering itself. Based on a specific conception of engineering as a universally possible activity, I will then derive a set of obligations and rights which specifically apply to engineers. These guiding principles will need to be somewhat fluid in application, because none of them can be considered absolute or completely determined, needing instead to be thought through in the process of application to specific instances. They will, however, provide a general framework on which to base ethical engineering judgments. What I am proposing here is similar to the development of a code of ethics for engineers like those which have been promulgated by a number of engineering societies throughout the world, with the difference being that codes come to us as finished products with no justification for the individual entries being attached to them. They thus appear as instruments of external authority, in a similar fashion to laws. They share the further characteristic with law that they are ultimately political instruments based on compromise. My process is instead intended to have engineers see the why behind the adoption of specific principles and to therefore have a rational basis for following them. It is worth mentioning that this has become a more common approach in the more mature field of bioethics, where use of lower level principles is often advocated, rather than an emphasis on theory as such (Beauchamp et al. 2008).

13.4.1 The Nature of Ethics

To begin the process of determining a set of appropriate ethical principles for engineering, we must first define the term "ethics." For the purposes of this discussion, I am defining "ethics" as being about *actions which have the potential to have a serious impact on the lives of other people.* A number of aspects of this definition are subject to debate in the contemporary literature, such as its limitation to people and not including conduct of a self in isolation. As well, the meaning of the word "serious" is quite vague. This limited conception of the domain of ethics does not mean, of course, that animals or the environment should not be covered in ethical discourse, since our actions toward other beings and things often have consequences for the lives of people. For example, global warming as such is not of ethical interest, but when we consider that what we do to the environment can seriously harm people it becomes a matter of ethical concern.

In the context of a global ethics, especially, it must also be noted that the definition of "ethics" is framed in terms of actions. The question of the inner being of individuals, or their character, is thus left unresolved. There exist a number of moral traditions which stress the idea of character development or the spiritual state of the person. My neglect of this issue in establishing an ethics for engineers is not to indicate that this is not an important dimension, but rather that it is often not suitable for assessment by an outsider. For example, private thoughts which some individual has, as repulsive as those might be to others if they knew about them, if they do not have effects on others do not fall under the proposed definition, which must be one that is useful and acceptable in a cross-cultural context.

13.4.2 The Nature of Engineering

A number of alternative definitions for "engineering" have been proposed historically, with none having achieved universal assent. Perhaps the biggest contrast among the definitions is that some emphasize the requirement of engineering activity to benefit humanity, while others choose a value neutral approach. Here I choose the latter course, as it avoids having to deal initially with the questions of culturally based ideas of benefit and harm. It also seems to me that not all engineering activity needs to have a socially constructive purpose. However, some value element is unavoidable, in that I assume that engineering activity should leave the world no less well off and that disbenefits created by engineering not be catastrophic in nature. Whether these assumptions are justified requires extensive separate discussion.

Another concern relevant to defining "engineering" is the common public conception that engineering is solely concerned with the making of things, with the creation of artifacts. This understanding of engineering is likely linked to the craft tradition of engineering and is less typically relevant to more modern occupational activities of engineers, which include dealing with processes rather than simply with products.

A final issue is that some would argue that engineering is centrally, and perhaps exclusively, about the activity of designing. While this is certainly a core activity for engineers, it does not capture the wide variety of activities trained engineers engage in. Yet there are numerous attempts to segregate engineers into different hierarchies and to separate "true" engineers from others. The question of who does engineering is thus integrally connected to what engineering is, and the answer varies across different countries. My definition in a global context will thus have to be somewhat stipulative and subject to possible criticism.

Based on the above discussion, I then propose the following definition of "engineering:" Engineering is the transformation of the natural world, using scientific principles and mathematics, in order to achieve some desired practical end.

This is a relatively broad definition which attempts to capture the great variety of activities possible for engineers. The definition also attempts to be value neutral as far as possible. It clearly, however, reflects the modern scientific foundation of engineering, rather than the craft tradition, and this in itself involves a value judgment.

13.4.3 Deriving the Principles

Once the above definitions have been established, we can ask what ethical principles follow from them, using the tool of reason. The basic question is: Using the ability to reason, what makes certain types of actions appropriate or inappropriate, given our definition of engineering? Key elements to remember are that the world should not be left less well off as a result of the transformation, and that costs incurred in the process should not be catastrophic. In addition, when speaking of costs or benefits, the final concern is the potential impact on the lives of human beings, as was stipulated in relation to our definition of "ethics." In other words, ethical discussion in relation to transforming the natural world will determine the appropriate application of engineers' abilities.

The principles established will be somewhat general in their enunciation and subject to interpretation. That is the nature of general principles, but is also what makes them at times less useful in the sphere of application than might be expected. This is one reason why engineers need some practice of dealing with example instances where they use the principles to analyze specific situations, thereby helping to clarify the nature of the principles for themselves.

13.5 Foundational Principles of Engineering Ethics

13.5.1 The Principle of Public Safety

Modern technology has vast power to impact the lives of people. What might at the time seem like minor design decisions may harm or benefit millions or even billions. The power of even contemporary dictators is puny compared to the power of engineers. This power carries with it a great deal of responsibility, yet it is often unrecognized by the holders of the power themselves. A quote from the American Accreditation Board for Engineering and Technology *Code of Ethics* is an apt reminder: "Engineers shall recognize that the lives, safety, health and welfare of the general public are dependent upon engineering judgments, decisions and practices incorporated into structures, machines, products, processes and devices" (ABET 1997). While the power of engineers can greatly benefit the public, it also has the potential to do great harm. Neglecting appropriate safety considerations in the design of a nuclear reactor, for example, may result in destroying many lives and making great swatches of land uninhabitable for decades. The emphasis on safety shows us that ethics is central to engineering, for it means that the engineer is responsible not only for the technical adequacy of products, but also for the consequences which result from their intended and unintended (but foreseeable) uses, insofar as these products have the potential to harm the public.

There is a strong association of safety with not being subjected to harm, but harm can take many forms. It can be physical, psychological, emotional, monetary, and so on. Clearly, it would unjustified to hold engineers accountable for all of these possible consequential harms resulting from the introduction of technology, although they might have contributory responsibility. However, due to their expertise, they do have a central connection to the potential for resulting physical harm.

For the individuals affected by technology, the greatest possible cost to bear is loss of life or bodily integrity, that is, significant injury. Some have even argued that life is of infinite value and that therefore any societal benefits derived from actions cannot be measured against the potential for loss of life. In practice, however, we do assign value to human life, albeit to different degrees in various cultures. Yet the import of the more radical claims is clear: human life is of very high value. Actions which risk life have significant primacy in countering potential benefits from the introduction of technology and must be of special concern to engineers. If engineers are aiming to not leave the world less well off as a result of their transformations of the world, they must give great consideration to the possible endangerment of human beings. This is not to claim that no introduction of technology which can potentially harm the physical integrity of human beings can be justified, because that would imply that no degree of risk could ever be justified, which in turn would eliminate the possible introduction of technology, but only that engineers must give great weight to such risks. This conception of the priority to be given to safety is in accord with statements found in many codes of engineering ethics, as in, for example, the ethics code of the American National Society for Professional Engineers: "Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties"(NSPE 2007). Given that engineers have knowledge and expertise regarding technology which is not available to the general public, it is part of their role responsibility to protect more ignorant individuals from potential danger. It is reasonable to assert that knowledge generates responsibility. As an example from ordinary life, if we gain knowledge that an individual is about to murder someone, a duty is generated to warn that person or to take other appropriate action, a duty which we would clearly not have if we were ignorant about the potential murder. The first principle based on the nature of engineering can then be stated as follows:

> *The Principle of Public Safety:* Engineers should endeavor, based on their expertise, to keep members of the public safe from serious negative physical consequences resulting from their development and implementation of technology.

13.5.2 The Principle of Human Rights

Once the safety principle is established, a number of others follow, which I will here discuss only briefly. Although the assertion of rights has perhaps gone too far in some Western societies, the idea of respect for human rights has by now been firmly established on the world scene, for example in the UN convention on human rights. Most fundamentally, the rights that are asserted to be human rights are the protection of human life and the right to conditions being met which are required for the continued existence of that life in a condition fit for human beings. Most basic to support life might then be the right to food and shelter, the right to education, and the right to just treatment. For engineers, a duty derived from keeping people safe, or protecting them from physical harm, is then the demand that they do not undercut the conditions which are necessary for life to be maintained in a viable state. It would, of course, be asking too much of engineers to be responsible for all positive promotion of human rights. If that is a duty, it is a duty for governments and/or the general public. Engineers' duty in relation to rights is thus a limited one, namely that they should not cause the violation of human rights through their actions. This would amount to a requirement for engineers to exercise the duty of respecting fundamental human rights in carrying out their role and the ability to refuse to participate in activities which threaten those rights. The second principle then reads:

> *The Principle of Human Rights:* Engineers should endeavor to ensure that fundamental rights of human beings will not be negatively impacted as a result of their work with technology.

13.5.3 The Principle of Environmental and Animal Preservation

Emphasis on the preservation of the natural environment is a relatively recent phenomenon on the world scene. However, engineers clearly have a major role to play in contributing to a sustainable global environment or to its destruction, a role which has perhaps been insufficiently recognized. If the global environment is not adequately sustained, human life will be endangered. A similar claim can be made for destruction of diversity in the animal kingdom. Thus the relevant engineering duty follows from the safety responsibility of engineers for human life, but again as a limited duty.

> *Environmental and Animal Preservation:* Engineers should endeavor to avoid damage to the animal kingdom and the natural environment which would result in serious negative consequences, including long-term ones, to human life.

13.5.4 The Principle of Engineering Competence

If engineering work is carried out in an incompetent fashion, it takes no great stretch of the imagination to envision that it might turn out badly and endanger the lives of human beings. Although it is often not recognized to be such, technical competence is at its core an ethical requirement. The next principle then follows directly:

> *Engineering Competence:* Engineers should endeavor to engage only in engineering activities which they are competent to carry out.

13.5.5 The Principle of Scientifically Founded Judgment

An important component of my definition of engineering is that engineering is based on the use of scientific principles and mathematics. Using these tools in one sense is then simply acting as a competent engineer in the global context where the criteria for good engineering must be expanded beyond local craft traditions. But, in another sense, it has wider implications, namely that using other types of principles or other decision-making procedures is inappropriate and not in line with appropriate engineering work. This proposition is clearly somewhat controversial, since it would hold that engineers are engaged in an illegitimate conflict-of-interest when they let non-engineering considerations influence their judgments. If we view the issue from the perspective of engineering seen in isolation, however, non-engineering considerations are not relevant. Thus for example, cost considerations are clearly part of the ultimate decision-making process regarding the products of engineering. These, however, become relevant only when a wider context for engineering is established (as it will be elsewhere). Further, it must be kept in mind that the ideal of scientifically founded judgment is not an absolute one, but must rather be seen in conjunction with the other principles established in this chapter. In that context, the following principle then applies:

> *Scientifically Founded Judgment:* Engineers should endeavor to base their engineering decisions on scientific principles and mathematical analysis, and seek to avoid influence of extraneous factors.

13.5.6 The Principle of Openness and Honesty

The final engineering principle concerns the direct relationship of engineers to the public. I have shown that engineering is an esoteric activity, in the sense that much of what engineers do is opaque to the public. However, explanation of the above principles has shown that engineers cannot take sole responsibility for everything which is a potential effect of their actions. Although they must be worthy of trust, their direct responsibility relates only to engineering aspects. To begin to fit this responsibility into a larger context, communication with other constituencies is necessary. This communication must of such a nature that competent decisions can be made by others. Our principle then follows:

> *Openness and Honesty:* Engineers should endeavor to keep the public informed of their decisions which have the potential to seriously affect the public, and to be truthful and complete in their disclosures.

13.6 Limitations of the Discussion

There is no claim implied in the previous discussion that the proposed principles are radically innovative, although some do project a relatively new emphasis. They should in fact have an intuitive appeal to engineers, since otherwise the implication would be that the current practice of engineering fails to meet ethical standards, a claim I am not prepared to make. The important point is that they are derived from a foundation which should be able to gain acceptance in the global engineering community, whereas emphasis on instruments which have an apparently Western bias will not.

For evaluation of the appropriateness of the above discussion it needs to be kept in mind that the principles derived are solely from the perspective of engineering as an isolated activity, independent of particular cultural, societal, or business contexts. The principles considered thus do not include, for example, as do most current engineering ethics codes, the important issue of the duty of loyalty to employers or clients and its potential for conflicting with the principle of public safety (NSPE 2007). That duty does not follow from the activity of engineering itself. It is instead established as a result of the fact that most engineers function in the employ of someone else (be they considered employers or clients) and requires analysis in a broader contextual framework. It must thus first of all be recognized that the engineering principles are not to be taken as necessarily supervenient, either individually or as a set. A fundamental assumption of the current discussion is that while engineering ethics can be derived from the activity of engineering, in practice it is a contextual activity in the course of which engineers function in multiple roles. For example, engineers may also be managerial employees and thus have to be concerned with their duties in those capacities. Those duties may well conflict with duties assigned to engineers. With W.D. Ross' distinction between *prima facie* and actual duties in mind, it should not be assumed that engineering duties should always become the actual duty (Ross 1930).

More significantly even, engineers themselves have responsibilities to others which are not solely based on engineering. As I have pointed out, each human being plays many roles. For engineers, often two additional major roles are that of being a member of a family and an employee of a corporation. These other primary roles can create conflicting interests. Traditional professional engineering ethics holds that engineering duties, especially the duty to the safety of the public, should always take priority. However, this seems an unreasonable expectation in light of the implications of failure to fulfill one's duties in the other areas. Ethical theory typically holds that one life is the equal of another, so that if two were to die as a result of failure to do one's engineering duty while only one of the engineer's children should die, then ethical theory would demand that the engineering duty be performed. From the perspective of role responsibilities, on the other hand, the situation is less clear, because the duty of the parent is first and foremost the welfare of the parent's own children. If there were only one child, the role of being a parent would, in fact, be completely destroyed with the death of the child.

For most parents the choice in this type of situation would be obvious. Would we be willing to condemn them for acting unethically? If not, then we have to recognize that we cannot look at engineering duties in isolation and simply condemn any action contrary to them as unethical.

Finally, I want to remind readers that the above discussion is intended to be part of a larger project. A fuller discussion of ethical principles for engineers in a global environment will need to stress two important elements: the connection of engineering to the business environment and the need to understand that a variety of cultural value systems exist in the world which must be recognized and taken into account. It will also require that the ethical discussion of engineering be seen in a real-world framework, rather than looking at it as an ideal phenomenon which can be analyzed independently of external considerations. Further principles thus need to be developed regarding duties of engineers as employees, requirements for potential involvement by engineers in public affairs, rights of engineers as employees and as engineers, and intercultural requirements for engineers. However, those are subjects for other venues.

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Chapter 14
Professional Ethics Without a Profession: A French View on Engineering Ethics

Christelle Didier

Abstract Bioethics and business ethics have their international conferences, their networks, their international scientific journals, as well as their schools of thought and their internal disagreement. To the contrary, engineering ethics is a little known area of study which gives rise sometimes to scepticism. First developed in the US, this academic field it is now present in many countries. In this article, we intend to make known the progress made and the issues at stake in this area of contextualised ethics: philosophical issues, but also cultural one. We will defend the idea that reflecting upon the ethical issues of engineering is not of interest to engineers alone. However, as it also concern engineers, we will try to describe what could (or should) be the focus of an ethical reflection on engineering for engineers in countries (like France) where the concept of profession does not hold an ethical dimension as it seems to be the case in the US.

14.1 Introduction

Ethical reflections applied to engineering are a lot more recent than to other professional activities. Nevertheless, there is a subject called "engineering ethics". Created in the United States in the 1980s, it has since developed in other countries, starting with countries where the professional organizations have a code of ethics. In France, this concern is novel and faces some specific problems: it is not well understood. While some observers question its theoretical foundations and methods, others simply doubt that the engineers' professional activities may raise specific ethical questions.

Thus, nobody seems to be surprised when philosophers and ethicists question certain aspects of technological development; technological development that is barely imaginable in the absence of engineers. Here are two established facts:

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first, technological development brings up ethical questions. Second, engineers contribute, in a necessary way, to the existence and to the deployment of these techniques. For some authors, this confrontation compels us to question the morals of engineering. For others, the ethical challenge of techniques is not the concern of engineers. I do believe that observing engineers, their everyday practice and, sometimes, their quest for moral signposts deserve the attention of those who are interested in the ethical challenges of technical development as well as those who are interested in a more general way in the challenges of professional ethics.

I will first say a few words about the concept of engineering ethics, which is very hard to translate in French, in France especially, because the meaning of the word profession carries different connotations. Then, I will try to identify the specific characteristics of human actions that engineering ethics focuses on. Finally, I will go back to the engineers. If they are not the only ones concerned with engineering ethics, what can be said about their individual and collective moral responsibility? Three questions will be discussed: What is their legitimacy when taking into account their ethical values in their decisions at work? What do engineers know about the ethical issues of engineering? What can they actually do?

14.2 Engineering Ethics: Professional Ethics, Applied Ethics, or Something Else?

14.2.1 Is Professional Ethics Inherent to Professions?

In France the word *profession* can refer to any kind of job; in the United States, a profession legally means a type of activity whose members are provided with specific rights. The division of the job market between professions and occupations fits in with the functionalist theory of professions that dominates professional sociology in many countries such as Great Britain and the United States. According to this framework, professions are characterized by intrinsic attributes from which come obligations of their members towards their clients, their peers, and the public. These obligations are inscribed in a code of ethics

In fact, what distinguishes professions from mere occupations is not agreed upon. Professions are often characterized by their function: they are indispensable because they serve a crucial social need such as Health or Justice... Some authors insist on the pursuit of a common ideal between members of professions. But professions can also be described by the type of organization of their members. The interactionist sociologists insist more on the monopoly practiced by the professions on certain activities, than on the ideal they are supposed to serve. They consider professional groups as processes of interactions which lead the members of a same work activity to organize themselves, to defend their autonomy, and to protect themselves against competition: socially idealised occupations organized in closed occupational communities.

The code of ethics promoted by the organized professions is therefore understood differently according to the authors' appreciation of what is a profession. Codes can be seen as distinctive signs freely chosen by a group which contribute to raising their activity to the rank of a profession. They can be understood as intrinsic attributes of activities whose nature itself would make them professions. They can also be seen as a strategic tool to defend the corporation's interests.

14.2.2 Is Engineering a Profession?

"Is engineering a Profession?" is a question that can be found in all of the introductions of engineering ethics text-books in the USA. But this question may seem a little useless in other countries such as France. Some scholars in the field of sociology of the professions consider that it is not possible to talk about engineering professional ethics because engineering is not a "true" profession. This field does not satisfy all of the necessary requirements to be recognized as a profession as health professions or law are, for example. For others, the affirmative answer to this question is evident. Engineering is "not just a way of making a living" but "a calling in which individuals are personally committed to using their skills and abilities to achieve a high social goal" (Schlossberger 1993). But this is more an act of faith than a demonstration.

According to Michael Davis, there are three main arguments that are put forth to deny engineering the status of profession. First, there is no intrinsic ideal in the practice of engineering. Second, this ideal, if it existed, would only be technique, that is to say a matter of means, and therefore value-free in contrast to health which is morally good in itself. Third, engineering lacks the type of social arrangement which characterizes a real profession, i.e. a professional organization with authority. Deconstructing these arguments, one after the other, Davis points out that accepting or refusing to count engineers as professionals depends on the choice made by each author among all the available definitions of the word "profession" (Davis 1997).

For Davis, engineering ethics is a kind of practical wisdom in the professional practice which can and must be transmitted. It is a matter of choice. Like the other norms that the engineers use in their work, "ethical standards, like other engineering standards, are not discoveries but useful inventions". He comes to classify engineers as among the professionals because, as he has observed, the engineering community has adopted standards defining what is morally permissible, which are specific to its members and go beyond the requirement of law, market and ordinary morality (Davis 1998, p. 177). If this statement, the existence of standards, can be made in the USA, this is not the case all over the world.

Nevertheless, Karl Pavlovic already considered in the early 1980s that the question for engineering of being or not being a profession uselessly interfered with the debate. He argued that "(a) there is an ethical dimension to the practice of engineering, (b) that this dimension has no essential connection with engineering being a profession, (c) that professionalism in engineering is rather an issue parasitic to this ethical dimension, and finally, (d) that there are factors in the practice of engineering that make a discussion of ethics in the context of engineering appropriate" (Pavlovic 1983, p. 224). This approach seams to me very helpful especially in a country like France, where *profession*s are neither a cultural nor a judicial matter.

14.2.3 Engineering Ethics as Contextualized Ethics

Some authors who are skeptical towards engineering ethics base their criticism on the arguments generally put forth against the entire field of applied ethics. They disagree with the idea of deducing solutions to particular problems from moral theory. Indeed, the concept of applied ethics is problematic because it suggests that it would be possible to solve problems by "applying" moral theory or the article of a code of ethics. But, it also suggests that the goal of ethics would consist in the solving of problems.

I prefer to use the concept of contextualized ethics than the one of applied ethics. Contextualized ethics is defined as a heuristical method which deals with moral questions posed by a practice in a specific context. With this approach, what come first are not the duties of a profession, but the questions raised by a specific type of activity in its context. This context, this area, is not only the one of a professional group: it is a socially shared space. It is also a space where a dialogue can take place between various stake-holders, where moral theories can contribute along with other methods and tools to understand the reality and study the ethical dimension of choice – past, present, and future.

For Carl Mitcham, the role of engineering ethics is not so much about promoting respect of professional obligations or applying theories. It is an ethical reflection on the technical act in context. Moreover, he adds that in our "engineered world", engineering ethics cannot be a preoccupation reserved for engineers only. On the contrary, it is a questioning about our relationship with objects and technical processes and their conception which must concern everyone without exception (Mitcham 1997, p. 123).

Why not then talk about "technethics" or "ethics of technology"? The concept of engineering ethics seems to me more fruitful, despite the risk of giving it a too narrow definition, because it reminds us of the human origin of the technologies. Engineering ethics refers to a type of work, to humans; functionalists would say to a "profession". It also refers to a human community or social group: the engineers.

14.3 What is Engineering?

How does one then define this activity, the specific area of human action which is at the heart of engineering ethics? Engineering ethics is not an abstract ethical reflection on technical objects: this is what I would call "ethics of techniques". Neither is the role of engineering ethics to evaluate technical decisions: this has been the aims of a field called "Technology Assessment" since the 1980s. The focal point of engineering ethics is not a status, a profession. Neither is it knowledge, engineering sciences. The focal point of engineering ethics is an activity.

14.3.1 Engineering as Humanism

According to Hélène Vérin, the word engineer etymologically suggests a certain moral ambivalence. The Latin word *ingenium* meant skill, manual skill as well as spirit and cleverness. But between the XIIth and XVth centuries, it also meant trick and deceit. In the middle of the XIIIth century, *engignement* was used for actions meant to be surprising. The *enginiour* of the XVth century was the person who was skilled (from *engin*, for inborn characters in old French) and who knew how to use his creativity (*engin*, for cleverness) to conceive and build a machine (also *engin* in French). During the same period, the devil was called *enghinhart* or *mal engegneor* and the word *engineresse* was used for witches.

We can find this ambivalence in more recent discussions on engineering. The nineteenth century which bore witness to the tragic consequences of industrialization, was also the stage for a profusion of technophile speeches. George Morison, one of the first bridge-builders in the United States, described the engineers as the priests of technical development, "priests without superstition". Edwin Layton who analyzed the speeches given by the American engineering organizations between 1895 and 1920, wrote that their spokesmen described engineers as "the vital force of human progress and of enlightenment", also as "uninterested logical thinkers" whose social responsibility is "to protect progress and ensure that technical changes are used for the good of humanity" (Layton 1986, p. viii).

Although the twentieth century with its human and ecological disasters born of modern techniques shook the ideology of progress, the discourses describing engineering as intrinsic humanism resisted. Eugene Schlossberger, an enthusiastic defender of the profession in the USA, still refers to an "engineering way" whose characteristics are to be "precise, rational and careful". According to him, the engineering way implies being responsible about safety. He also writes that "technology *is* practical wisdom". According to Michael Davis, the first commitment of engineers is not to a theoretical or applied knowledge as we might expect from scientists, but to human well-being. If these discourses are typical of corporate organizations, we can find them in some catholic milieu when engineers are exhorted to carry on the mission of the humanization of the Earth. French Bishop Albert Rouet declared at the 100th anniversary of the *Institut Catholique des Arts et Métiers* that "the engineer is someone who is situated at a place where the world is being created, that is to say, where creation is being perpetuated". This was only ten years ago.

14.3.2 Questioning the Amorality of Engineering

Quite unlike the authors who define engineering as humanism, others consider engineering as being morally indefinable. They are rooted in an understanding of what technology is which has not changed since Aristotle. For them, the association of the terms ethics and engineers does not make sense because the activity of engineers consists in the putting into practice a means to achieve external goals, whether good or bad. Therefore, the technical act would not be the object of a moral judgment because of its status of "means", value-free by nature.

According to Günther Anders this division of means and ends applies only to singular acts and mechanically isolated actions (Anders 2001). Jacques Ellul also questioned the neutrality of techniques. Although he believed technology had a status of means, he underlined a new specificity which was "that these means now obey their own rules and are not subordinate to ends". According to him, we should not see in technologies only the tools because they constitute a system which modifies the totality of man and his environment. For him, the technical system is not amoral: it imposes "technological ethics", that of "normality, efficiency, success, work, professional conscience, and commitment to collectivity" (Ellul 1983).

Moral judgments on engineering do exist. They reveal feelings of confidence or of fear toward technology. Those feelings are rooted sometimes in beliefs, sometimes in an accurate observation of the world. Anyway, these discourses do not tell us much about the fundamental characteristics of the technical act. How can one study the ethical challenges of an activity whose borders are so uncertain? Until recently, human social sciences and philosophy showed little interest for engineers and their practice. It has been the same for a long time for the sciences and technology.

In the United States, the works of Edwin Layton founded a history of technology independent of the history of science. Walter Vincenti was one of the first researchers who attempted to elaborate on an epistemological distinction between engineering and applied sciences. In France, Bruno Latour is seen as a precursor with his ethnographical works on life in the laboratory. However, similar ethnographical works dealing with engineering remain scarce. Finally, we can mention the effort of Gary Lee Downey and Juan Lucena to attempt to trace the outlines of a specific field for engineering studies.

14.3.3 Engineering in the Literature

Several characteristics of engineering are described in academic literature. Layton insists on the dual nature, scientific *and* economic, of engineering: engineers are scientists but also businessmen because the testing of their work does not occur in laboratories, but on the "market place". Downey and Lucena also underline the social dimension of this practice recalling the "combination of labour and capital" which characterizes engineering. Wiebe Bijker and John Law describe it as a contextualized practice where technique and non-technique contribute to building a "political network". Engineering therefore appears intimately linked to a complex context where political, social, ecological and economical challenges intermingle.

The knowledge of engineers has something to do with scientific knowledge, but it remains different. Mike Martin and Roland Schinzinger define engineering as a "social experimentation". Carl Mitcham insists on the fact that the product of engineering is not knowledge, but an object which transforms the world: "when science takes the world into its laboratory, engineering takes the world for a laboratory" (Mitcham 1987, p. 138).

According to Michael Davis, engineering is not simply resolving a problem: it is "as creative as art, as political as law, and no more a mere application of science than art or law is" (Davis 1997, p. ix). Most authors agree on giving a central role to the activity of design, defined as a creative act of translation of ideas into visible forms. Edwin Layton stresses that the capacity to draw was tacitly the common denominator of American engineers of the last century and sometimes the official criterion for admission to a professional society (Layton 1983, p. 130).

14.3.4 Towards a Definition of Engineering as a Technical Act

What are then the main characteristics of engineering? Firstly, engineering takes place in a complex work environment. The agents of technical acts are engineers, but also technicians, non-technical executives, and sometimes administrative and political decision-makers... Latour would certainly add the objects. Engineering is therefore characterized by the complexity of the human organizations in which it develops. Where is there room for ethical decision making? How can we take on responsibility when any individual act is diluted among so many?

Secondly, this act has the ability to transform the real world and produce consequences which are sometimes irreversible and partially unknown. Engineering is characterized by the potential power and the partial uncertainty of its impacts, both present and future, on the natural and human environment. In whose name should we accept the risks induced by the numerous social experimentations that surround us? Who can and who must decide? What is a socially and morally acceptable risk?

Finally, engineering is characterized by a central act: the act of designing. This act is a process by which objectives or functions take shape in plans for the creation of an object, a system, or a service which aim at achieving the goal or this function. How can one evaluate the morality of this act of the transformation of ideas into concrete forms which is the heart of engineering? By which process values and worth are part of the shaping of objects, programs and procedures?

14.4 How are the Engineers Concerned by Engineering Ethics?

The moral obligations of engineers do not derive from the existence of a code of ethics. They come from the dependence of the whole society on engineers, for certain things at least: the acts of technical design. This dependency creates a responsibility for the engineers toward clients as well as to employers, towards neighbors as well as to co-workers, towards the ultimate users as well as to all the animate and inanimate beings who are transformed, in one way or another, by their technical acts, by their "social experimentations". Kenneth Alpern defines the principle of proportionate care in saying that: "when one is in a position to contribute to greater harm or when one is in a position to play a more critical part in causing harm than is another person, one must exercise greater care to avoid doing so" (Alpern 1983). Therefore engineers have a great responsibility because if they fail to do their job with technical competency or commitment to ethics, not only may an individual be harmed or killed (as is the case if a doctor fails to do his job) but dozens, hundreds, even thousands of individuals.

Although the principle of proportionate care obviously forms the basis of the engineers' moral responsibility, we must keep in mind one difficulty, the phenomenon of dilution of individual responsibility in large corporations. This problem makes it hard to identify who is morally responsible when a lot of different people contribute in various ways to the decision-making. Today, most engineers work in large organizations; moreover, they rarely remain in the same position for a long time. Engineering projects are transmitted from one decision-maker to another, successively taking on the same position. Many engineers change position, and sometimes company, before they see the concrete outcomes of their decisions. The "problem of many hands", as Dennis Thompson calls this phenomenon may favor impunity, and a mentality of hired-guns among engineers.

However, it may be considered unjust to have an individual agent bear the responsibility of the unwanted harm due to a structural failure of a collectivity. The line seems to be narrow between making the individual engineers excessively responsible and the abdication of any responsibility as a subterfuge for inaction. In the shift from the activity to the actors, from the ethical challenges of engineering to the moral responsibility of the engineers, three questions need to be addressed: What is the moral legitimacy of engineers when taking into account the ethical issues of engineering in their decisions and actions? What is the specific knowledge that they have access to? What is their specific freedom of action within the organizations which employ them?

14.4.1 The Legitimacy of the Engineers

For some authors, the ethical questions raised by technical development do not really concern the engineers because of its highly political dimension. Samuel Florman is very skeptical regarding the obligations of engineers in the American codes of ethics that seek to protect the public against the bad effects of technical developments. "Fortunately", he writes, "engineers are no more agreed upon how to organize the world than are politicians, novelists, dentists or philosophers". According to him, engineers have no right to establish goals for society. Already Aristotle recognizing that there were actions which were better judged by the "actors" whereas other actions were better judged by "those acted upon", said: "a feast is judged by the guests, not by the cook."

As such, the engineers would not have a word to say on technical development and even less on the ethical challenges created by these developments. Yet, there are many places where engineers would have legitimacy alongside other stakeholders of technical development. Engineers can express their point of view in the debates about the technical choices at different levels: within their companies, with peers and other colleagues but also with staff representatives; outside the company with local associations, standard organizations, governmental agencies, parliamentary commissions, NGOs. . . Because of their position in the socio-technical system, engineers are expected to be citizens of technical democracy, more than any other member of society.

Concerning their obligation inside their company, Christiaan Hogenhuis and Dick Koegela stress that besides the role which consists in the communication of technical specifications, engineers can also (and must also in certain cases) suggest alternatives to their superiors or their clients. If they have no legitimacy to decide which impacts are socially, economically, ecologically, politically acceptable, they are often among the only ones to be able to suggest alternatives. Besides, they often take part in executive teams. And when this is not the case, their superiors or their clients, who have the legitimacy to make decisions, often trust them. Engineers are responsible because those who have to make the choices trust in them.

Andrew Feenberg reminds us that there is, at the beginning of the development of any plan, a large range of possible technological choices, all of them responding to the interests of one or more social groups: the entrepreneurs, their clients, the engineers, the political leaders. . . The struggle between these groups leads to a selection at the end of which technology becomes a “black box”. Before it is closed, the social interests at stake in the process of choice come through very clearly but, they are quickly forgotten: retrospectively, the object seems purely technical and its creation just inevitable. The engineers are not legitimate decision-makers for the whole society. But they are situated close to this barely visible and strategic place, the blind spot of technique: the black box. And this position implies a specific responsibility.

14.4.2 The Knowledge of the Engineers

The highly compartmentalized work situations of engineers, the labor division which characterizes the large corporations where they work, creates another risk-factor than just the dilution of responsibilities: the loss of direction, the forgetting of the aims, which can turn for the actors into an accepted blindness. The study of Evelyne Desbois on Mining engineers in Northern France during the German occupation gives a good example of this possible loss. She shows how most mining engineers continued to work as they used to do before the war, with one goal: searching for results. For them, there was just one way of working: “when one has a job”, said one of them “he is easily polarized about it. He easily steps back from all external circumstances, even if they are a lot more important than the job itself” (Desbois 1984, p. 118). There probably is a moral obligation for the engineers not to be ignorant, or worse indifferent, to the goals they contribute to achieving, and a necessity to be able to express their positions clearly for those goals.

One cannot be held accountable for something about which one is ignorant: this has been one of the foundations of the notion of responsibility since ancient times. But there are ignorances that are more morally acceptable than others. Prudence is required because the impacts of technologies are partly uncertain, but many industrialists worry about seeing a precautionary principle put forth wrongly. They believe that it would restrict crucial innovations because of fear of potential unwanted drawbacks. What about the engineers? They are not expected to become experts in ethics or in public health. But, they probably have the moral obligation to be aware of the debates which surround highly-controversial engineering question, especially when they concern their own work or their own companie. They certainly have to be among the best informed of their fellow-citizens, and even the most educated among them.

Some people believe that the participation of engineers in decision-making is simply unknowable. Thus, their moral responsibility would be indescribable. I do believe that there are, in any case, means to broaden their room for freedom and responsibility through enlarging their knowledge and their understanding. If ethical decisions are difficult to make for engineers, ethical judgments are always possible, and they can improve. Considering the intrinsically risky nature of engineering, they could be expected, for instance, to be able to answer the questions such as: are the stake-holders involved correctly informed? What are the social benefits of the decision worth in comparison to its social costs? Is the distribution of risks just?

14.4.3 The Power of Engineers

Another reason put forth for saying that there is no room for ethics in engineering is based on the engineers' status as employees which does not give them enough freedom. This old argument is put forth either to say that, by principle, the position of an employee is incompatible with the exercise of professional ethics because of a lack of autonomy, or to say that it is often true in practice. Ralph Nader already wrote more than thirty years ago: "in essence, how free is an engineer within a large corporation, whose primary mission is profit-maximisation via all possible shortcuts, and whose bureaucartic structures pose real problems for individual expression and initiative both in matter of skill and conscience?" (Nader 1967).

The question of the engineers' professional autonomy and of their power in decision-making in the companies was studied by historians and sociologists who looked at engineers not as professionals but as workers. Their approach was often linked to the concept of social class and was more present in countries such as France where there has always been a very hierarchical system. Although it is necessary to remind ourselves that engineers are hardly independent professionals we can wonder if their freedom of action within the organizations which employ them is as narrow as some theses on the proletarization of engineers seem to suggest.

The reflections on the specificity of engineering, its impacts on the social world and its hybrid nature, social as well as technical, compel us to think of the place where the engineers exercise their power outside the most visible aspects, i.e. in the games of relationship vis-à-vis authority. The actor-network theory may give us a new outlook with scholars such as John Law and Michel Callon, for instance, who describe the engineers as "social activists", because "they design societies and social institutions to fit machines" (Law and Callon 1988, p. 284). Langdon Winner also observed that the design of nuclear power plants had implications for the structuring of societies and the distribution of social roles. Wondering if the artifacts "had politics", he concludes that "the issues that divide or unite people in society are settled not only in the institutions and practices of politics proper, but also, less obviously, in tangible arrangements of steel and concrete, wires and semiconductors, nuts and bolts" (Winner 1989, p. 29).

Thus, the engineers are not only close to the "black box" of technology, they are sometimes the principal actors of the closing of this box. But what we remember at the end are the economic and political constraints. Engineers appear then as employees among others whose only social responsibility would be to obey their hierarchy. As many scholars in the field of engineering ethics have already written before me, one of the engineers' obligations may consist of in extreme cases blowing the whistle and in taking the risk to overpass their obligation of loyalty towards their employers. But, another obligation, less spectacular maybe, would consist of engineers contributing to the improvement of the structures in which they act, to turn them into more just and responsible institutions. This point of view fits very well with Paul Ricoeur's definition of ethics an "aim of the good life with and for others in just institutions" (Ricoeur 1990, p. 202).

14.5 Conclusions

Engineering ethics is a new field of contextualized ethics, far from its maturity. It has been marked by its north-American origins where it developed among other "professional ethics". For many years already, first in the USA, and now in some European and Asian countries, engineering ethics has started to interest a larger community of scholars. Its focus has widened from the specific nature of engineering as a "true" profession, to the relevant characteristics of engineering as an activity which is at the articulation of the social, the economic, the political, and the technical. In this chapter, I have tried to define the challenges of research in engineering ethics and stressed the interest in an epistemological approach to the question, aiming at defining the outline of the activity which is at the heart of engineering ethics: engineering.

The most recent research works in engineering ethics also show a greater understanding of the different scales in which engineering may be questioned ethically: on the individual micro-level, on the mezzo-level of a group, a professional body or a company, and on the macro-level of the planet. These works study situations where these different levels articulate, run into each other, and even disturb one another. Some issues related to sustainable development and corporate social responsibility, which are now considered as a relevant matter for engineering ethics, can mingle macro and mezzo levels. The discussion on whistleblowing which used to focus solely on the engineer's individual heroism or lack of courage, can take into account the mezzo level of corporate regulation and culture. Thus engineers' freedom of expression in the working place and whistleblowers' policies can be part of a larger scope for engineering ethics.

These evolutions of the scope of research in engineering ethics should have (and have already had in some places) impacts on engineering education. Most courses in engineering ethics have long offered studying the ethical dilemmas that students could encounter in their careers. Although this approach seems to me interesting and useful, I have tried to show in this chapter that numerous other entries can contribute to broaden the individual responsibility and ethical sensitivity of future engineers.

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Chapter 15
Imagining Worlds: Responsible Engineering Under Conditions of Epistemic Opacity

Mark Coeckelbergh

Abstract How must we understand the demand that engineering be morally responsible? Starting from the epistemic aspect of the problem, I distinguish between two approaches to moral responsibility. One ascribes moral responsibility to the self and to others under epistemic conditions of transparency, the other under conditions of opacity. I argue that the first approach is inadequate in the context of contemporary society, technology, and engineering. Between the actions of an engineer and the eventual consequences of her actions lies a complex world of relationships, people, things, time, and space. How adequate is the concept of individual action under these circumstances? Moreover, in a technological society it is hard to sharply distinguish between her contribution and those of others, and between her action and "accident" or "luck". How, then, can we still act responsibly? I propose that we equip our moral thinking to deal with these new conditions, and argue that imagination can help engineers, researchers, and other stakeholders to reconstruct a world, imagine a history and a future, and imagine consequences for others in distant times and places. I illustrate this by exploring what it means to reconstruct a world of offshore engineering. I conclude that not only engineers but also other stakeholders could benefit from an education of the imagination, and I suggest further transdisciplinary work that contributes to a better understanding of responsible engineering under conditions of epistemic opacity.

15.1 Introduction

How must we understand the demand that engineering be morally responsible? Discussions of responsibility in the context of engineering often focus on the actions and decisions of the *individual*, but engineering takes places in a *social* context that involves many stakeholders. What kind of theory of responsibility can account for this social dimension of engineering? Shall we understand moral responsibility

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as shared or distributed, and what does that mean? Furthermore, in tune with its emphasis on the individual, engineering ethics is often understood as a subdiscipline of *professional* ethics and left unconnected with discussions in philosophy of *technology*. How can we connect both discourses?

In this chapter, I aim to contribute to the discussion about engineering, technology, and responsibility (1) by framing the problem in a particular way and (2) by offering one possible way to tackle the problem.

First, I frame the problem by distinguishing between two approaches to moral responsibility that respond to the epistemic dimension of responsibility. One ascribes responsibility to the self and to others under the epistemic condition which I shall call *transparency*, the other tries to tackle epistemic *opacity* instead. I show that many influential moral theories – traditional ones and others – appear to go for the first approach. I then argue that this approach is inadequate in the context of contemporary society, technology and engineering. But if this is true, then how can we still act responsibly?

In response to these difficulties, I propose that we equip our moral thinking to deal with the challenges poses by contemporary conditions. I argue that imagination can help researchers, engineers, and other stakeholders to reconstruct a world, imagine a history and a future, and imagine consequences for others in distant times and places. I refer to insights from the philosophy of technology (in particular Jonas and Anders), discuss various senses of "world", and offer the example of reconstructing a world of offshore engineering to understand responsibility for a near-disaster. In this way I hope to contribute to a better understanding of responsible engineering under conditions of epistemic opacity.

15.2 Two Approaches to Moral Responsibility

To better understand the demand that engineering or engineers be morally responsible, let us first turn to the contemporary discussion about moral responsibility. I detect at least two reasons for calling that discussion one-sided in the light of concrete, practical problems of responsibility.

First, in the literature responsibility is usually understood as *individual* and undistributed (see for example work of Strawson, Watson, Fischer and Ravizza, Kane, Pereboom, van Inwagen, etc.; an exception is Feinberg, who has described types of collective responsibility, Feinberg 1968). But this focus is highly problematic given that human action is often distributed and co-operative. As Lenk and Martin put it, "As a rule, cases in which an individual alone must take on the entire responsibility are examined in philosophy. Yet are there not also cases of co-operative responsibility, collective/co-operative decisions and collective action in general, that are becoming much more important today, in which someone carries full responsibility by *sharing* responsibility" (Lenk and Maring 2001, p. 100). What does it mean to share responsibility?

Second, following Aristotle's discussion in the *Nicomachean Ethics* (Book III, 1109b30-1111b5) a distinction is often made between two negative conditions for ascribing moral responsibility: (1) one should not be forced to do something and

(2) one must not be ignorant of what one is doing. Contemporary discussions of moral responsibility typically focus on the freedom/control condition (e.g. Fischer and Ravizza 1998, p. 13), not the epistemic condition. (And even Aristotle already emphasised the question whether or not an act is voluntary.) As a result, much of the discussion of moral responsibility merges with the free will/determinism discussion (see again the work of Strawson, van Inwagen, and others). There are only a few exceptions. In his well-known *Harm to Self*, Feinberg discusses ignorance about background facts and mistaken expectations of future occurrences, although these elements are understood to be "failures of consent" and are not as such discussed as epistemic conditions for responsibility (Feinberg 1986, pp. 269–315). And Hadji briefly discusses the epistemic problem in terms of the moral beliefs of the person, defined as the belief that something is right or wrong (Hadji 1998, pp. 172–173). However, the epistemic problem is an important one. For instance, we often have to act with incomplete knowledge and uncertainty about the future. What if we are confronted with unforeseen or unforeseeable consequences (Lenk and Maring 2001, p. 101)? Do we really know what we are doing? Are we still morally responsible under such conditions?

These two problems of responsibility are relevant to all human action, but they seem to get only worse when we consider action in the contemporary, technological world – the world we live in. Perhaps because they are confronted with real, practical problems of responsibility, some authors in engineering ethics have offered more useful discussions that can help us to take seriously the epistemic problem in the light of a technological world. I already mentioned Lenk, who recognises and discusses the problem of distributed responsibility. Furthermore, Harris, Pritchard and Rabins discuss impediments to responsible engineering such as ignorance and microscopic vision (Harris et al. 1995). The term "microscopic vision" has been introduced into engineering ethics by Michael Davis (Davis 1989) and means that engineers – or any other members of a profession – may get a narrow field of moral vision. They become blind to the concerns of the wider society (see also Coeckelbergh 2006a, pp. 252–253). A possible remedy is the development of moral imagination, which can help engineers to know the further consequences of their actions, to put themselves in the places of others outside their profession and to envision more action possibilities (Coeckelbergh 2006a).

In order to further develop these suggestions and to further analyse the epistemological problem in the light of contemporary technological culture and society, let me present my own distinction between two approaches to moral responsibility.

15.2.1 Transparency

The first approach ascribes moral responsibility to the self and to others under the following epistemic conditions, which I shall summarize as *transparency*:

- *Transparency of the relation between action and consequences.* The link between actions and consequences is clear, both from my point of view and from the point of view of others. First, I can, in principle, know and experience the consequences of my individual actions, since there is only a small time and space gap between my actions and the consequences of my action, and I can oversee the effects of my actions on others. Second, others can, in principle, monitor my action. In this context, individuals receive moral praise or blame from others, and traditional ethical codes such as the ten commandments develop. Corresponding moral systems are build on expectations of reciprocity, which can be tested in small, not too complex communities that are overseeable.

- *Transparency of the relation between my action and what is not under my control.* First, the actions of others are not under my control. But the distribution of action is clear. I can distinguish between what I did and what others did. From a social perspective: if actions are individual, or the contribution of one individual to collective actions are clearly distinguishable from the contribution of other individuals, responsibility is assigned on an individual basis. The distribution of action is clear. Although we may praise or blame several individuals, we know who does what, and we distribute responsibility accordingly. Second, there is transparency of the relation between my action and whatever else is not under my control, described in terms of luck, chance, contingency, natural causes, divine influence, etc. Again the distribution is clear. I know what I did. Either the action is completely mine, in which case my responsibility is absolute, or something happens which I cannot help, in which case no-one (including myself) can praise or blame me for it. (Although many theories of responsibility allow for degrees of responsibility, most of the most influential discussions assume that it is an either/or question.)

Although these conditions are unlikely to apply in circumstances when questions regarding moral responsibility arise (and indeed may appear exotic in many other circumstances of human life), influential moral theories appear to assume them. This is not only regrettable for philosophy; it is a disaster if we want to understand responsibility in engineering practice, which takes place in the context of contemporary technological culture and society. Consider religious ethics: these ethical systems developed in an entirely different historical and cultural context, tailored to small communities or at most a "people" (defined in ethnic and cultural terms), and are struggling to cope with the modern and highly technological world (Consider questions such as: How should Christians respond to nanotechnology? How can a Muslim be a good Muslim in space?). But modern, secular ethics, too, struggles to adapt itself to our contemporary *technological* culture. Let me explain these problems.

15.2.2 Opacity

The transparency assumption, which may have been already unrealistic in the pre-industrial world, becomes even more problematic if we consider the context of technology and engineering in contemporary society. Between the actions of an engineer and the eventual consequences of her actions lies a complex world of relationships, people, things, time, and space. How adequate is the concept of individual action under these circumstances? Moreover, in a technological society it is hard to sharply distinguish between her contribution and those of others, and between her action and "accident" or "luck". In engineering design, for example, there is an "experiential gap" (Briggle and Mitcham 2007) between the design of a technological installation (e.g. an oil platform), however conform it is to safety regulations, and potential future (disastrous) consequences when something goes wrong. There are simply too many factors, agents, relations that play a role. Moreover, the contribution of the designer is only one part of the process, which also includes other agents and many things (equipment, installations). Consider the difficulties with determining what went wrong in aircraft accidents: blame can neither be ascribed exclusively to human agents, nor to technological artefacts (computers and other systems in the aircraft). Thus, both in time and space there are barriers to complete knowledge of the (causal) relations between action and consequences, there are problems with monitoring, it is hard to know the full distribution of action, and it is difficult to see what, as an individual, the engineer can do about avoiding a disaster. The engineer's moral condition, therefore, is a tragic[1] one, in the sense that incomplete knowledge seems to prevent her from grasping her contribution to what goes on, and, therefore, to assign moral responsibility to herself and to others. How to deal with this problem? The question can be generalised to other activities in a contemporary, technological context. We fail to know the consequences of what we do, if we do not know the distribution of action, and if we cannot clearly distinguish between what we do and what happens outside our control. How, then, can we still act responsibly?

15.3 Imagining Worlds

An alternative approach may assist us to answer this question. My proposal is not that we should try to achieve full transparency (which is impossible), or that we should replace traditional moral theory altogether. We should keep the best moral insights we have. However, we must equip our moral thinking to deal with the challenges poses by contemporary conditions. I recommend imagination as an important tool for this purpose. It can help researchers, engineers, and other stakeholders to reconstruct a world, imagine a history and a future, and imagine consequences for others in distant times and places. To support this claim, I will refer to insights from the philosophy of technology (Jonas and Anders), and offer the example of reconstructing a world of offshore engineering to understand responsibility for a near-disaster. In this way, my argument moves back and forth between ethics of technology and engineering ethics.

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[1] The relation between technology and tragedy is, by itself, an interesting issue that deserves further discussion. For example, Jos de Mul has argued that technology is the locus of tragedy today, since although we create(d) it ourselves, it gets out of control de Mul 2006. My own understanding of the tragic is informed by my reading of Kierkegaard's essay "The Ancient Tragical Motif as Reflected in the Modern" in *Either/Or* (Kierkegaard 1843; Coeckelbergh 2006b). The gist of my view is that tragic action, and therefore tragic responsibility, is situated between absolute control and the absence of control. If we had absolute control, our actions would not be tragic, and we would be fully responsible. If, on the other hand, we lacked *any* control, as is the case with the weather, for example, such external circumstances would not constitute a tragic condition for us either. Engineers (and many of us at many times and in many circumstances, given that we live in a technological culture) find themselves in such a situation: they can do something, but they lack complete control. Under epistemic conditions of opacity, there is insufficient knowledge available for that purpose.

15.3.1 Moral Imagination and Technology: Jonas and Anders

Let me further develop my analysis of the conditions of responsibility as well as my proposed solution (imagination) by using the work of Jonas and Anders.

In *Das Prinzip Verantwortung* (1979), Hans Jonas observes that traditional ethics assumes a narrow scope of human action and responsibility, whereas with technology the nature of human action changes (Jonas 1979, p. 15): we realise that we can wound nature, that we soon will be able to change our own species, and that our actions have consequences for the remote future. He concludes that we need a new ethics to cope with this new situation, and therefore proposes his "heuristic of fear" (*Heuristik der Furcht*). Feeling teaches us that something is at stake. It is easier to see the bad (the *malum*, the danger) than to recognise the good. Therefore, we must consult our fear to find out what we really value. This is not sufficient in our search for the good, but it is a necessary first step. To imagine the *malum*, then, is a duty (64). We should try to imagine what happens to future generations, and let ourselves be affected by it (65). Thus, we must conduct a thought experiment (67) by using feeling and imagination. Jonas also refers to what he calls "the serious side" of science fiction, which can help us in our heuristic exercise (he mentions Huxley's Brave New World) (67). Imagination in this context is not a private fantasy, but a projection of the future, which is a (moral) duty according to Jonas (76). In Chapter 5 he says that the future of humanity is the first duty of human collective action. Since the future of humanity is at stake, we need an emergency ethics (*eine Notstandsethik*) (250). We should mobilise the vision of our imagination and our emotional sensitivity. Fear, then, becomes a preliminary duty of an ethics of historical responsibility (392).

I infer that for engineering, this analysis means that we must take seriously the fears of the general public as a guide to what we value, and that all stakeholders involved must exercise their imagination to assess potential consequences of engineering design for future generations. Science fiction (in literature, film, games, etc.) can help here. Of course we should make sure that such imaginative explorations indeed aid and strengthen, not *replace* a professional practice (and philosophical inquiry) that is responsive to concrete, contemporary problems. Furthermore, we should not forget that scientists and engineers themselves have visions of the future as well. Since both scientific and science-fiction visions are already to some extent part of a shared culture, we can be optimistic about at least one prerequisite for a constructive dialogue between science and society: we *already* explore future possibility, and often we are aware of ethical danger.

However, we should not underestimate the problem given the limitations to our capacity to imagine and to feel what is at stake. In *Die Antiquiertheit des Menschen* (1956), Günter Anders also proposes imagination and emotion as ways to cope with contemporary technology, but puts more emphasis on the psychological and existential difficulties we have to face. Anders sees a discrepancy between production (*Herstellen*) and imagination (*Vorstellen*). We fail to emotionally and cognitively deal with technology, we are blind in this sense. For Anders, in the stage of industrial mass production there is a gap between, one the one hand, our capacities to imagine and feel, and, on the other hand, our actions. We are unable to imaginatively and emotionally cope with our products and their consequences (Anders 1956, p. 273). Moreover, our existence is torn apart, fragmented. With the Second World War in mind, he suggests that we can have ethically incompatible roles: someone can be at the same time an employee in a death camp and a family father (272). With regard to engineering, and less extreme, we could consider the gap between a professional role as engineer (perhaps developing military technology) and a private role as father/mother, lover, friend etc. We could also think about other public/private gaps typical for modern society. The solution Anders proposes is the development of moral imagination to bridge the gap (273). I guess he means that engineers and designers try to emotionally and imaginatively grasp the consequences of our professional actions– including consequences for the "private" life of others. Perhaps he also means that we should take a more "private" ethics perspective on our "public" responsibility. Anders doubts whether it is possible voluntary to expand our imagination and feeling. If it is not, he thinks that the situation is without hope. But as a moral person we must at least will to try to break through the limits of imagination (273). We should start the experiment: we should try to stretch our imagination, try to transcend our imagination and feeling (274). Anders uses the term "*moralische Streckübungen*" (moral stretch exercises) (274). He contrasts this to human engineering, by which Anders seems to mean changing humans by technological or organisational means. For him, that would entail conformity to the world of appliances. Rather, we want to cope with that world, we want to draw it back into our imagination and feeling. We have to try to take in the world we created (274). Anders thinks it is impossible to provide more concrete instructions for such an exercise (275). When the imagination (*Phantasie*) is unwilling and feeling is lazy – Anders calls this "*[der] inneren Schweinehund* " (275), we should force them to listen, to obey. He compares this to similar techniques to change the self[2] (*Selbstverwandlungs-Techniken*) in mysticism and religion: we try to access regions which cannot yet enter (275). But instead of trying to reach into metaphysical regions, we here must try to grasp artefacts: things we made ourselves. Of course we can already reach them, but *as imaginative and feeling beings* we are still remote from them (276). Anders refers to the atomic bomb, and prescribes that we should not accept work that directly or indirectly destroys us. In general, he seems to mean that we – as beings who create things – come to fully realise what we are doing. If we try to stretch our imagination and feeling with that purpose, we do not know if our exercise will succeed, but we should try (276).

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[2] One may also consider Foucault's notion of 'technologies of the self' at this point, a notion which he developed in his later work (Foucault 1988; compare Foucault 1976 and following works on the history of sexuality).

I conclude from these arguments that engineers and other stakeholders should also engage in such techniques of the self. But what does this "duty" to exercise one's emotional and imaginative capacities imply in the real world? And what about imagining the present and the past (as opposed to the future only)? Looking at Anders's examples, we *can* make Anders's moral stretch exercises more concrete. But perhaps something else is needed first. If we are to imagine the (future) consequences of our actions in a technological and engineering world, and if we are to deal with responsibility questions concerning past disasters in the engineering world, we must start with (re)constructing such a world.

15.3.2 Senses of "World"

What does it mean to say "the world of engineering"? There are various ways to understand "a world" or "worlds": for instance, it can be given a positivist (Wittgenstein 1921), naturalist, phenomenological (Heidegger 1927), or (social) constructivist (Latour 1993, 2005; see also Bijker et al. 1987) meaning. Let me clarify these meanings:

1. From a positivist point of view, "world" means, in Wittgenstein's words, "everything that is the case". "What is the case" (facts) refers to the existence of atomic states of affairs (Wittgenstein 1921). In a naturalist interpretation, it could also refer to the planet earth, or to the (physical) universe. A "world of engineering", then, could mean "everything that is the case in engineering" or perhaps "that part of the universe that concerns engineering".
2. In the positivist or naturalist interpretation, we note the absence of the *human* (observer, participant, . . .). From a phenomenological point of view, one should ask the question: *whose* world(s)? We are involved in the world, we interpret the world. Let me clarify this sense of "world" by using Heidegger's analysis of "world" in *Sein und Zeit* (Heidegger 1927, pp. 64–65) and Dreyfus's useful summary and interpretation of that passage in *Being-In-The-World* (Dreyfus 1991, pp. 89–91). The term world can refer to a universe, that is, a set of particulars. For example, the physical universe is the set of all physical objects. What defines the physical world, then, is what all physical objects have in common. This meaning is similar to the positivist or naturalist definition. But phenomenologists are more interested in a sense of "world" that refers to our involvement in that world. The stress is then on our (Heidegger: *Dasein*'s) living in it – or being thrown in it. For example, the business world is what one is "in" when one is in business (Dreyfus 1991, p. 90). It is what Kuhn calls a "disciplinary matrix": "the entire constellation of beliefs, values, techniques, and so on shared

by the members of a given community" (Kuhn quoted in Dreyfus 1991, p. 90). For example, whereas the physical world is a set of (physical objects), the world of physics is, in Dreyfus's words, "a constellation of equipment, practices, and concerns in which physicists dwell" (Dreyfus 1991, p. 90). Such a world is a shared world by definition. In a similar fashion, we could define the world of engineering as *the entire constellation of beliefs, values, techniques, and so on shared by the community (profession?) of engineers*, or, better, *the constellation of equipment, practices, and concerns in which engineers dwell.* I prefer the latter definition since it includes "equipment".

3. Another way of defining the world of engineering is to say that it is the world constructed by engineering *and* society. It is not given, but constructed, and it is not only the product of engineering (broader: technology). Society cannot be disconnected from these technological activities. The world of engineering, then, is co-constructed. Bijker and others have described how this works (Bijker et al. 1987), although their work has not been focussed on engineering in particular but on technology in general. We could also use Latour's actor-network theory (Latour 1993, 2005): the world is a network of *actants*, including people, things, and relations between them. The advantage of such a definition is that there is more emphasis on *things* and relations. However, I hesitate to buy his symmetrical view that puts humans and things on the same level.

I have now clarified three interpretations of "world of engineering". I have expressed my preference for a definition inspired by Dreyfus's interpretation of Heidegger and for a definition that accounts for the constructive relation between science and society but that does not assume symmetry between humans and things. For an adequate and relevant ethical analysis, however, it is not sufficient to focus on "the world of engineering" at large. We need to delve into empirical detail, we need to look at more specific domains; activities, and *events* within that world. For example, we could discuss "the world of offshore engineering" as related to a specific case or event. Let me clarify this by looking at the Snorre A case. For this purpose, I shall re-interpret earlier work I did with Ger Wackers on the role of imagination in the Snorre A case (Coeckelbergh and Wackers 2007).

15.3.3 Reconstructing a World of Offshore Engineering: The "case" of Snorre A

Snorre A is a technological installation used for the offshore production of oil and gas on the Norwegian continental shelf. In November 2008, gas escaped and clouded the platform, but was not ignited. The platform crew managed to avoid a disaster. How should an ethical analysis of this case proceed?

One could start from an ethical theory and ethical principles, and then apply them to the "facts" of the "case" at hand. In practice, this means that we first have to "get the facts right", to "see what is the case"; then we can judge about responsibility, about right and wrong using our ethical principles. But if I take seriously my methodological preference expressed above, there is an alternative to the positivist and naturalist perspective on the world assumed by the term "facts" or "case". We can understand the object of ethical inquiry not as a "case", a world of facts, but as a world in which we involved (phenomenological insight) and which we co-shape (social constructivist insight). If we want to do ethics informed by this understanding of "world", we face a different task. Rather than beginning a "passive", uninvolved, and "objective" registration, observation or collection of facts, we must start with an "active" reconstruction of the world of offshore engineering related to this event, an activity which also entails being involved in what happens in the world and – by means of philosophical analysis – co-shaping that world. Furthermore, we must equip our analysis with conceptual tools that do justice to the human-involved and narrative dimension of the world. Just as our world is not merely a collection of atoms, it is not merely a collection of facts. I shall understand the world of offshore engineering as a combination of agents (individual and collective), things, and relations between agents and things. Furthermore, the time dimension is important as well: apart from a world we must also reconstruct a narrative, or rather, narratives (plural) that stretch from the past to the present and the (possible) future(s). Let me explain this twofold task by using the example of the world of the Snorre A and offshore engineering. I will also take this as an opportunity to illustrate and draw together my earlier arguments concerning responsibility and imagination.

First, a world (or worlds) must be reconstructed. Things include the technological installation and its components, the oil and gas, the rescue material, etc. Agents include the oil company (Statoil) and its contractors and subcontractors, such as a drilling company, but also the safety agency (here: the Petroleum Safety Authority), the state, etc. Relations are ethically highly relevant. For example, the Norwegian state is financially involved in Statoil (the oil company) and Norsk Hydro (the company that operated Snorre A).

Second, there is a narrative about how the Snorre A unit changed hands several times, and about contracts which jeopardised safety. The world of offshore engineering cannot be disconnected from the corporate world, and the differences between these worlds are again highly relevant for ethics. Agents in this world include ceo's, bankers, and lawyers. In that world it is important to reduce costs, improve efficiency, and strive for maximisation of shareholder value. The consequences within the world of engineering can be a reduction of safety at platform level (Coeckelbergh and Wackers 2007). Furthermore, since the state was involved here as owner (Statoil until 2002) or half-owner (Norsk Hydro), politicians are also among the relevant agents, and the political world needs to be considered as well when discussing moral responsibility. But people in one world are often unable to imagine the impact of their decisions in a different world. People from both worlds would benefit if they were able to imagine the other world. And given the interlocking of these worlds, not only engineers, but also ceo's, lawyers, politicians, etc. should do an effort to imagine (other) worlds.

Note that someone may well be able to imagine the consequences for another world, but deliberately chooses not to take this into account. However, we must assume good intentions on the part of engineers as a default.

However, in spite of all good intentions, I argued above that in a technological society it is hard to imagine the precise (long-term) consequences of one's actions, and assigning responsibility to one agent is inadequate, since that would require us to imagine the consequences at other levels for other people in different worlds at different times. Furthermore, as a researcher (an outsider position), it is difficult to grasp all relevant events that are going on, the actors involved, etc. The negotiation of a contract at one point in time is only one element in the narrative, and the people involved are only one group of agents involved. (On the one hand, for a better understanding of the "case", therefore, more involvement would be better. On the other hand, when one is too involved, one may be subject to the same imagination problem mentioned before, since one could be so much "in" one world one finds it hard to imagine what happens in other worlds. Moreover, one may start to share part of the responsibility.)

Indications of problems with imagining a complex world can also be found in other worlds. The legal system, for instance, seems to assume epistemic transparency.[3] But legal cases involving technology and corporations become so complex, that it becomes increasingly difficult to prove the accused guilty. If moral responsibility is distributed over many agents, things, and relations between these, and if this distribution is in principle not transparent, our traditional legal and moral procedures fail to the extent that they assume transparency. Of course this argument needs further support, but it is plausible that engineering is not the only practice that struggles with epistemic conditions of opacity.

To tackle the problem, we may resort to imagination, as Jonas and Anders do, but this does not completely solve the problem, since what can be imagined depends on the epistemic input we can get – which is exactly a problem when conditions of opacity apply. Thus, there is not only the psychological problem of our limited capacity to feel and imagine (a "hardware" problem, to use an ICT metaphor), but there is also an information and communication problem, which we can understand in terms of the argument developed in this chapter. Under conditions of opacity, our knowledge of the relevant worlds and narratives is always in principle incomplete. This limits the (re)sources our imagination can draw on. Nevertheless, I propose that we try to stretch our imagination as far as we can, and attempt to gather as much information as we can – for example by enhancing our connections with other people and other worlds. We usually do not reach the limits of our capacity to imagine, since we easily get stuck in our particular roles and perspective, in our particular world or even just a part of that world. For example, in this case the official accident investigation reports of the Norwegian Safety Authority (PSA) and of Statoil limited the scope of their analysis to the Snorre A operations unit. The alternative would be to imagine the complete offshore engineering world connected to Snorre A, as well as the business world and the political world relevant to the problem. The same holds for other cases. The project of epistemic opacity reduction – in the service of enhanced responsibility analysis and awareness – needs many hands; it is a task that cannot be accomplished by individuals alone. Pooled intelligence relying on accumulated experience drawn from many perspectives is needed. If this is difficult under contemporary conditions, then researchers, engineers, managers, and politicians need to imagine *structural* changes, new social institutions, which bring together different worlds. Of course, we already have some means to improve the situation. For example, we may think about web-based tools and other ICT tools to bring together people and gather more information. Furthermore, we should also recognise that there are already many imaginative processes going on in existing institutions such as academia and professional bodies, although such institutions must be further adapted to that task. If, being under conditions of opacity, we stick to our old engineering, business, legal, political, and moral institutions models, our attempts to ascribe responsibility remain leaps in the dark.

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[3] Consider also criminal justice cases: the legal apparatus has not been adapted to the tragic conditions I referred to. I intend discuss this issue in another publication.

15.4 Conclusions

In this article, I have drawn attention to the difficulty of analysing engineering responsibility under contemporary conditions of epistemic opacity. To better cope with these conditions, I have suggested imagination as a tool. One way to understand this appeal to imagination is to require that engineers (and those who ethically analyse engineering disasters) stretch their moral imagination and imagine a world (and worlds). I developed this thesis by interpreting Jonas, Anders, and phenomenological and social constructivist views. With regard to engineers, I conclude that imagination must be stimulated. I leave it open how this can best be done. However, I have argued that such a project cannot suffice with educating *engineers* to be more imaginative. Worlds are very much interconnected, there are specific structural links between worlds, such as those between the world of business and the world of engineering. For reform, this implies that changing one world cannot be done in isolation, but must also involve changes in other worlds. It may also require more radical structural social changes. Furthermore, we (engineers and researchers) must also recognise that there are limits to our capacity to stretch our moral imagination and moral sensitivities. But, as Jonas says, we must at least try. And finally, trying to change our cognitive and emotional capacities is only one way of better coping with a world and changing a world, only one way of making moral progress.

The potential of the approach suggested here is not exhausted by the discussion and illustrations I have offered. Both the imagination argument(s) and the proposed "imagining worlds" approach need further elaboration, and more possible gains may show up in the course of that exercise. For this purpose, I recommend that engineering ethics should not be separated from sociology, philosophy of technology, business ethics, political philosophy, and other fields of inquiry relevant to the moral-epistemic problem indicated in this article. Only transdisciplinary work can contribute to a better understanding of responsible engineering under conditions of epistemic opacity.

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Chapter 16
Transferring Responsibility Through Use Plans

Auke Pols

Abstract Engineers are initially responsible for the artefacts they produce, but at some point, part of the responsibility for the artefact shifts from the engineer to the user. This chapter will analyse how and when this transfer of responsibility takes place. Specifically, it will combine the theory of responsibility and control of Fischer and Ravizza (1998) and the use plan theory of knowledge of artefact functions by Houkes and Vermaas (2004) into a new theoretical framework which specifies the conditions under which this transfer can take place. After introducing both theories and combining them, I will give an example of how the combined theory works and apply it to a test case to show how it functions in practice.

16.1 Introduction

Engineers are responsible for the technical artefacts they produce. The claim seems straightforward enough, yet how far does this responsibility go? Both on a theoretical and a practical level, issues are entangled.

On a theoretical level, responsibility can be approached in two different ways. The merit-based approach ascribes responsibility to agents on the basis of their actions, focusing on what it means for an agent to *be* responsible: whoever performs a certain action merits, or deserves, a certain reaction. The consequentialist approach ascribes responsibility to agents so that it will lead to the desired effects, focusing on when an agent should be *held* responsible, namely: if he or she is in the best position to make those desired effects happen, or avoid undesired effects (Eshleman 2004). Both views can affect engineers: on the one hand, they are causally responsible for the technical artefacts they produce. This means they can be held morally responsible and be praised or blamed for those artefacts and the effects

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they produce. On the other hand, they are in a good position to improve aspects of both single technical artefacts and extensive technical systems, so it makes sense to ascribe certain responsibilities to them in advance. Sweden, for example, has introduced a policy for road transport systems where system designers are designated "ultimately responsible" for traffic safety. This does not mean that responsibility for traffic safety is taken away from individual road users, but rather that the system designers are encouraged to take measures "so that the mistakes and errors of some individuals, regardless of who is considered to be responsible, do not have fatal consequences and that such mistakes and errors will not be committed with the same frequency" (Fahlquist 2006, p. 1118).

On a more practical level, just as meaning and application of the term "responsibility" has shifted over time (Mitcham 1987), ideas about the responsibilities of engineers have changed as well. A century ago, for example, ethical codes for engineers did not mention responsibility for the welfare of the public. While this has lead Mitcham and Von Schomberg (2000) to claim that this responsibility was considered less important than that of loyalty to the firm and customer, Davis (2001) makes a good case against this interpretation, though only later responsibility for the welfare of the public was explicitly made of paramount importance. The American National Society of Professional Engineers' Code of Ethics, for example, states that the engineer should "hold paramount the safety, health and welfare of the public" (NSPE 2007), while the British Royal Academy of Engineering has issued a statement of ethical principles which mentions that engineers "work to enhance the welfare, health and safety of all whilst paying due regard to the environment and the sustainability of resources" (Royal Academy of Engineering 2007). While laudable, these statements have their drawbacks. It is not always clear how these requirements translate to engineering practice and Broome (1989) has argued that certain risks in engineering are unavoidable.

This chapter will give a merit-based account of responsibility, focusing on who *is* responsible for a technical artefact, the engineer or the user, and under what circumstances this responsibility is transferred. While the responsibilities of the engineer have increased over time, responsibilities for what the artefact can or cannot do and for the consequences of using the artefact remain "core responsibilities": these are the responsibilities that will be analysed here.

This does mean that because of its specific scope, my framework allows for an engineer to make a torture device and successfully transfer responsibility for that device to a user. Isn't this letting the "evil" engineer off too easily? It is important here to keep in mind that not all responsibilities of an engineer are transferrable. Next to the responsibility for specific artefacts, engineers also take on more general, non-transferrable responsibilities when they enter the profession like those established in ethical codes. These allow us to say that any engineer who would knowingly and willingly build torture devices would always behave irresponsibly, as this is a violation of the engineers' responsibility for the safety, health and welfare of the public. Likewise, being responsible for the safety of a product might entail recalling it when tests bring unnoticed defects to light, and responsibility for the environment might translate into offering opportunities for recycling used products. For these aspects, the engineer remains responsible for the artefact during its complete lifecycle.[1]

What are the conditions under which engineers can actually transfer transferrable responsibilities for the artefact to the user, and when does this transfer fail? This chapter will clarify the conditions of responsibility transfer between engineer and user by combining two existing theories into a new theoretical framework. The first theory concerns control over and responsibility for actions by Fischer and Ravizza (1998). The second theory is the use plan theory for technical artefacts by Houkes and Vermaas (2004). Fischer and Ravizza are not interested in applying their theories to artefacts and engineers, while Houkes and Vermaas are not concerned with responsibility. I will argue that (the communication of) use plans can account for the transfer of control over an artefact, and can thereby affect a transfer of responsibility for the artefact from the engineer to the user.[2]

Four caveats are in place here. First, it is *not* the purport of this chapter to analyse the distribution of responsibility within a specific case in engineering. The combined theoretical framework will be its main focus, though I will apply it to a test case to show how it could function in practice.

Second, this chapter is about *moral* responsibility for artefacts, not *legal* responsibility or liability. However, assuming that legal responsibility at least overlaps with moral responsibility, the findings of this chapter would be relevant for legal responsibility as well.

The third remark concerns the role of the individual engineer. My account uses a simplified model of engineering where one engineer creates a product for one user. This does not fit well with real practice, where teams of engineers often work together, embedded in institutional frameworks, and users might also be groups or institutions. As my framework is concerned with the *transfer* of control and responsibility between two parties, however, I will adhere to the simplified model of one engineer/one user for the sake of practicality. My analysis will show on which side the responsibility lies. A theory describing the distribution of responsibility within organizations could then be used to more accurately pinpoint the person(s) responsible.[3] The test case will show how the theoretical framework works in a more complex situation.

Finally, I mentioned that engineers are “causally responsible for the artefacts they produce”. While this may be trivially true – without the engineer, there is no artefact, engineers may not be responsible for all aspects of the artefacts they create, as they are themselves dependent on raw materials, machinery with which to build the artefacts, etc., which may all be delivered by third parties.[4] This, however, does not affect my framework, which only determines whether responsibility lies on the engineering or the user side. If in a certain case responsibility is shown to be on the engineering side, it could well be that responsibility turns out to lie with the supplier: maybe the raw materials delivered lacked a promised quality. It would be interesting to see if the framework could be adapted to work on different levels, for example to distinguish between the responsibilities of engineer and supplier, but such a project lies outside the scope of this chapter.

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[1] See Whitbeck (1998) for a good overview of non-transferrable professional responsibilities of engineers.

[2] Whenever I refer to Fischer and Ravizza, I refer to Fischer and Ravizza (1998). Whenever I refer to Houkes and Vermaas, I refer to Houkes and Vermaas (2004).

[3] Research on the distribution of responsibility within organizations has for example been done by Royakkers et al. (2006).

I will begin this chapter by constructing the theoretical framework. I will summarize the theory of control and responsibility by Fischer and Ravizza and the use plan theory by Houkes and Vermaas. Next, I will show that two assumptions have to be made to connect both theories, and that a strong case can be made for both. After that, I will apply the framework to a test case: the Abcoude dosing lock.

16.2 Responsibility and Control

In *Reponsibility and Control,* Fischer and Ravizza aim to "explore and develop systematically the conditions of application of the concept of moral responsibility." (pp. 9–10).[5] More specifically, they examine responsibility for actions, omissions and the consequences of those actions and omissions. While I will apply their account primarily to cases where actions have negative consequences, I agree with Fischer and Ravizza that responsibility can also elicit praiseworthiness, e.g. when you are responsible for doing good (p. 2). Also, the book of Fischer and Ravizza is primarily situated in the determinism/free will debate: I will extend their theory in another direction by applying their concept of responsibility to artefacts.[6]

Fischer and Ravizza start by examining the two conditions first formulated by Aristotle[7] under which agents have no moral responsibility for what they do. The first condition is ignorance: if you are unaware of what you are doing or what the consequences can be, you are not responsible for those doings and their consequences. Of course, you *can* be responsible for being ignorant, reckless or failing to investigate what the possible consequences of your actions could be. The second condition is force: you are not responsible when you can not act freely, or more specifically, when you can not control your behaviour (p. 13). It is this condition Fischer and Ravizza focus on when developing their account of responsibility.[8]

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[4] I am grateful to Carl Mitcham for bringing this point to my attention.

[5] According to Fischer and Ravizza, you are morally responsible when you are an appropriate candidate for the reactive attitudes (gratefulness, resentment, etc.). In this, they follow Strawson (1962).

[6] For a critical examination of *Responsibility and Control,* see the book symposium in the journal *Philosophical Explorations* 8(2). For a good overview of the topics in the contemporary debate on responsibility and free will, see Fischer (1999).

[7] *Nicomachean Ethics* (1985), 1109b30–1111b5.

It is important to note that Fischer and Ravizza distinguish two kinds of force: resistible force like threats or coercions and irresistible force. Only the latter is strong enough to exempt someone from moral responsibility. This can happen either when the mechanism issuing in the action is not “the agent’s own”, for example when a brain implant controls my behaviour, or when I fail to be at least moderately responsive to reasons, for example when I am hypnotized.[9] If I am “merely” threatened, say, a robber puts a gun to my head and demands my money, none of these conditions are met: I decide to give him my money because my desire to remain alive makes for a good reason to do so. I thus exercise control over my action of giving the robber my money, and am responsible for that action. Fischer and Ravizza mitigate this conclusion by stating that while I am responsible, given the circumstances I will probably not be considered blameworthy.

As control seems to be an instrumental notion to understand moral responsibility, Fischer and Ravizza set out to examine it. They distinguish two different kinds of control over actions: *guidance control,* which involves an agent’s freely performing an action and *regulative control,* which involves the power to exercise guidance control over an action and the power to exercise guidance control over another action instead (p. 31). Usually, both forms of control are not clearly separated. Fischer and Ravizza give an example where they are: that of Sally taking driver’s lessons in a car with dual controls, one for her and one for the driving instructor (p. 32). Imagine that the car approaches a right turn. Sally steers the car to the right. In so far as she guides the car, freely performing the action of steering to the right, she can be said to have guidance control over her action. However, if she would have turned left, or not turned at all, the instructor would have intervened and steered the car to the right instead. This means Sally has no regulative control, as she could not have caused the car to do anything else than go to the right. Only the instructor has regulative control. This does not mean that Sally is not responsible for her action: she is, because she freely performed it. Furthermore, both bear full responsibility for the consequences: Sally has guidance control over (and is responsible for) the consequences because she has guidance control over her action, and in this case it is reasonable to expect her to know what the consequences of that action will be (p. 121). The driving instructor is responsible for the consequences because he is responsible for the omission of actions: if he does not intervene, that should only be because he approves of Sally's actions. Since he could have intervened and prevented the consequences, he is also fully responsible for their occurrence.

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[8] These conditions are not only recognized by the Anglo-American analytical tradition in which Fischer and Ravizza write. Jonas (1984) adopts them too as he writes: “The first and most general condition of responsibility is causal power, that is, that acting makes an impact on the world; the second, that such acting is under the agent’s control; and third, that he can foresee its consequences to some extent” (p. 90). While Fischer and Ravizza take the causal power of actions for granted, they view the recognition of an agent that her actions have causal power as a crucial part of her becoming a responsible agent.

[9] Chapters 2 and 3 of Fischer and Ravizza’s book deal in more detail with what they mean by “moderate reasons-responsiveness”. Roughly, they claim that an agent is moderately reasons-responsive when he acknowledges that at least in some situations there might be reasons to choose another course of action than in the current situation, and that there should be a pattern to those reasons, e.g. “I will not buy this car if the price is over $5000.”

One more question needs to be answered here: where does responsibility come from? Fischer and Ravizza claim that initially, you have to *take* responsibility. They view the taking of responsibility as a vital step in the life of a human being. By recognizing yourself as an agent, realizing that the mechanism that issues in actions is "your own", you take responsibility for those actions (p. 210).[10] Whoever does not do that will not be recognized as a person, but rather as "a distasteful object or a dangerous (or annoying) animal." (p. 213). Dennett (1984) uses an engineering metaphor to illustrate the concept of taking responsibility: "I *take* responsibility for any thing I make and then inflict upon the general public... (. . .) I have created and unleashed an agent who is myself; if its acts produce harm, the manufacturer is held responsible" (p. 85).

Fischer and Ravizza and Dennett talk about taking responsibility as a human being. Engineers, however, have special responsibilities over and above their basic responsibilities as human beings; this is emphasized by the concept of "role responsibilities". According to the idea of role responsibilities, we each play many different roles in our society: we are not only humans, but also colleagues, parents, supervisors, customers, etc. Each role is accompanied by specific responsibilities which you have to take and internalize in order to properly fulfill that social role. In this light, "being an engineer" can be seen as adopting a certain social role which requires specific training and commitments.[11]

16.3 Use Plans

While Fischer and Ravizza give a nice example of how both forms of control work, they take it for granted that the car works as it should and that Sally and the instructor have adequate knowledge of how it works.[12] Also, there is no mention of the skills needed to drive a car: it seems that guidance control involves at least a basic skill in the action, but this is not explicated. This might be unproblematic for everyday actions like walking and pressing buttons, but especially in the operation of complex technical artefacts skills are important. Lastly, there is no mention of cases in which the engineer might be (partly) responsible, for example when the car would malfunction. How do engineers transfer knowledge about artefact functions to users? Which skills can they assume, and which should they mention explicitly? To deal with these questions I will now turn to the use plan theory (Houkes and Vermaas 2004; Houkes 2006).

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[10] For a critical examination of this claim, see Judisch (2005).

[11] For an elaboration of the concept of role responsibilities, see for example May (1992), Chapter 9, or Mitcham and Von Schomberg (2000). Mitcham and Von Schomberg, however, find that the concept focuses too much on the individual to be useful for engineers. They propose an alternative called "collective co-responsibility" to better fit engineering practice.

[12] Indeed, Yaffe (2000) notes that Fischer and Ravizza never directly address the issue of how physical constraints in general might affect moral responsibility. This chapter should help to at least fill the lacuna concerning the constraints those physical objects known as artefacts place upon us.

The use plan theory investigates the nature of knowledge of artefact functions. Houkes and Vermaas argue that it is better to speak of knowledge of artefact *use*, and that this knowledge is different from “classical” declarative or procedural knowledge. They call this knowledge “use know-how”, which has two components: “knowledge that a sequence of actions leads to the realisation of a goal, and the skills needed to take these actions” (Houkes 2006, p. 105). The first component is called knowledge of a use plan.

Artefacts are designed for embedding in use plans (Houkes et al. 2002; Houkes and Vermaas 2004). Moreover, successful design requires the construction and communication of at least one use plan. This does not mean that such an artefact would only have one use plan: if a sequence of actions with that artefact will lead to the realisation of a certain goal, then that sequence is a use plan, whether it is explicated by the engineer or not. What it does mean is that the use plan constructed and communicated by the engineer defines the “standard use” of that artefact (Houkes and Vermaas 2004).

Use plans can be communicated from engineer to user in a variety of ways: textually (via user’s manuals or written instructions), through pictures or icons, hardwired in the design itself, etc. The engineer needs to communicate more information together with the use plan, however. According to Houkes and Vermaas, “in a rational plan, the user believes that the selected objects are available for use – present and in working order – that the physical circumstances afford the use of the object, that auxiliary items are available for use, and that the user herself has the skills necessary for and is physically capable of using the object” (p. 59). If any of these factors might not be a matter of course, the user should be alerted to it. When communicating the use plan of a car with a manual transmission in a country where automatic transmissions are dominant, for example, it should be mentioned that operating this kind of transmission requires a specific skill. That some countries do not allow you to drive a car with a manual transmission when you have taken your licensing test using an automatic transmission is information important for the social and legal context of driving, but it does not have to be communicated together with the use plan, as it is not necessary for “using” the car itself: it is physically perfectly possible to drive a car with a manual transmission without a corresponding license – as long as you possess a minimal skill in operating manual transmissions.

While reasonable for practical use, Houkes and Vermaas’ requirements can become problematic. After all, there is no clear boundary between what can be regarded as “common knowledge” and what is important or specific enough to mention together with the use plan. To avoid claims of legal responsibility, engineers prefer to include too much over too little. On the other hand, large manuals full of warning signs may deter rather than invite potential users, and the list of possible conditions influencing the operation of the artefact is endless: at some point, even the thorough engineer has to rely on the "common knowledge" of the user. It might also be argued that the user has a certain (role) responsibility to acquaint herself with the intended use plan of the artefact and actively seek out how it is supposed to work. However, this does not diminish the responsibility of the engineer to communicate the use plan, for she still needs to make the information accessible to the user in some way. In practice, what should be mentioned in a use plan seems to depend on a number of factors, for example the risk involved in improper use of the artefact.

Some knowledge might not be necessary to use an artefact, but might help to enhance its lifespan or efficiency. Knowledge of how efficient your engine is at specific speeds is not necessary to drive a car, but it can help you drive more efficiently, using less fuel, saving money and reducing emissions. This "supererogatory knowledge" does not have to be communicated with any use plan as long as it does not significantly affect the artefact's functioning. However, in so far as engineers have to hold paramount the safety, health and welfare of the public, they might be said to be responsible for communicating these aspects of artefact use as well.

What the use plan theory does *not* do is investigate what this transfer of knowledge about artefacts means for the moral responsibility of both engineers and users. This issue will be addressed in the next section.

16.4 Combining Approaches

Here, I will argue that the theories of Fischer and Ravizza, and Houkes and Vermaas can be combined, and that communication of use plans can transfer responsibility from engineer to user by transferring guidance control over an artefact. For this combination, however, both theories need to be extended. The theory of Fischer and Ravizza deals with control over actions; in order to be relevant for engineers, it should include control over (and thereby, responsibility for) artefacts as well. The use plan theory needs to be extended to show that use plans not only transfer a procedure, but control as well to enable the transfer of responsibility. In this section, I will show that both extensions follow naturally from the existing theories.

What do we mean by "controlling an artefact"? Fischer and Ravizza seem to assume this can have two different meanings when they state about their example: "Sally controls the car, but she does not have control over the car (or the car's movements)" (p. 32). Dennett (1984) makes a similar distinction in an example about an airplane: "...The pilot not only strives to control the plane at all times; he also engages in meta-level control planning and activity – taking steps to improve his position for controlling the plane by avoiding circumstances where, he can foresee, he will be forced (given his goals) to thread the needle between some Scylla and Charybdis" (pp. 62–63). I will argue that both forms of control correspond with both forms of control over action.

The first meaning of "controlling an artefact" is really a subclass of control over actions, namely control over actions performed with artefacts. I control my car in so far as I exercise guidance control over the actions I perform with it.

The second meaning of “controlling an artefact” is more similar to exercising regulative control over actions. Artefacts are not passive recipients of human action, but can exhibit behaviour of their own. “Controlling an artefact” can then be seen as ensuring that the behaviour of the artefact does not interfere with the agent’s goals and keeps within certain limits of for example safety and sustainability. More specifically, by exercising regulative control in such a way, the agent will not end up in a situation in which the exercise of guidance control becomes impossible. For example, if I drive in a car and see an icy road ahead, on which I know I might go into a skid and lose control over the car, I can take measures to prevent this from happening such as putting snow chains on the tires. By exercising guidance control over the action of putting snow chains on the tires, I ensure that I will remain able to exercise regulative control over the car. Apparently, both forms of control over artefacts can be reduced to control over actions.[13]

This elaboration enables us to make more explicit what is meant with “being responsible for an artefact”. I will continue my parallel between actions and artefacts here. Fischer and Ravizza distinguish between three main forms of responsibility: for actions, for omissions and for the consequences of those actions and omissions.[14] I will treat responsibility for artefacts as being of a similar threefold nature, including responsibility for actions performed with artefacts, omissions of actions with artefacts, which may either be not performing an action with the artefact, or not intervening in the behaviour of the artefact, and the consequences of those actions and omissions of actions with artefacts.

Now to the second question: do use plans transfer control? To be more precise, I will rewrite this question to: does the communication of a use plan (for an artefact) transfer guidance control (over that artefact) to an agent? If we write the question out with the definitions of use plan and guidance control, we get the question: does communication of a sequence of actions that leads to the realisation of a goal transfer the ability to freely perform those actions to an agent?

The problematic part of this definition is the word “freely”. It would be bizarre to assume that use plans enable someone to act freely if he couldn’t do that in the first place. To provide for this, I will assume that Houkes and Vermaas make the implicit assumption that the agents to whom the use plan is communicated enjoy freedom of action. Indeed, by definition an agent structurally without freedom of action could not be considered an “agent” at all.[15] This assumption will account for the most problematic part of the question.

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[13] Fischer and Ravizza argue that nobody really has regulative control, as the thesis of determinism they endorse entails that people never have the “freedom to do otherwise”. I use “exercising regulative control” here as similar to “choosing” and “deciding”: useful to make sense of our behaviour in everyday practice, but if determinism is true, possibly an incorrect description of what actually takes place.

[14] These are not the only forms of responsibility possible. Dennett (1984), for example, also deals with “responsibility for the self”.

[15] An agent does not need to have freedom of the will to execute a use plan: the use plan might already have been constructed specifically with the goals of this agent in mind. The distinction between freedom of the will and freedom of action is elaborated upon in Frankfurt (1971).

Apart from the freedom condition, there seems to be a second point of attention, namely that communication of an action does not necessarily lead to the physical or mental ability to perform that action.[16] I might be told how to drive a car, or ride a bike, or play golf, but that in itself is not sufficient. I also need to practice, or in other words, to gain procedural as well as declarative knowledge. This problem is removed by Houkes and Vermaas' requirement that it should be mentioned whether specific skills or abilities are needed for the execution of a use plan, like the driving skills necessary to operate a car. In short, if freely performing an action, and thereby exercising guidance control over it, might be difficult or require training for an agent, it should be mentioned together with the use plan. The "ability" in the question is thus reduced to not so much a physical or mental ability, as well as the ability to perform actions "under a certain description."[17] For example, if I know nothing about cars, my actions with them are limited to "turning the wheel" and "pressing the pedal on the right". Knowledge of the use plan also allows me to intentionally perform the actions of "steering to the right" and "accelerating".

The theoretical framework thus obtained can be formalized as follows:

An engineer *E* transfers moral responsibility for an artefact *A* to a user *U* if:

(I) *E* is morally responsible for *A*.[18]
(II) *E* successfully communicates at least one rational use plan *P* for *A* to *U*.[19]
(III) *P* can (under normal conditions) physically be executed with *A*.
(IV) *U* is able to execute *P*.
(V) *U* has access to *A*.

Conditions (I)–(III) need to be met by the engineer to enable the transfer of responsibility. Conditions (IV)–(V) need to be met by the user in order to accept that responsibility. In other words, when an engineer transfers responsibility to a user, the engineer of an artefact enables the user to take responsibility for that artefact.[20] The user thus gains a (forward-looking) responsibility for that artefact, so that if her actions or omissions of actions with that artefact cause harm, she can be held (backward-looking) responsible.

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[16] I assume that all technical components needed to perform those actions are already included in the artefact (e.g. batteries) or readily available. After all, the use plan is explicitly made for a functional technical artefact.

[17] I take the concept of actions under a description from Anscombe (2000).

[18] Specifically, this condition is about forward-looking moral responsibility.

[19] Houkes and Vermaas see the construction and communication of at least one use plan as a prerequisite for "good design".

[20] While an engineer cannot exempt herself from responsibility by fulfilling conditions I–III without an able user present, a user can take responsibility for an artefact (or any natural object) by fulfilling conditions IV–V, assuming he has acquired a use plan *P* in some way and actually tries to execute it (experimenting). Houkes and Vermaas (2004) analyse several ways in which users may aquire use plans.

I will illustrate this framework with an example. Suppose an engineer *E* wants to make a car *A* for user *U* and also wants to transfer responsibility for this car to user *U*.[21] First, *E* has to take responsibility for *A*. Within our society she has already (implicitly) done so by becoming an engineer, designing and constructing the car and providing it to *U*. By accepting her job, her "role in society", she has accepted her role responsibilities, which include in this case being responsible for the artefacts she designs and constructs. Because of this, *E* is morally responsible for the car. Condition (I) has been met.

Second, *E* needs to communicate at least one rational use plan *P* for the car to *U*. *E* has several ways to do this and she will probably use more than one of them. A user's manual might highlight specific features of the car, the car itself is made to "suggest" certain actions: pedals are made to be pushed, the gearstick can only be moved in such directions as to switch to certain gears and so on. Part of the use plan will probably be communicated via intermediaries such as driver's schools, and commercials and advertisements can also alert the user to aspects of the use plan. Because different users might already know different parts of the use plan, some information might be redundant to some users, but this is less problematic than an incomplete communication of the use plan in which case condition (II) might not be met. By these different channels, a successful communication of at least one rational use plan *P* for the car takes place.

Third, it must be physically possible under normal circumstances to execute *P* with *A*. What normal circumstances are, depends on what the artefact is made for: for a space shuttle, for example, they are quite different than for a car. This condition precludes the transfer of responsibility when the artefact doesn't function as stated in the use plan, for example, when it would malfunction due to a construction failure that could reasonably have been prevented. When constructing the car, *E* probably performs various tests and safety checks, which ensure condition (III) has been met, before she gives *U* access to the car. In so far as these tests and checks are required by law, she would not only risk accountability by skipping them but also liability for defects in the car and the consequences thereof.

There are two more conditions to be met. (IV) states that the user needs to be able to execute *P*. *P* assumes certain sensorimotor skills, but its communication should include the mention that minimal driving skills are required to execute *P*. *U* is thus warned that she cannot take responsibility for (driving with) the car unless she has the driving skills needed in order to execute *P*. Assuming that *U* is rational and has no overriding reasons to try and use the car unskilled, she will heed this warning and not try to use the car until she has learned how to drive and is thus able to execute *P*.

Condition (V), finally, states that *U* has to have access to the car: she should be physically able to get to the car and drive it onto the road in order to become responsible for it.

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[21] I will leave out middlemen like car dealers to focus on the transfer itself: the section on the Abcoude dosing lock will deal with a more complex case. Alternatively, you could read "engineer" as "the institution or organization that employs the engineer". The "user" can similarly be an institution or organization.

In this section I have argued that control over actions can be extended to control over artefacts as well, and that use plans can transfer control and thereby responsibility. I have illustrated this with an idealized example of how the transfer of responsibility for a car can occur. In the next section I will bring up a real-life case to further test the theoretical framework, clarifying the distribution of responsibility and identifying issues where further research might be necessary.

16.5 The Abcoude Dosing Lock: A Test Case

Responsibility for traffic safety is a complex issue. I here want to examine a test case with multiple users, where one of the users is a municipality, which has installed a traffic safety system affecting the behaviour of road users. In this test case, control is transferred to the municipality but *not* to the road users. For them, the use plan does not transfer control; rather it communicates the fact that road users do *not* have control over certain actions.

In 2006, the municipality of Abcoude, The Netherlands, installed a "dosing lock" (*doseersluis*) on one of the exit roads. The goal was to reduce cut-through traffic and thereby increase traffic safety in the village centre. The dosing lock consisted of a narrowing of the road, a traffic light, warning signs that only one car could pass every time the light turned green, and a moveable obstacle that would block the road when the light turned red, to sink back in the road when the light turned green. The dosing lock was activated only during rush hours (Abcoude 2006).

The dosing lock was very successful in reducing cut-through traffic. It had an undesirable side effect, however: within half a year, over forty cars had crashed on the obstacle,[22] leading to leakage of oil and dangerous chemicals, many traffic jams and drivers bypassing them by driving over the bicycle path. The lock was disabled for some time while the municipality took extra measures to alert drivers to the obstacle, which apparently has lead to a decrease in the number of accidents.

Who would be responsible, according to the theoretical framework? First, it seems that the engineers have successfully transferred responsibility to the user, the municipality. The engineers have taken responsibility for building the dosing lock (I), and communicated its use plan to the municipality (II), thereby giving the municipality control over the dosing lock – and responsibility for it as well. This use plan could physically be executed with the dosing lock (III). The municipality was able to execute the use plan to realize its goals (IV). It also had access to the dosing lock (V).

Now, the municipality took on the role of "engineer" by having the artefact implemented in a road system used by other users. The municipality thus had a dual role as user (of the dosing lock) and engineer (of the public infrastructure, in this case, the road-with-dosing lock): I will regard their situation as comparable to an engineer who uses existing components to construct a new artefact, commonly called "off-the-shelf engineering", or as Houkes et al. (2002) put it, "brochure engineering".

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[22] The main cause was people driving through the red light (project leader public works Abcoude, private correspondence).

The municipality did construct the road-with-dosing lock for the users, mainly car drivers, of that particular road. Their intention was also to transfer responsibility for the road-with-dosing lock to the road users.

Condition (I) was met in so far that the municipality had taken reponsibility for the road-with-dosing lock as part of its role responsibility for maintaining traffic safety. The communicated use plan for the road-with-dosing lock could physically be executed with it (III). The road users had the ability to use it, in this case, to pass the dosing lock safely (IV). Also, the road-with-dosing lock was accessible to them, indeed, the logical choice to reach some particular destinations (V).

The main complaint of the road users concerned condition (II): they felt that the municipality had failed to communicate certain aspects of the (rational) use plan to them. One particular problem seemed to be that the use plan for the traffic light of the dosing lock differed from that of regular traffic lights. Regular traffic lights leave regulative control to the user: if you are willing to risk the fine, you can choose to drive through a red light. In this case, however, road users mistakenly thought they still had regulative control and could either exercise guidance control over the action of stopping and waiting, or exercise guidance control over the action of driving on. The obstacle prevented users from exercising guidance control over the last action. As the road users claimed they didn't realize that, they held the municipality responsible for the results of their actions, in particular the damage done to their cars.[23] The municipality didn't agree, but they did close the lock down for some time in order to increase the salience of the obstacle by several measures.[24] In other words: they sought to better communicate a rational use plan for the road-with-dosing lock to the road users.

In this test case, the framework has shown that the fault lay not so much with the engineers who designed the dosing lock as such, as well as with the municipality who placed it in a context, designing the road-with-dosing lock, making it clear on which level the success of the transfer of responsibility was in question. In particular, the framework has given a possible reason for why the traffic light of the dosing lock wasn't as effective as it should have been, namely that its use plan differed from that of "ordinary" traffic lights, indicating that special attention was needed for communication of the differences.

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[23] The municipality *did* give control over the dosing lock to emergency services and regional buses, who could turn it off with a remote control if they had to to pass quickly.

[24] In January 2009, the magistrate of Utrecht found the municipality partially liable for two out of three examined accidents, as the safety measures taken at the time of the accidents were judged insufficient.

16.6 Conclusion

In this chapter I have argued that certain responsibilities of engineers for artefacts can be transferred to users. I have also shown how this transfer can take place. I have done this by first summarizing the relevant parts of the theory of responsibility and control by Fischer and Ravizza and the use plan theory by Houkes and Vermaas. I have then shown how both approaches could be combined to support my thesis. I have given an example of how the framework functions and demonstrated its practical merit in helping to indicate the responsible party in the Abcoude dosing lock case.

At the beginning of this chapter, I mentioned the two "Aristotelian conditions" which exempt an agent from responsibility: being ignorant and being forced. Fischer and Ravizza started out working on the second, but the use plan approach seems to have brought us to the first. After all, the communication of a use plan is a transfer of knowledge, relieving the agent of ignorance about an artefact. Is this shift strange? Not if we notice the overlap between the force and ignorance conditions: if an agent has no clue about how an artefact works, he is "forced" to submit to its behaviour just as much as he is "forced" to submit to the laws of nature. However, where knowledge about the laws of nature does not give an agent the ability to control them, knowledge about the workings of an artefact can give the agent control over that artefact, and thereby, responsibility for it.

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Chapter 17
Design Problems and Ethics

Wade Robison

Abstract The intellectual core of engineering is the solution to design problems. Those solutions are embodied in artifacts – software, a bridge, elevators, and so on. An engineer who so designed artifacts as to maximize the harm they bring into the world would be unethical. Ethical considerations are internal to engineering because the introduction of each engineering artifact will produce more or less harm, no matter what the solution may be.

17.1 Introduction

An engineer's decision about what to do to solve a particular design problem does not rest wholly on the crystalline clarity that quantification provides, but on ethical considerations. Engineers may well blanche at the idea. For, they may think, if the design solution depends, even in a small part, on ethical considerations, something qualitative, vague, subjective, and contentious will have found its way into that pristine quantitative realm they think is the heart of engineering.

The standard view seems to be that ethical considerations are extraneous to engineering practice. There may be ethical issues about what people do with what engineers create, but engineers are not responsible for the use others make of what they do. On this view, engineering rests in a pure quantitative world completely separated from the messy world of our lives where we use what engineers create to do good and evil. Engineering has nothing to do with that.

Some engineers might concede that what they create can have ethical implications regarding, for instance, pollution, but think that engineers should concentrate on those aspects of their practice which permit quantitative answers and let others consider whatever may be the qualitative and so contentious moral implications of their work.

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However reasonable these responses may seem, they rest upon a mistaken contrast between engineering and ethics, one that permeates discussions of ethics in engineering texts and rests upon mistaken understandings of both engineering and ethics. As I shall argue, ethics is integral to the solution of design problems. The judgments engineers make in solving design problems are ethical judgments. This is not to suggest that engineers are unethical. It shows that they are.

17.2 Ethics in Engineering

As Henry Petroski has argued, engineers learn best from mistakes (Petroski, 1992, pp. 21–34). Accidents tell us how to do things better provided, of course, we find out what went wrong. So when flood walls are breached, as during Katrina, engineers investigate, and it is always an open question whether the fault lies with the artifact, or with something someone did or neglected to do, or with both.

We cry “Operator error!” if the operator

- is too stupid to have learned what needs to be done (or not done),
- was poorly trained,
- or is insufficiently motivated.

These three possibilities work in tandem. If an operator is intelligent and well-trained, we focus on the operator’s condition. Distracted? Tired? Depressed? Asleep? If the operator is motivated and intelligent, we hone in on the training. If motivated and trained, we hone in on the operator’s intelligence and wonder just how well trained the operator could be.

Whatever we may discover regarding the operator, we still need to examine the artifact in question to determine, if we can, if that contributed to the problem and if so, how. Was there something about the object in question that contributed to or caused the accident? As we well know, there often is.

I will cite just one example here. The crash of a airliner in Columbia that killed “all but 4 of the 163 people on board” has been attributed to the pilot’s error in locking onto the wrong navigational beacon. But part of the fault lies in the data system in the computer. The captain “apparently thought he had entered the coordinates for the intended destination, Cali,” but he typed only an R. “When that letter was entered into the flight management computer, the screen responded with a list of six navigational beacons” (Manes 1996). But “though the names for the beacons at Cali and Bogota both start with R,” and the navigational beacons are ranked from nearest to farthest away, “typing a single R takes a plane toward Bogota” no matter how close any other beacon designated by “R” may be.

The computer accepted “the top entry on the list” – not the Rozo beacon in Cali, but the Romeo beacon in Bogota. That is over “100 miles away and in a direction more than 90 degrees off course” (Manes 1996). When the autopilot kicked in, the plane thus turned away from Cali and directly toward a mountain. It is not likely that even the most experienced pilot would have expected the computer to choose a beacon 100 miles away when the norm is that beacons are ranked by distance, with the closest at the top of the list.

The result was that the pilots spent 66 seconds trying to “follow an air traffic controller’s orders to take a more direct approach to the Cali airport.” They crashed before they were able to “figure out why [or even for some time that] the plane had turned.”

Having a computer take over some of the difficulties of landing can be a godsend to harried pilots, but the computers must be programmed correctly. The pilot made a mistake in this case, but the source of the error was a design problem in the computer database, one likely to cause such errors to occur. The database needs to be redesigned so as not to provoke errors in situations in which stress makes errors more likely and even the smallest of errors can cause great harm.

It is easy enough to find other examples of problems with the artifacts of engineering – the Hyatt-Regency walkway collapse in Kansas City, the Big Dig in Boston, the flood walls in New Orleans. But we do not need other examples to make such an obvious point that things can go wrong with engineering artifacts, sometimes causing great harm. At issue is whether ethics enters into the design of such artifacts.

17.3 An Evil Genius of an Engineer

No one is suggesting that the software in the airliner was deliberately designed to mislead the pilots. But the faults are there, and we can see best how ethics enters into engineering design by supposing an evil genius of an engineer who puts in such faults deliberately.

What could such an evil genius of an engineer do to cause the most harm? Consider the ways in which we all can cause harm – through stupidity, ignorance, or lack of motivation. We all, at some time or another, have experienced difficulties with some artifact or other – the remote for our TV, those automatic faucets – where the fault was clearly ours. We are not bright enough, at least in that area, to learn how to do what needs doing; or we are bright enough, but fail to know what to do; or are bright enough and know what to do, but just do not bother to do it. So a really evil genius of an engineer would so design artifacts that even the brightest, most knowledgeable, and highly motivated would be provoked into making a mistake that would cause harm. The designs would capture the best as well as the rest of us who are not the brightest, most knowledgeable, and most highly motivated.

What would such an evil genius of an engineer do? Deliberately design artifacts that seem to tell us to do one thing to get done what needs doing, but that cause harm when we do it. We are all familiar with such artifacts – stove top layouts that falsely signal us to use one knob rather than another, doors that appear to open one way but open another, door handles that appear to turn one way to open, but turn another, and so on. None of these particular examples may cause great harm, but we need only consider artifacts with far more potential for harm than these to see the problem.

How about designing the control system for a nuclear plant so that the button for releasing the coolant is right next to the button that must be pushed twice a day to vent the system and then make the buttons identical in size, color, and shape and not put a cover over the never-never button? Welcome to the Ginna nuclear plant on the Lake Ontario shore in New York. How about designing a shoulder harness for a car – the Subaru SVX – that fastens across your shoulder automatically and so makes you think you are safe, but puts you at greater risk in an accident if you do not fasten your seat belt as well? As the instruction manual puts it, "severe head trauma" may occur in an accident: the harness may slice your head off. How about designing a truck so the gas tank is outside the internal frame? If the truck is struck from the side, the gas tank is likely to be punctured and explode or leak gas. How about designing a pressure gauge so positioned between the O-rings in shuttle booster rockets that more than moderate pressure, far from ensuring, as intended, that the O-rings are seated, pushes the primary seal out of position?

The list can go on and on, but the point, I hope, is made. An evil genius of an engineer could do much harm in this world of ours, and we are lucky that engineers are not evil. Engineers could easily cause evil, if they wished, by so designing artifacts that provoke harm when used as their design tells us to use them. That engineers could do that makes the decisions ordinary engineers make in designing those artifacts not ethically neutral at all. Those decisions instantiate ethical judgments whether the engineers are aware of making ethical judgments or not. Engineers could cause great harm, and they (generally) do not.

As I say, I am not suggesting that engineers are evil, but, some may think, that makes all the difference. How can ethical judgments be attributed to engineers when they are just doing their job in designing artifacts and are not knowingly or intentionally introducing anything that could cause harm into those designs?

As professionals, we are morally responsible not only for any harm we intentionally cause as professionals, but morally responsible as well for any harms we introduce in what we do as professionals that could have been avoided with proper professional care. I would hardly laud my dentist if he drilled through a tooth intentionally, but I would be as appalled if he were so careless as to drill through a tooth accidentally. We would wonder about his moral character if he intentionally caused me harm, but we do not need to concern ourselves with his character in judging that he has caused me harm by drilling through my tooth. He is supposed to be exercising great care when working on my teeth. It does not matter to any moral judgment we make about his having harmed me whether he intentionally caused me harm or did it by accident. Just so for any professional. We hold professionals morally blameworthy, and rightly so, if through inattention, carelessness, neglect of advances in their field or a failure to do whatever they are obligated as professionals to do, they cause harm.

The last thing we should want from engineers are what I call error-provocative designs, design solutions that provoke mistakes and thus harms from even the most intelligent, knowledgeable, and motivated of users. An engineer who intentionally produced such designs would be drummed out of the profession, but we should also look askance at engineers who unintentionally introduce such problems into designs. Some problems are simply not going to be predictable, of course. There are too many ways in which humans can be stupid to know how to guard against all of them. But many problems are predictable, and for at least those readily predictable problems, engineers are to be held morally accountable should their design solution either encourage or fail to discourage such problems.

17.4 Benign by Design

Engineering solutions are always constrained by at least two different sets of conditions. There are, first, the conditions of the specifications – that the bridge be capable of carrying such-and-such a load, that the software cannot be accidentally disabled by touching any key, that the driver and passengers are not killed if the car is hit by another vehicle of comparable size at such-and-such a speed, and on and on. Then, second, there are the general criteria of efficiency, economy, simplicity, and so on engineers adopt. The simpler a design solution is, for instance, the fewer parts an artifact has, the less likely it will need repair, the more likely it is to be cheap to make, and so on and on.

Suppose we add to these various constraints a fundamental principle for engineering designs:

BENIGN BY DESIGN!

By this principle, engineers are to design artifacts to be as benign as we can make them, and this principle is to be fundamental, first among equals.

Some may think this ludicrous. Engineers work all the time on artifacts whose sole purpose is to cause harm – armaments of various sorts, including land mines, cluster bombs, atomic bombs, white phosphorus ammunition, IEDs (improvised explosive devices) with armor-piercing capabilities, and on and on. Adopting this principle would seem to urge engineers to withhold their engineering expertise from any but benign artifacts – as Athenian women were urged to stop the Peloponnesian War by withholding sex from their husbands.

We must distinguish two different ethical issues here, however:

- What are engineers obligated to do as engineers?
- What are engineers obligated to do as citizens with special expertise?

The latter question is an instance of a general question about what those with special expertise are obligated to do as citizens. Are health care professionals obligated to help the ill in a plague which puts their lives at risk? Are lawyers obligated to defend those they know are serial killers in order to ensure that everyone has a fair trial? These are not easy questions to answer, but they are each what we may call external to the professions in question.

They ask what physicians, nurses, lawyers, and engineers are obligated to do as citizens, not what they are obligated to do as professionals. If I am ill and go to my physician, he has an obligation to examine me and determine, to the best of his ability, what is wrong with me. If I need to sign a contract with someone and so go to an attorney to be sure what I am committing myself to, the attorney has an obligation to read the contract carefully and to inform me, in plain language, what it commits me to. These obligations are internal to the professions in question. They come with the territory, so to speak. You cannot be a physician without being obligated to examine your patients. You cannot be a lawyer without giving legal advice to your clients when they ask for it.

You can be a lawyer and represent, or not, a serial killer. You can be a physician and refuse to practice during a plague. Many will think you ethically irresponsible, but you are nonetheless a physician for all that. Just so, an engineer may refuse to design weapons, but will remain an engineer. The issue of what obligations someone with special professional expertise has as a citizen concerns an ethical issue external to the profession in question. My concern is with what obligations engineers have as engineers, and the principle "Benign by design!" expresses an obligation internal to the profession.

Suppose an engineer is designing a land mine. A land mine is supposed to explode when it is activated by the pressure of something as light as someone's foot passing close by, but will be handled by individuals who must put it in place, who may hold it as an angle (so an engineer should not design the mechanism so it is triggered by pressure pushing it off an even keel), who must cover it to hide it (so that it cannot have a hair trigger because then putting dirt on it would set it off), who must get it to the place where it is to be placed (thus loading it onto some vehicle, perhaps, or carrying it on their backs, jostling it), and so on. The number of ways in which the trigger mechanism could be so badly designed as to cause injuries to those who must store them, move them, and place them in position are many and various. An engineer must figure out the ways in which something could go wrong and then design a mechanism that will not explode prematurely. An engineer has to determine how to make the mechanism benign for those who are to use it. That obligation is internal to the practice of engineering.

Consider three possible responses of engineers being told to design a land mine:

- Refuse to do it.
- Do it, but intentionally design it to explode prematurely, causing harm to those who are using them.
- Do it, but mistakenly design it so it explodes prematurely.

What would we say if the engineers opted for (1)? They made a decision about the role of engineers as citizens, regarding the public good. (2)? They also made a decision about the role of engineers as citizens, but decided that engineers are obligated to use their professional expertise to sabotage projects whose purpose is to produce harm. (3)? We would not think the engineers unethical because of an intentional wrong, but incompetent and so in that way responsible for the harm that resulted.

The engineers who designed the software for the plane that crashed in Columbia were morally obligated, as engineers, to ensure that the software not rank Bogota at the top if "R" was typed in when all other beacon letters ranked the airports by distance from the airplane. That design flaw caused great harm, and the engineers who designed the software bear at least some moral responsibility – as engineers who failed to do their job. Making "Benign, by design!" fundamental to engineering practice is not to address the question of the moral responsibility of an engineer as a citizen, but the moral responsibility of an engineer as an engineer.

Making the principle fundamental does not mean making it absolute so that, come what may, what we design must be benign. A physician's oath to do no harm does not mean that a physician can never cause harm. Sometimes causing harm is necessary to prevent further harm as when a physician gives a vaccine or pushes on various parts of the body to see what elicits pain. Just so, solving an engineering problem in the most benign way possible does not mean ignoring all other constraints and all other principles. We must take everything into account and do the best we can to achieve the ideal.

For engineering artifacts requiring operators, the ideal would be to aim at a design that even someone who is unmotivated, poorly trained, and stupid is not likely to screw up or aim at a design where, when the inevitable happens, no great harm results. The way in which the controls for flaps and wheels on planes are now configured is a good example of redundancy to protect against the kinds of mistakes a tired or distracted pilot can make. The layout is benign by design for those best positioned both to cause and to prevent great harm. Rather obviously, the principle "Benign by design!" can have an effect on engineering practice.

Indeed, it could have an enormous effect. It tells us to mitigate any harms engineering artifacts may create, and harms are as varied and diverse as human life and interests. We can cause harm by making something unsafe; we can cause harm by making things more difficult than they need to be so that we must spend more time and money training those who use it; we can cause harm by using more material than is necessary, by requiring a manufacturing process wasteful of energy and material, by failing to consider how what we design can be recycled or remanufactured, and on and on.

So, for example, if engineers adopt the principle that the artifacts of engineering be benign by design, they ought to strive to produce designs that are benign as possible for the environment. We can cause harm not just for those who use what we produce, but for those who are affected by it after its use. Designing a paint with lead in it causes harm to those who use it, but also harm to those who must live with it after its use. Batteries with mercury cause no harm in their use, but do harm us as the batteries corrode and its components leach into our water supplies.

Engineers ought to strive to produce a design that is easy to operate. If an engineering artifact requires significant training to operate well, costs increase. So does the likelihood of failures because the more highly trained someone must be to operate something, the more likely it is that a failure from a mistake or lack of training will occur.

There are other implications of adopting the principle. Engineers should strive to produce artifacts that, where appropriate, are easy for anyone to use. If the ornamental doors to a civic building are too heavy for the weak and the elderly to open, they need to be changed so that the weak and elderly are not excluded from civic matters. Doors that exclude some from participation in civic matters, or make it more difficult for them to participate, harm those individuals as well as civic society, and a benign design is one that causes the least amount of harm possible.

However, even a fundamental principle must be mediated by common sense, by considerations of cost, and by other constraints that a good engineer will need to take into account. “Benign by design” does not trump all other considerations. Saying it is more fundamental means that other considerations must be considerable enough to outweigh the demand that a design be benign. It may turn out that changing the design of some simple commonplace object so that it is more benign will cause too much confusion because everyone will bring to that object the habits of a lifetime created by using a less benign object.

We know how to design a keyboard so that it is far more efficient than the current design, making better use of our fingers and hands, causing less stress for our wrists, and so producing, in the long run, fewer errors and injuries. But though we would gain efficiency and some mitigation of stress and injuries, we must weigh those against the costs of the inevitable errors that will ensue because we will all approach that new design with the habits in hand, as it were, created by the old keyboard. It is certainly not obvious that the trade is worth making. So “Benign by design!” does not always obviously trump other principled considerations.

We should also note a standard objection to concerns about ethics in engineering. That is that engineers cannot make things so safe that no one could have an accident. But safety is only one of a vast number of considerations brought into play by the principle that we be benign by design. It is a harm to use materials that pollute when there is no necessity to use such materials. It is a harm to use more material than necessary (because, among other things, the harms of obtaining and disposing of that material and the byproducts created by preparing it for use are not trivial). It is a harm to design doors that are too heavy for the elderly to open, and so on and on. The kinds of harms are numerous and varied, and so the principle that engineers be benign by design covers all the ways in which engineering artifacts can cause harm, the safety of such artifacts being only one consideration.

Ethics enters into the design of engineering artifacts because such artifacts can cause harm. Whether they wish it or not, what engineers design will as a matter of necessity be benign or less than benign, and they have some control at least over how benign it can be. There will no doubt be cases where constraints will prevent engineers from producing the most benign design. Some of these constraints are internal. A battery just is a package of chemicals, some of which perhaps must be, with current technology, relatively lethal to the environment and to us. Some constraints are external: the costs of changing a design may be too high. None of these problems affects the ideal that, in the best of circumstances, the most brilliant engineering solution to a problem is one that is completely benign and so is also ethical.

17.5 Quantitative Versus Qualitative Problems

We can readily imagine an evil genius of an engineer, and we can readily imagine engineers adopting as their primary principle that their solutions be benign by design. We can readily imagine, that is, the worst and the most benign of design principles: designing so as to ensure that harm will result and designing so as to ensure, as best we can, that harm will not result.

Any time we introduce harm or what could cause harm into the world, we have a moral problem if we are in a position to preclude that possibility – if the harm is gratuitous because it need not be introduced. That we can imagine an evil genius of an engineer and a benign engineer is all the proof needed that ethics is integral to the design process. Engineering artifacts, that is, can be designed to cause great harm and to be as benign as possible. The latter is morally preferable because it is morally wrong to cause gratuitous harm. In solving the design problems that are the intellectual core of engineering, engineers thus have a moral obligation to provide solutions, as best they can, that at the least do not cause harm. That means that the engineering decision that such-and-such is the best solution to a design problem has moral weight – a negative weight when it causes harm that some other solution, equally acceptable, would not, a positive weight if it is at least benign.

I suspect I will get two very different responses from engineers. One stems from this view being very far from the common belief of engineers. In the Preface to *Essentials of Engineering Design*, for instance, Joseph Walton says that the last of the ten chapters "raises ethical questions that an engineer may face from time to time, the non-mathematical problems that need more than a calculator to answer" (Walton 1991, p. xv). This remark is typical in two ways:

- It implies that engineers will run into ethical problems only occasionally and thus that ethics is not essential to engineering.
- It implies that ethics and engineering differ fundamentally. Engineers pose the sort of problem solved by using calculators while ethics poses "the non-mathematical problems" for which calculators are useless. Engineering is quantitative; ethics is not. The implication is that if ethics were integral to engineering practice, engineering practice would be worse off, muddied by qualitative matters.

This story of the relationship between engineering and ethics is a popular one, the contrast it depends upon permeating our understanding of how the arts and the sciences differ from one another. It is no wonder, given such an understanding, that engineers may blanche at the idea that ethics is integral to engineering. For it matters that there are right answers to engineering problems, answers determined by the nature of the problem and not by what anyone may wish or hope or prefer. Either a particular metal will survive the stresses when used to fabricate the girders of a bridge or it will not. If it does not, the girders and, presumably, the bridge will not survive. So engineers must calculate – using a calculator – the right answer to questions about metals and stress. If ethics were integral to engineering, they may think, the right answers risk being overwhelmed by issues about which there are no right answers.

As I have argued, that is a mistaken understanding both of engineering and of ethics. Embodied in an artifact, an engineering solution will have causal effects. A moral engineer will minimize those that are harmful; an evil genius of an engineer will not. A really perverse evil genius of an engineer will so solve design problems as to maximize harms. We can objectively appraise harms. We do it all the time when we drive, for instance, assessing what harms will likely result from an accident with that somewhat careless driver, what the likelihood is of having an accident, and how best to minimize the possible harm. We may have difficulties with making these judgments, but, I think, engineers make these sorts of judgments all the time in their professional practice.

That brings us to the second response my view is likely to provoke. I can hear engineers telling me, "We're not evil! We're already moral! You are just describing what we already do!" Exactly. I am describing what is already the general practice of engineers and suggesting that once engineers realize that their current practice is driven by ethical considerations, they will widen the scope of their concerns about minimizing potential harms and self-consciously strive to produce ethically better engineering artifacts.

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Chapter 18
Ethics in Innovation: Cooperation and Tension

Merle de Kreuk, Ibo van de Poel, Sjoerd D. Zwart, and Mark C.M. van Loosdrecht

Abstract An ethical parallel study has been carried out during the development of a new technology for wastewater treatment. Different aspects of the network involved in this innovation were studied. These include the inventory of the network, the risks in implementation of the technology foreseen by the different actors in the network and the responsibility for ethical issues, in particular the risks of the technology. Participating in a parallel study made the ethicists part of the network and influenced the discussions in the network, which indirectly affected the direction of the research. In this contribution the researchers reflect on the influence of the ethical parallel study on the innovation itself and on the proper role of ethicists in ethical parallel research.

18.1 Introduction

In the last few years a new wastewater technology has been developed by researchers from Delft University of Technology and the engineering firm DHV. During the development of this new technology, an ethical parallel study was carried out. The ethicists started their project as observers of the innovation process to analyze ethical aspects related to this technology development. They interviewed the different parties within the project (researchers, end-users, and engineers) and organized a group decision room (GDR) session. The results have been analyzed to get insight in the risk perception within the network. Results from the ethical parallel study and GDR have been published in van de Poel et al. (2005) and Zwart et al. (2006). This chapter reflects on the contribution of an ethical parallel research to technology development, the tensions that can occur between engineers and the parallel researchers and the changing responsibility of ethicists involved in a parallel study.

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18.2 The Innovation

Since the late 19th century, the importance of sewage treatment has been generally recognized and wastewater treatment is now common practice in developed countries. Sewage is treated to avoid spreading of water-borne diseases and to remove and convert contaminants before the wastewater is released to surface water. In conventional and widely used biological wastewater treatment plants like the activated sludge system installations have large footprints. Moreover sewage treatment has to deal with many conversion processes (oxidation of organic matter and ammonium, nitrate reduction, biological or chemical phosphate removal etc.). Traditionally, flocculated biomass with low average biomass concentration in the reactors and with low settling velocities is applied to treat the sewage. Because of the low settling velocity of these biomass flocs, large settling tanks are needed to separate clean effluent from the organisms (Fig. 18.1). Besides large settling tanks, separate tanks are needed to accommodate the different treatment processes. Conventional processes need many steps for nitrogen, COD and phosphate removal, with large recycle flows and a high total hydraulic retention time. Surplus sludge from municipal wastewater plants needs different steps to dewater (e.g., thickening and filterpressing) before it can be processed.

Since treatment plants are generally found in densely populated areas, compact systems are needed. To build smaller reactors, biomass should grow in dense structures to increase separation efficiency of biomass and treated water and maintain the energy friendly use of gravity for sludge separation. Sludge that settles better will also lead to an increased biomass concentration in the reactor tanks, and therefore smaller tanks. In the nineties, it was found that the use of sequencing batch reactors (SBR) instead of the conventional continuous systems, could lead to formation of granular sludge under aerobic circumstances (Beun et al. 1999; Morgenroth et al. 1977). These aerobic granules are biomass aggregates grown under aerobic conditions without a carrier material. Due to the compact morphology of the granules, granules settle with a velocity of 12–20 m/h (while flocculated sludge settles with only 1 m/h). This means a short settling time can be included in the process cycle of an SBR based on aerobic granular sludge, to keep the biomass in the system while separate settling tanks become superfluous. Besides these settling characteristics, aerobic granules have a unique layered structure. Due to diffusion gradients inside the granules, the various process conditions usually found in different tanks are now satisfied inside the granular sludge and thus effectively only one tank is needed

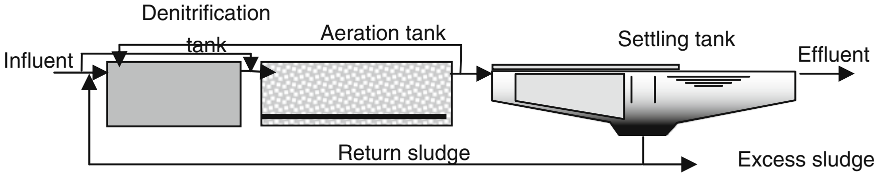

Fig. 18.1 Overview of a traditional sewage treatment plant

without the need for large recycle flows. Laboratory and pilot studies showed that high removal efficiencies were reached with aerobic granular sludge, namely 100% organic carbon removal, 90–95% of phosphate removal and 90–95% of total nitrogen removal (with 100% ammonium removal). Furthermore, in activated sludge systems, the maximum concentrations are 3–5 g/l, while in aerobic granule reactors at laboratory scale 15–20 g/l is feasible (De Bruin et al. 2005; De Kreuk et al. 2005). This leads to an equivalent decreased reaction time, and therefore reactor volume.

Feasibility and design studies showed that due to all aspects described above, the required land area can be reduced to 80% and the energy need can be reduced with more than 30% (De Bruin et al. 2004). Due to the compact building, less construction material (concrete) is used, and building and operational costs are less compared with conventional systems. All these factors can help to increase the sustainability of wastewater treatment significantly.

The development of the aerobic granular sludge technology has been carried out in a close cooperation between a university (TU Delft) and a consultancy company (DHV). For this development a scaling-up and scaling down methodology was used, in which results from laboratory experiments (TUD) were translated into a design of the full-scale plant (DHV) and the bottlenecks for the technical design were translated back to experiments. This combination of fundamental research at a university level and the practical approach of a consultant turned out to be very effective. Knowledge transfer from the university to the outside world led to the rapid application of that knowledge and its implementation in the design of the required installations. The feed back from practice helped in its turn fundamental research to define its course and targets. The technology (brand name Nereda®) is currently applied in industry and sewage treatment plants are designed, the first of which were built recently. Full-scale design and pilot plant research was carried out by DHV in close cooperation with the TU Delft.

18.3 Ethical Issues

The ethical issues in the development of Nereda® technology were recognized using a newly developed network approach to ethics and innovation (Zwart et al. 2006). This approach was developed to take as seriously as possible the moral concerns and considerations of the actors in the development network. It was decided to focus on the ethical issues related to risks and responsibilities. A session in the Group Decision Room was organized with the main actors (researchers, water boards, and engineering firm DHV) from the Nereda® network. A Group Decision Room is an electronic environment used by groups for brainstorming and to caste votes. The GDR-session resulted in an inventory of potential risks, actors' estimates of the seriousness of these risks, and potential gaps in the distribution of responsibilities. It also appeared that actors attached different meanings to some crucial terms. These results were later verified by interviews.

The most serious risks that were mentioned during the GDR session were (van de Poel et al. 2005; Zwart et al. 2006):

- the installation cannot cope with influent fluctuations (volume, composition, temperature).
- the controllability of the granules formation.
- the process fails to meet the primary effluent requirements. The primary requirements refer to the requirements that are currently laid down in the law.

In addition, the following differences between the actors were found (van de Poel et al. 2005; Zwart et al. 2006):

1. Whereas the researchers (and the representatives of engineering firm DHV) employed a notion of risk defined as the product of the probability of an undesirable event times the impact of such an event, a notion that was also suggested at the beginning of the GDR session, the users – i.e. the water boards – seemed to employ a more commonsense notion of risk, in which risk is implicitly understood as a measure for acceptability. Consequently, for some risks, the users' estimates of the probability of a certain accident strongly correlated with the impact of the accident. Most researchers, however, clearly separated probability and impact.
2. Whereas the researchers (and the engineering firm DHV) were optimistic about the new technology meeting the primary requirements, the water boards as intended users of the new process were more pessimistic.
3. The Dutch term "beheersbaarheid" was interpreted in different ways by different participants of the GDR session. The translation of this Dutch term is "manageability" or "controllability." The intended users of the new technology used the term "beheersbaarheid" to refer to *manageability* of the treatment process, i.e., the possibility to run the process whatever the fluctuations in the influent effectively. For the researchers "beheersbaarheid" referred to *controllability* of the process, i.e., knowledge of the mechanisms and the relevant input variables that determine the output variables, even if these cannot be manipulated in practice. According to the researchers the probability of problems with the "beheersbaarheid" of the granules was medium, whereas according to the users it was high. This difference is in line with the ambiguous use of terms.
4. Four out of the five users of the technology delegated the risk of secondary emissions – i.e. emissions not (yet) regulated by the law but potentially hazardous for people or ecosystems – to the research phase, for which they are not primarily responsible, and three out of five researchers allocated the risk to a phase for which they bear no responsibility. Nobody therefore assumed responsibility for dealing with such risks.

18.4 Risks and Responsibilities

The notion of risk is inherently connected to the occurrence of undesirable events or effects. Usually, reducing risks is therefore desirable. The development of wastewater technology has in fact always been motivated by the desirability to minimize health risks, e.g., by avoiding the outbreak of epidemics like the cholera epidemic in the 19th century, and more recently by reducing ecological risks.

Still, it cannot be concluded that reducing risks is always desirable. The reason for this is that risk reduction often comes at a cost. Reducing risk often makes a technology more expensive or it implies tradeoffs with other design requirements. The safest installation may, for example, not be the most sustainable. Deciding what risks are acceptable therefore requires the weighing of different considerations through moral deliberation. For innovative technology, the situation is further complicated by the fact that risks are often uncertain or even unknown during the development phase. Risks first need to be identified and to be investigated before they can be reckoned with. This, however, costs resources like time and energy that cannot be spent otherwise and thus raises the question how much effort ought to be put in the analysis and investigation of risks.

In some fields of engineering, like nuclear engineering, it is common practice to carry out extensive risk assessments before an installation is built. In waste water treatment, systematic risk analysis is not yet widely applied. One reason is perhaps that the risks of waste water plants are usually lower than those of, for example, nuclear plants or chemical installations. Another reason might be that the pace of innovation in wastewater treatment used to be slow. In fact, risks of new wastewater technologies are often supposed to be similar to the ones of the known technologies and engineers use intuitive analogies to estimate the risks of the innovation.

In the Nereda® case, the researchers assumed that the variety of bacteria in the granules was similar to the variety of bacteria in traditional activated sludge plants. Heavy metal adsorption to the aerobic granular sludge had been researched elsewhere and had been published. Based on these results, the analogy seemed correct. However those published studies did not cover all secondary emissions. On the basis of the analogy, it was assumed that the secondary emissions (like pathogens, hormones and heavy metals) of the new reactor would be of the same level as in traditional treatment plants. It is not certain, however, whether this analogy holds. One reason to question the analogy is that in traditional sewage treatment plants the retention time is typically ten hours (Hawkes 1983), whereas in the Nereda, it is approximately four hours (De Bruin et al. 2005). This difference in retention time might make a difference for the removal of certain secondary emissions like pathogenic bacteria. Of course, this does not prove that the risks of secondary emissions are higher with Nereda® technology, but it is at least a prima facie reason to investigate whether the presumed analogy holds water, e.g. through measurements of the secondary emissions during the pilot phase.

Initially the engineers did not investigate the degree of removal of the secondary emissions. The reason for this seems to have been twofold. First, the researchers and the representatives of the engineering firm DHV believed that fast introduction of innovations in wastewater treatment was needed, because of strong worldwide competition. Choices needed to be made between this fast implementation and a thorough research track. It is common practice in such cases to focus on the technology and primary effluent requirements first and to pay attention to potentials risks and secondary effects only later. The next numbers illustrate the latter: in the

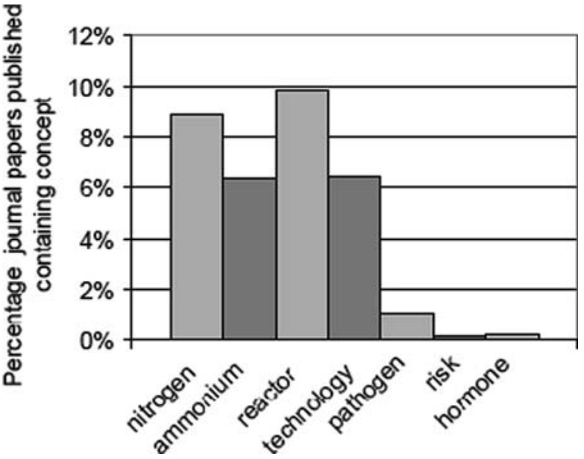

Fig. 18.2 Number of published journal papers in the past 50 years containing the concept sewage or wastewater together with the concept in the diagram

last fifty years, around 1% of the journal papers mentioning the terms "wastewater" or "sewage", also used the term "pathogen" (Fig. 18.2, Source: SciFinder Scholar).

As a result, researchers focused on the technology and effluent-demands outlined in European legislation (primary effluent requirements), rather than on aspects that are more difficult to study or quantify (as measuring the impact/risk of effluent and secondary effluent requirements). Because of the (economical) benefits for society (less space, less energy, cheaper), priority was given to rapid introduction and optimizing accompanying primary effluent demands and granule stability and formation.

The second reason was that, as indicated earlier, nobody assumed the responsibility for secondary risks. All agents allocated the task of dealing with these risks to other agents in the network. This situation can be described as a "problem of many hands" (Thompson 1980; Bovens 1998). This term is usually used to describe the difficulty of attributing responsibility in (inter)organizational settings once something has gone wrong. Here we deal with forward-looking responsibility. Nothing has yet gone wrong, but the question is who is to assume responsibility for investigating the risk of secondary emissions. In fact, nobody did. As it turned out some actors did not assume responsibility because they considered the risk to be very small, others thought it was best addressed by others than themselves, still others held that secondary emissions should not be reckoned with during the development of a new wastewater technology unless required by legislation.

Typically, a problem of many hands did not arise with respect to risks covered by current legislation or which directly hamper the technical and economical feasibility of the new technology. It seems then that secondary risks are more liable to the problem of many hands, even if from an ethical point of view such risks are often as relevant as risks covered in legislation or risks that directly effect technological and economic success.

18.5 New Engineering Directions

In the course of the project, due to the discussions originating from the results of the ethical parallel research, certain issues (e.g. secondary emissions and pathogen removal) became more important than they were before the interviews and the GDR meeting. For reasons outlined above, these topics were initially not studied The example of secondary emissions clarifies how ethics can play a role in innovation: it forces the researchers to think about all aspects of their innovation and to discuss where and at which moment certain aspects are investigated and who's responsibility it is. Even if the outcome would be that it is not an important issue at that specific moment in the development (because of lack of legislation or minor impact on environment or humans), all risks need a conscious judgment where and when to be investigated.

The researchers also realized after the GDR session that they estimated the risk of casualties much lower than the users did. For example, when the probability of not meeting the primary effluent quality was questioned, researchers answered a very low to low probability, while users estimated a high probability (Zwart et al. 2006). So, a direct result of the ethical parallel study was an increased awareness of the researchers about the risk-perception of the end-users. The discussion and mapping of uncertainties in a GDR session have led to a better understanding between end-user and researchers and it forced them to discuss their doubts and risk estimations.

Parallel to the existing track of scaling-up the technology and fast introduction of the Nereda® system, the shift in discussions led to new research projects and proposals. Currently, the researchers are involved in a 6th framework project, funded by the European Union, called INNOWATECH "tailor-made solutions for end-users" (www.INNOWATECH.org), which studies the application of new technologies in industrial wastewater treatment. Aerobic granular sludge is one of the new technologies being evaluated. Research topics include the stability of aerobic granular sludge under extreme conditions and the influence of xenobiotics or other toxic compounds. Attention is given to stability of conversion processes under influence of different influent conditions, common in industrial influents (presence of particulate organic matter, elevated temperatures and toxic compounds like high salinity). The risk that end-users foresaw in the quality of the effluent of Nereda® systems has been an extra stimulus for the researchers to continue investigating the limits of the system. Other (PhD) studies have been formulated to study scale-up aspects (such as hydraulics), microbial ecology, and secondary emissions (such as pathogen removal). These topics were addressed in the GDR too, as risk factors for the success of the new technology. We conclude that, from the point of view of the engineers/researchers, the surplus value ethical parallel research is the clarification of and the instigation of discussion about doubts and risk perceptions. Furthermore, new research questions are formulated, that can lead to new insights, increased knowledge and finally to a better, more robust innovation. Also, this extra research will decrease the economical and environmental risks of introducing the new technology into the market. Consequently, this ethical parallel study contributed to the overall process, research and communication quality.

18.6 The Role of the Ethicists

By carrying out an ethical parallel study during the development of the Nereda® technology, the ethicists influenced the process of development and initiated new discussions. They did so by creating awareness among the researchers and end-users and by presenting the intermediate results. At this point, the fundamental question might be asked whether ethical parallel researchers have a right to influence the research process at all, since they are at best amateur engineers, and their advice might result in deteriorated technical decisions. A superficial, and perhaps even an opportunistic answer to that question reads that the head of the research engineers agreed upon and even looked forward to the collaboration. The question, however, needs a more profound answer since even if the people in charge allow for a non-technical influence from outsiders; they cannot bestow the moral right to them to influence the research. The answer consists of two parts; first, the ethicist never made any technological decisions. If they have influenced the research process, it was indirectly via the consent of other actors in the network. The ethicists helped to increase the awareness among the researchers and end-users of the factual and normative aspects they left out of the considerations, but the ethicists never directly approved or rejected certain research decisions. Even if it is agreed upon that indirect influence in the technological process with the consent of the engineers differs from direct influence by making technological decisions, the former still affects the innovation process. So, the question still might be asked where the parallel researchers get the moral right to do so. This moral right originates in the large impact technology has on society, and the right of members of the public to try to manage this impact. Since, just as ethicists are amateur engineers, engineers are not professional ethicists, it might be thought effective to manage the moral impact of technological research by helping engineers and applied scientist to find out the moral role and impact of their endeavors. The most effective and just way of assisting the professional engineers according to the ethicists involved in this way is assisting the engineers in a bottom up way in discerning and dealing with relevant ethical issues.

As a consequence of this bottom-up approach, the ethicists were not simply passive and independent observers but acquired a new, more participative role. Such a participative role is inevitable in ethical parallel research because the ethicists need the cooperation and trust of the engineering researchers in order to obtain the relevant information. This participative role has methodological implications. The innovation process and the behavior of the engineers that the ethicists observe are not independent from their own – intended or unintended – interventions. The new role of ethicists has also moral implications because it implies new responsibilities and can potentially lead to tensions with the engineers.

Although the influence of ethicists on the project was indirect and overall positive, ethical parallel research can also lead to tensions between ethicists and engineers and even to moral dilemmas. One example is the presentation of the results of ethical parallel research to a broader audience. Focusing on the risks of an innovation can result in a negative (public) perception of the innovation. Like many other sectors, the wastewater treatment sector is conventional and a new technology is often met with skepticism. Moreover, a risk-inventory does not necessarily imply the actual existence of a real risk: especially when probability and impact are separately judged by the actors. For example, the impact of not meeting effluent standards is very high, although the risk of occurrence might be low, since this has thoroughly been tested at laboratory, small-pilot and large pilot-scale. If the actors in a GDR judge the risk for not reaching these standards as high, because of the high impact, presenting that judgment to the public could lead to confirmation of the negative view people often have about new technologies. For such reasons, the ethical researchers should be careful about what to publish and how to phrase their concerns.

The potential tensions between ethicists and engineers regarding the publication of the ethical parallel research results stem from various, potentially conflicting, ethical considerations. One consideration is that the ethicists have to be able to carry out their research independently and to publish about the situation as they see it. Independence is an important academic value as is witnessed by the Netherlands Code of Conduct for Scientific Practice. In this code, independence is described as follows: “When presenting insights as correct and relevant, a scientific practitioner is independent if he allows himself to be influenced by another person’s judgment only to the degree that this judgment is deserving of scientific authority” (VSNU 2007, p. 10). Among others things, this implies that “[t]he possibility of publication of scientific research results is guaranteed. Arrangements with an external financier always stipulate that the scientific practitioner is at liberty to publish the results within a specified, reasonable period of time” (VSNU 2007, p. 9). Independence is important to guarantee the quality of academic research and to avoid that research results are affected by partisan interests. As a general academic value it is not just important for ethicists but for the technical researchers as well.

Another important consideration is that if the public safety or another important value is endangered by a technology this may warrant publication. In fact, this again is not just an obligation for the ethicists but also for the engineers. The first article of the code of ethics of the IEEE (Institute of Electrical and Electronic Engineers) for example requires engineers to make “decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” (http://www.ieee.org/web/membership/ethics/code_ethics.html). Other codes of ethics for engineers are less explicit on this point; they commonly stress, however, that engineers should hold paramount the safety, health and welfare of the public and that the right persons or authorities should be informed if those values are threatened (e.g. NSPE 2007).

Moral considerations may also speak against publication or may at least require a careful choice of words. It is not in the public’s interest when a certain innovation fails because of unjustified bad publicity instead of technical shortcomings or other disadvantages. Ethicists also have a duty to take into account the legitimate interests of the engineers with whom they cooperate. This duty is comparable to the duty engineers have towards their clients, which the code of ethics of the National Society of Professional Engineers in the USA formulates as follows: "act for each employer or client as faithful agents or trustees" (NSPE 2007).

Ethical parallel research thus creates new moral responsibilities or duties for ethicists. In some situations, conflicting moral duties result in a moral dilemma. The codes of ethics for engineers suggest that the safety health and welfare of the public are in such cases paramount and thus override obligations to clients or employers. However, the obligations to the public may not always or in all circumstances be weighty enough to override the obligations to clients or employers (cf. Harris et al. 2000, p. 177; Martin and Schinzinger 1996, p. 110). We think that something similar applies to ethicists doing ethical parallel research. Protecting the public from or informing them about certain risks may be paramount, but the risks may not always be severe enough to warrant publication, or at least to require careful wording of the results. The situation may be further complicated by the fact that the engineers and ethicists involved may disagree, for example about the seriousness of a risk. This need not be a factual disagreement about the magnitude of the risk but can also concern the moral acceptability of a risk, which is not only determined by the magnitude of the risks but also by such considerations where the risk is voluntary, whether alternatives are available and how risks and benefits are distributed (Hansson 2003).

Dealing with the dilemmas that ethical parallel research might introduce, requires not just honest ethicists and engineers but also several institutional safeguards. In particular, we suggest two kinds of safeguards. One set of safeguards should protect the independence and scientific integrity of the ethicists. For example if the ethical parallel research is commissioned by an engineering company developing the innovation, arrangements should be made so that the ethicists can carry out the ethical parallel research independently and as they consider it appropriate. Another set of safeguards should protect the interests of the engineer. For example, the engineers must have the opportunity to comment on the preliminary results of the ethical parallel study and the ethicists should take seriously their comments. In case of lasting disagreement, the publications of the ethicists should describe the disagreement, and the particular reasons for the disagreement should be mentioned.

18.7 Conclusions and Further Research

Ethical research and network analysis carried out in parallel to the development of a new technology can be very helpful in mapping responsibilities and risk perception, and in uncovering possible ethical problems. It was shown that a newly developed network approach to ethics and innovation (among others GDR sessions) contributed to reveal risk perception of the different groups of actors. This research can induce better communication in the network about risks, which leads to improved understanding and solving bottlenecks for the application of the innovation. This may lead to new research and improved technologies. Carrying out ethical parallel research, ethicists encountered new roles and responsibilities. Dealing with these new responsibilities, requires integrity and the willingness to cooperate with the engineers. Additionally, it calls for institutional safeguards to guarantee, on the one hand, the independence of the ethical research and to protect, on the other hand, the legitimate concerns and interests of the engineers.

Finally, regarding future research, it might be interesting to make a comparison between the engineering sciences and other applied sciences such as, for instance, the medical sciences, which are well known for their moral impact. The moral dilemmas related to the advocated approach to ethical parallel research might play a role in medical ethics as well. Studying the similarities and differences between our approach and those practiced in medical ethics therefore seems to be promising future research.

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Chapter 19
Teaching Ethics to Engineering Students: From Clean Concepts to Dirty Tricks

The Impact of Practical Circumstances and Personal Relationships on Ethical Decision-Making

Otto Kroesen and Sybrand van der Zwaag

Abstract Already for many years the faculty of Aerospace Engineering includes a compulsory course on ethics in its MSc curriculum. The course aims at introducing the students to ethical decision making in an aerospace engineering context and is traditionally terminated with a role play re-enacting the fatal decision making process around the launch of the Challenger. The authors report on the setup and experiences of a new role game about a risky maiden flight with a newly developed composite airplane and compare experiences with both role games. In the new role game the outcome is not known beforehand and more emphasis is put on the performance and the quality of the social relationships among the actors. It appears, that relationships of loyalty or distrust, friend or foe, manipulation or authenticity affect the moral quality of the final decision making process. In practice decisions are not only determined by competent reflexive reasoning of lonely individuals, but they are much more the outcome of a group process and hence are strongly affected by the quality of communication. In practical decision making processes there is a constant tension between the moral imperative at stake and practical circumstances and the complexities of gaining enough support among the different group members.

19.1 Introduction

Due to the personal commitment of one of its former professors, Ad Vlot[1] the faculty of aerospace Engineering of the TU Delft has a long tradition of offering an introductory course in which basic ethical concepts and issues are presented

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[1] Ad Vlot was Professor in Fibre Metal Laminates and other Aerospace Materials. He initiated a course on ethics even before the board of the university decided to introduce compulsory ethics courses in all curricula. While fully developing his powers he was struck by cancer and died at a very young age.

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and made operational in an aerospace relevant context. The course has now been a compulsory item of the aerospace engineering MSc curriculum for several years. The principal goals of the course are to make our students: (1) sensitive to moral issues, (2) able to apply a framework of ethical concepts to practical cases and situations, (3) potentially competent players in policy discussions about moral issues in their future profession. Up to two years ago, the course was concluded with a role game related to the "Challenger" space-shuttle disaster. In this role play the attention was focused on the ethical dilemmas only and no attention was paid to the conditions during which the ethical dilemmas have to be appraised. Recently this role game has been replaced by a newly developed role game under the title "ToFlyOrNotToFly". In this contribution we will motivate this change and report on the experiences of the new role game in comparison to the former one. The major difference in the setup of the new role game consists in the fact that personal relationships and the quality of communication have explicitly been made part of the role game. We evaluate our experiences with the role game and extract the benefits other courses in ethics of engineering might gain from including exercises on performance and communication processes in general.

19.2 Description and Analysis of the Original Challenger Role Game

At the end of the 7 weeks (3 ECTS credit points) course a role game about the Challenger disaster (1986) was scheduled in order to train the deliberative abilities of the students and put the theoretical insights the course offers into practice. In this role game the chain of decisions leading to the fatal launch of the Challenger space shuttle under adverse weather conditions was re-enacted. The students are put in the situation of the teleconference which took place on the evening before the launch, where the engineers put forward their concerns and tried to get the launch postponed. Especially Boisjoly was very concerned because for that night very low temperatures were predicted, way beyond the specifications. On the other hand the pressure to go on with the launch was very severe and the data which were available about the relationship between launches at cold temperatures and leakage of the O-rings were not without ambiguity. So the main dilemmas which emerge in the role game are about sound moral judgment under time pressure and about the interpretation and presentation of the relevant information about the problems with the O-rings.

Although the game was in general well appreciated by the students, in some of their evaluations it was pointed out that the game did not fully reflect real life situations as in-retrospect the more correct decision not to launch is known beforehand. Students took this into account in their technical and ethical deliberations during the game, which gave the game a slightly clinical aspect allowing the students to apply the ethical concepts taught during the course in a rather academic, detached setting.

In addition to this criticism, course instructors with a professional experience in industry pointed out that group management decisions are not only made on the basis of the technical input from experts but also by that of non-experts whose input is coloured by earlier personal relationships with the experts in the group creating higher or lower levels of blind confidence in their colleagues. They stressed that personal relationships of trust and distrust, like and dislike, do significantly affect moral decisions and may change the outcome of the deliberations.

This criticism runs parallel to a critical view on the process of decision-making in moral dilemmas in ethical theory itself, especially when approached from a design perspective (Whitbeck 1998). Mostly in traditional ethics a set of moral theories or rules is proposed and exemplified by specific cases, in which mostly an individual must take a moral decision at one specific moment in terms of either/or. If the moral decision process is compared to a design process it is no longer a matter of either/or anymore, but of optimization of different and often contradicting design requirements, to be put in terms of more or less instead of right or wrong (Van de Poel, 2001). In addition it means, that a decision is not a single action taken at one moment in time but constitutes an ongoing process in which the outcome is not predetermined or known beforehand. The group process by which decisions are taken influences the outcome with the result, that the outcome is not only a matter of ethical theory in control of the trained judgment of an intelligent individual, but also of the interaction and performance of the group members. If this is taken into consideration it appears, that moral deliberation is not only a matter of clean and clear-cut rational application of moral values and theories, but an optimization process of the interaction of the group members as well as an optimization process of mostly contradictory moral requirements which are in addition subjected to a time process, which puts different emphasis on different priorities at different moments. In such deliberations the quality of communicative performance influences the outcome, either in the form of authentic and open communication, or of rhetoric, manipulation and dirty tricks (Habermas, 1996).

19.3 Description of the Conceptual Background of the New Role Game ToFlyOrNotToFly

Hence a new game has been developed by us, named ToFlyOrNotToFly, which deals with a hypothetical but realistic situation in the year 2015. The case is about the aftermath of a minor accident with a new TU Delft developed passenger plane which is to have its maiden flight in the presence of national and foreign dignitaries the very morning after the accident. The new plane is built out of a special, in 2010 developed, fibre composite material with nanostructured reinforcements in the adhesive holding the composite together. The new nano-reinforced composite is a fantastic material with excellent performance, but like any fibre composite material it has the undesirable characteristics aerospace that large scale damage, which can jeopardize the integrity and reliability of the component, is very hard, if at all, to detect with the naked eye or more advanced techniques. Even sophisticated NDO (non-destructive observation) techniques have great difficulty in determining the extent of the damage (Aerospace Engineering MSc students are/should be well-aware that fibre composites have this undesirable feature).

The story in the role play goes like this: Very early in the morning an over-stressed employee of DUTCH (Delft University Technology Centre for Hybrids – the fictitious name of the company), embittered by the announced termination of his contract, intentionally drives his fork-lift truck into the junction between the fuselage and the wing. Before he could damage the plane even more, security guards overwhelm the employee and warn the manager responsible for the hall in which the plane was stored, who calls for company experts to inspect the damage. To the great relief of the inspectors there was barely any visible damage apart from possibly the suggestion of a narrow scratch of 15 mm length perpendicular to the leading edge of the wing well outside the reported impact area. Alarmed and informed by the security manager, at around 06.30 the CEO of the company calls together his management team (in total 6 persons) for a meeting at 08.00 to determine, whether the maiden flight can take place as planned or not. The discussions start essentially dealing with the ethical dilemma of flying with a potentially damaged and hence potentially unsafe aircraft. So far the situation is comparable to the Challenger role play but in order to make the game more realistic and to involve the students not only intellectually but also emotionally, the following ingredients were added.

19.3.1 Ethical Balancing is Not a Well Defined Event in Time but the Outcome of a Process

At first only four members of the management team are present. Two other members, among whom the head of engineering, are caught up in a traffic jam. They arrive after 15 minutes, while in the meantime the four people who are present already might have made up their mind as to what should be done. Especially the head of engineering does not want to take any risk with the maiden flight. Other team members are more concerned about the financial risks, which threaten the further existence of the company, if the maiden flight is postponed. DUTCH has made large investments and cancelling of the maiden flight might deter potential customers and it surely will lead to postponement of the actual production and damage the image of DUTCH. The financial situation is such, that DUTCH cannot survive such a blow and will most probably go bankrupt.

Discussions are resumed after the arrival of the two other members of the management team. These late entries can bring in new items in the discussion and can swing the balance in the opinion or even in the decision making process.

19.3.2 Hard Engineering Procedures and Models Can Also Lead to Conflicting Results

After some more 10 minutes of MT discussion the test results of two engineers, who simulated the impact of the accident by means of computer programs become available. The two engineers enter the meeting and present these results. Each of them used a different computer program for the simulation and the results are rather conflicting. According to one computer model it is very unlikely that the damage is severe enough to affect the integrity and reliability of the plane. However, according to the other model there is a real risk for more severe damage at the rear side of the wing, closest to the fuselage, which might result in the breaking of a wing on a harsh landing. At the site of the impact, the wing root, the composite is rather thick as the forces there can be rather large. To offer maximum performance and reliability the rear surface of the wing is constructed in such a way, that it can not be visually inspected except by totally dismantling and reassembling the wing, which would take about two weeks.

19.3.3 The Effect of External Opinions and Public Pressure

The debate continues until finally the CEO takes a decision. Since both the Prime Minister and the Minister of Finance happen to be heavily involved in the technical innovation program which has led to the development of this airplane, they too are informed about the accident and the dilemma: to fly or not to fly? “By phone” they too take part in the final discussions and although they will be wise enough not to take over the decision making role, their stance may influence or even reopen the deliberations in the Management Team, depending on the way the participants in the role game conceive their role. The game ends when the CEO of the company announces his final decision.

19.3.4 Financial Aspects Play a Major Role, Both in Reality and in the Game

Prior to the start of the game the group members are invited (it is not compulsory, but once accepted binding for all group members) to put an amount of money (typically 5 Euro) into DUTCH in order to provide them with the sense of running a real risk. If it is decided to cancel the maiden flight the group members lose their investment, which then goes to a pre-named charity. If the outcome of the game is a decision to fly, then by throwing a dice the outcome of the maiden flight is fixed (throwing a 6 means the plane crashes upon landing). In case the maiden flight is a success the students get their money back (and the supervisor can buy them a drink). Surprisingly, most student groups find it very hard to commit themselves financially even for the modest amount of money to be invested per participant.

However, if they do invest, it brings an enhanced involvement in the outcome of the game and if they don't, they at least got a flavour of the financial impact of these decisions.

19.3.5 Often Participants in Ethical Deliberations Are No Strangers to Each Other but Have a Past and a Mutual Relation

The most important new feature in the new game is the awareness that (established) personal relations i.e. relationships of loyalty and trust or animosity and distrust, play an important role in the moral deliberations. The actual role descriptions given to the students one week before the final role game explain these mutual relationships. The instructions are made explicit to those directly concerned only. So players know whom to like/hate and who likes/hates themselves, but are not informed about other interpersonal relations between other members in the MT. According to the game instructions one of the top managers got his job by bullying other people. Hence some team members got the instruction not to have confidence in whatever this manager comes up with. Another player in the game, who knows nothing about technology, has a good relationship with the head of engineering and fully puts his trust in this person. The head of engineering however has in his role description, that he is a man of little words, but that he stands his ground and will not give in to pressure to put the plane and its crew to any risk. In these and other instances, attention is paid not only to moral issues, and not only to the information available (whether it is clear enough and decisive enough) but also to what we may call the performative content of the role game itself.

The role game involves 11 players and in case the number of students in the group is bigger, the non-playing students (as well as the 6 students who have no active role to play in the first part of the game) are given the role of observer and are required to report on the following four items.

19.4 Analysis of the Ethical Aspects of the Deliberations, Actions and Other Events in the Game

The observers have to report on the normative, performative, informative and responsibility dimensions of the role game. In the introduction to the role game these are described as follows

1. The *normative* dimension: sometimes explicitly, but mostly in an implicit way, all the time the participants in a discussion refer to moral norms and values. Safety, loyalty to the company, not lying, etc. Somebody might say "I am not going public in order not to damage the reputation of the company" – in such a case the norm is loyalty to the company, even without being explicitly

mentioned. The observers keep track of such norms and values, whether implicitly or explicitly referred to, and report on what the impact of these is on the process of decision-making.

2. The *performative* dimension: this refers to the performance of the participants in the discussion, their authenticity, credibility, the impression they make or try to make, and by which they either are open to or manipulate their opponents. For instance, somebody might become angry, somebody may try to give another person the feeling of having said something stupid or somebody tries to give the impression that any normal person would act and speak like he or she. "Are you serious!", or "That's ridiculous!" or "Any normal person would…", are such expressions, by which people try to make room for themselves and push their opponents away. However, questions like "Do I understand correctly, what you mean…?" or "What is your opinion?", are signals of openness and sincerity. Often trust and good relationships, which are necessary for asking such questions, are lacking. If the communication channel is blocked, people stop taking each other seriously. They already "know", that the opponent simply belongs to the opposing party and they do not even try to speak to each other and do not even try to convince or listen to each other. This too belongs to the performative dimension.
3. The *informative* dimension: this refers to the question, whether the information available is presented in a coherent and clear way, without ambiguities and without unjustified shortcuts. It also refers to the question, to what extent the participants in a discussion group build up a reasonable argument or try to do so. Do they succeed in pointing to internal contradictions in the reasoning of the other party? Do they make use of all the relevant information and arguments at their disposal? Has all relevant information for the final decision been made explicit?, if not, why not?
4. The *responsive* dimension. The game is structured in such a way hat the different participants have different responsibilities and different levels of authority. Do the participants live up to their responsibility? Could we expect more from them, or not? The observers are required also to look at the division of responsibilities and authorities. Maybe some actors, like the engineers, have a certain responsibility but lack the authority to speak out or to make a decision. Maybe, there are certain gaps in the division of responsibilities: some information might remain unrevealed or some considerations may not be taken into account because it was not the explicit responsibility of any of the actors to do so. Still, from an overall perspective, it might have been desirable that this information had been revealed or that these considerations were taken into account.

Upon the termination of the game the observers report their findings and the players in the role game will evaluate their roles and the outcome of the game. It can be analyzed and explored, whether a different outcome would have been the result, if some of the players would have acted differently either on the normative, performative, informative or responsibility dimension. Questions can be asked like: have the norms at stake been made clear? Have they become explicitly part of the discussion (something which usually reinforces them)? Could the participants have performed better in terms of open communication? Were they authentic, listening, responsive, open, or using rhetoric, bullying even etc.? And what was the effect of all that? etc.

19.5 Experiences With the New Role Game

The role game has been enacted already many times from 2006 onwards and the plot and the role descriptions have been at some times readjusted on the basis of the experiences gained. For students without much working experience, at least not in the engineering profession itself, it is always difficult to imagine themselves in the role of decision-makers. In order to make it easier for them the role descriptions have been made more specific, so that they can imagine what kind of person this is, what information he has, and what his moral boundaries are and what his typical emotions, good or bad relationships to other persons and what his style of performance could be. In their role description they are instructed to take the relational aspects to fellow MT members not as a straitjacket but make something creative of it, possibly in such a way, that they can believe themselves in what they say and do.

Once the threshold has been taken, students like to play this game. Most of them throw themselves into it and give content to their roles in a very creative manner. They try to defend their position as good as they can and they cling to all sorts of arguments, some of them very realistic, some others far away from reality. It appears, that their playfulness as well as a sense of pride on their profession of being aerospace engineers make them prepared to run a high risk when it comes to this maiden flight. “Even if the airplane goes down, the pilot may save himself”, or “If the wing breaks off at the landing at least the maiden flight succeeded”, or “It is impossible, that such a fork-lift truck can really cause substantial damage”. But there are also moral concerns and it appears, that the outcome of the role game to a large extent depends on the power and vigour, the conviction by which these concerns are expressed by one or more key players. Part of such vigour and conviction is a sound moral or ethical argumentation for the course of action to be taken. Part of it also pertains to the performative dimension of communication.

Indeed, the performative dimension of communication is the big surprise of this role game and it also appears to be the most difficult part both to enact and to digest. Of course most of the performance is spontaneously. Unknowingly and without reflection participants come up with rethorical arguments, exclamations, showing off, making impression by a loud voice and long arguments, try to push each other off track and manipulate each other instead of opening up and creating authentic communication. The observers keep track of such arguments and to their surprise students in retrospect have done much more on the performative level than they originally expected they would. More difficult is it to play with such specifications in their roles like “A has an embroiled relationship with him B, which causes him not to pay attention to whatever B says". This actually is to be expected, because loyalty and distrust, like and dislike do not explicitly enter a decision process, but the quality of such relationships is expressed in connotations and sub-sentences and specific flexions of the voice. Of course, if some participant in the role game remarks "And in addition, I don't like you anyway", this is totally off the record and unrealistic. But the students do discover, that in "open" deliberations much more happens than the exchange of moral points of view and clear arguments.

In general the experience with the new game has shown that indeed interpersonal relationships clearly influence and sometimes swamp the ethical side of the decision making process in the group. Due to the new concept of the game the students have a much better insight into the effect of trust and communication (Habermas 1981) on the quality of the decision making process and also appreciate that ethical reflections are much harder to make under high tension conditions (Rosenstock-Huessy 1981).

19.6 Conclusion: Communication Process and "Moral Dualism"

The experience with this role game might affect learning goals of courses on ethics in general. Although the former role game already went beyond the habitually recognized learning goals for ethical courses in technical curricula in that it also trained the personal ability of students to participate in policy discussions about moral issues, it did not include the aspect of interpersonal relationships and their effect on ethical decisions. If relationships of trust and distrust, like and dislike are integrated into the learning process, students actually are also trained to be aware of such relationships in the process of decision-making and deal with them. The new approach of the final role play in this MSc course also affects the ethical discourse as such, in that it makes it clear to the students that the quality of moral decisions depends as much on the group process as on private deliberations based on theoretical ethical concepts.

Moral judgments and the communicative process within a group do affect each other. Moral norms do not have an abstract existence apart from reality. An individuals judgment may be sound in itself and supported by ethical theory, but if it is not supported by the company, or the team, which has to take the decision, somehow it needs to be watered down in order to survive. For the sake of clarity even this role game in the end puts the students in an either/or dilemma more than a more/less dilemma. Most decision-making processes are not of such a character but constitute an evolving process. In such a process moral claims need to take at least the following four steps in order to be realized:

1. They need to be felt and articulated, i.e. expressly named and put on the agenda. Often this is a matter of minority groups, or daring and creative individuals.
2. They need time, i.e. they need to become part of an ongoing discussion about diverging and partial ways to implement them, full of trial and error, like in a design process.

3. They need to be connected to the former experiences of a group or organization, i.e. the gap between past practices and the new normative claim needs to be bridged.
4. They need some support in existing conditions in the world outside in order to be realistic.

When these four elements come together and follow up on one another, i.e. when these four conditions are considered together (Rosenstock-Huessy 1970), only then an initial new moral imperative can gradually be turned into a matter of fact (and this also means: into procedures and regulations). For that reason we may conclude, that instantaneous moral judgments by individuals need to be translated and re-interpreted in a process of communication and implementation and it is only in such a process that their full meaning is discovered and realized, i.e. translated into practices. In the same process however such imperatives and normative issues and values probably will appear to have a surplus of meaning, that goes beyond that what for the time being can be realized. Crucial for the use of moral judgments to their full potential is the capacity of those involved to keep an eye on that surplus of meaning while at the same time putting such moral claims into practice in a limited and definite sense (Taylor 1989).[2] This is what we could call a sort of "moral dualism", in which the tension remains present between what can be reached at the moment and the unexplored reservoir of meaning for the future.

In the analysis of many cases in ethics this element of a sequence of events through time emerges. In a way it even was present in the case of the Challenger disaster, because it was a long lasting process of neglect, and for that reason an addition of small actions and (in themselves not so critical) decisions, which culminated in the dilemma of the teleconference either or not to launch. The framing however of the role game about the Challenger primarily paid attention to the time pressure and the ambiguity of the technical facts. It did not pay attention to the actual process of communication, the social, relational and performative dimension of the decision-making process. This is fully taken into account in the new role game ToFlyOrNotToFly. It shows that moral decision-making becomes a process of gaining support, negotiating, mutually convincing each other or failing to do that. Adding quality to this communication process amounts to adding quality to the resulting moral decision (Bauman 1993).[3]

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[2] In this respect Taylor speaks about "hypergoods": "An ethical outlook organized around a hypergood in this way is thus inherently conflictual and in tension. The highest good is not only ranked above the other recognized goods of the society; it can in some cases challenge and reject them, as the principle of equal respect has been doing to the goods and virtues connected with traditional family life, as Judaism and Christianity did to the cults of pagan religions, and as the author of the *Republic* did to the goods and virtues of agonistic citizen life. And that is why recognizing a hypergood is a source of tension and of often grievous dilemmas in moral life" (Taylor 1989, p. 65).

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[3] As Bauman says: "Negotiation implies an ongoing process, but also a process without a direction guaranteed beforehand, nor one whose outcomes can be surely anticipated. In such a setting, the triumph of morality is in no way assured in advance; it is touch and go all the way. Neither solemn preaching nor stern legal rules will do much to make the fate of morality less precarious. It is the realization that this is the case, that all and any promises to stop this being the case are – must be – naive or fraudulent, that is morality's best chance. It is also its only hope" (Bauman 1993, pp. 183, 184).

Chapter 20
A Collaborative Platform for Experiments in Ethics and Technology

Peter Danielson

Abstract This chapter describes the NERD platform: a web-based research instrument designed to support collaborative experimental research in the ethics of technology. Starting with our research group's goal to study democratic ethics, we sketch the resulting problems of public participation: the need to reconcile cheap large-scale methods with deep ethical engagement. We argue that our combination of scenario-based surveys and experiments can provide both ethically and experimentally significant data; results from our recent survey experiments support our claims, showing how large numbers of participants evaluate technologies ranging from genetic testing to genetically modified fish and pigs. While the initial use has been focused on the ethics of biotechnology, our approach unifies diverse ethical approaches, from bioethics to environmental ethics and is designed to generalize to any controversial issue with significant technical content. We discuss two aspects of the project of interest to engineers and philosophers: our platform is designed to stress test ethical decision making and some assumptions that social science and philosophy bring to applied ethics.

Spoiler alert: If you plan to participate in our surveys, please visit http://yourviews.ubc.ca *before* reading this chapter.

20.1 Introduction

The Workshop on Philosophy and Engineering addressed an audience committed to the interdisciplinary collaboration of engineers and philosophers in the ethics of technology. The project discussed in this chapter extends this collaborative approach in three ways. First, we argue for bringing social science into the mix, showing how empirical methods can stimulate and improve the ethics of technology. Many of the issues in ethics and technology raise empirical questions: How do different groups

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apply their moral norms (values, principles) to various new technologies? What happens when these moral judgments are challenged by expert advice, group influence, or critical reflection? Genomic biotechnology, on which our research group has worked for the past eight years, yields surprising answers to the first question: the more negative response to genetically modified food in Europe than the US (Gaskell et al. 1999) and the more positive judgments about genomics applied to human health than to food (Ahmad et al. 2008).

Second, we actively collaborate with the public. This is clearly required by our focus on empirical questions about public evaluation. It is also central to our normative orientation highlighted by the title of our first major research project funded by Genome Canada, "Democracy, Ethics and Genomics" 2001–2004. Continuing this project with our current "Building a GE^{3}LS Architecture" 2006–2010 my colleagues and I at the W. Maurice Centre for Applied Ethics at the University of British Columbia, have developed and compared three methods for public participation in the ethics of technology: focus groups (Tansey 2003; Tansey and Burgess, 2008), large group discussions (Longstaf et al. 2006), and online surveys and experiments (Ahmad et al. 2006), the subject of the current chapter. My group, Norms Evolving in Response to Dilemmas (NERD), has developed a unique web scenario-based experimental approach, which we have characterized as "deep, cheap, and improvable" (Danielson et al. 2007). We have, to date, implemented five surveys, collected data from over two thousand participants, tested online vs. face-to-face methods, collaborated with six other research groups, and developed three prototype platforms; see Table 20.1 and Danielson (2007).

Table 20.1 NERD surveys and experiments 2004–2008

Subject	Type	Authors	Platform	Dates	N
Genetics and Human Health (β-Thalassaemia in Cyprus)	Scenario/ experts	NERD team (Bornik and Dowlatabadi)	NERD 1	2004–5;	1107
			NERD 1.5	2007-current	245
Salmon Genomics and Aquaculture	Scenario/ experts	NERD team (Longstaff)	NERD 1	2006	561
Animals in Research	Scenario/ experts	ARCH Animal Welfare group (Schuppli and Weary)	NERD 1.5	2007-current	476
Food Preferences	Survey	UBC Psych (Heine, Henrick and Ruby)	NERD 1.5	2007-current	63
Personality Measures	Survey	NERD Team (Mesoudi)	NERD 1.5	2007-current	73
Salmon Research	Scenario/ experts	cGRASP GE^{3}LS (Secko and Ilves)	NERD 1.5	Expert mode	22
Parallel Ethical Worlds	Scenario/ lay	NERD Team (Mesoudi)	NERD 1.5	Early 2008	
Genomics and Forestry	Scenario/ experts	Treenomix Conifer Forest Health GE3LS (Wood and Bailey)	NERD 2	Early 2008	
Total	–	–	–	–	**2547**

Third, because our collaborations began with technologists in genomics, our focus is broader than engineering taken strictly as a professional discipline. We have explored the use of information and how groups define and assess topics as diverse as genomic research (Burgess 2005), genetic testing (Danielson et al. 2007), salmon genomics (Ahmad et al. 2008; Ilves et al. 2007; Levy et al. 2008; Tansey and Burgess, 2008) and bio-banks (Burgess and O'Doherty 2007). Our extensive collaborations and topics demand approaches to applied ethics broader than engineering or professional ethics. If we are to understand why people react so differently to biotechnological engineering in health, food, and environmental contexts, we will need to draw on normative frameworks that are not tied to one or other of these problem areas.

Wide collaboration across disciplines has costs; in particular, we need to satisfy conflicting methodological demands. My research group's web-based research instrument is designed as a platform to support these collaborations and meet these demands. We will argue in this chapter that our combination of scenario-based surveys and experiments allows us to generate both ethically and experimentally significant data. We sketch the motivation for our approach and the design of our platform and then show how our survey and experimental results stress test moral norms and assumptions social science and philosophy bring to applied ethics.

20.2 NERD Goals and Problems

The NERD platform is a research instrument and our main goal is academic: the advancement of knowledge about ethical evaluation of emerging technology. We face a deep problem of democratic ethics: how to combine large numbers needed for democracy with the serious reflection ethics requires. Our research group saw this problem surface via two methodological objections to the small group based approaches our colleagues use. First, small groups are expensive, so they provide only a small sample that is at odds with our democratic target. Second, small groups are an uncontrolled social environment ill-suited for research on ethics, which is likely to have an important component of social norms (Danielson et al. 2008). We designed our new web-based research instrument as a possible solution to both problems, as it is able to provide large numbers of participants with a controlled cognitive and social environment. In this section, we discuss how our design responded to the problems meeting these two new sub goals, leading to a two method approach with experiments run on top of scenario-based surveys.

20.2.1 Morally Serious Data

The first sub goal is to provide morally serious data about how people make realistic ethical decisions about various technologies. We use the phrase "morally serious data" to mark the difficulty in constructing surveys about moral issues. Surveys are notorious for provoking superficial "top of head" reactions. Indeed, ethics is often introduced by contrasting public opinion surveys as the opposite of serious ethical reflection. Converse (1964) showed experimentally that public opinion surveys could elicit what he called "non-attitudes" towards non-existent policies. To address this problem we constructed our first surveys (β-Thalassaemia in Cyprus and Salmon Genomics and Aquaculture; see Table 20.1) as richer scenarios, providing historical narratives and sources of advice, technical and moral, expert and lay. For example, our survey on genetic testing for β-Thalassaemia moves from the 1970s to current technology by raising twelve issues, with advice from Dr. Getwell on medicine, Rt. Hon. Funds on public policy, Prof. Considerate on ethics and religious perspectives, and a Yes and No Advocate with more direct, "street-level" exhortation. Here we were inspired by the success of the scenario-based computer games, *Sid Meier's Civilization* and Will Wright's *Sim* series, in providing excellent decision support in a motivating, accessible form (Friedman 1998; Wright 2006).

What we learned in these first surveys was that our goal of morally serious data required that we take an *educational* strategy of providing high quality information and advice; lacking relevant information one cannot seriously engage complex issue of ethics and technology. Our explicitly educational stance brought us up against the second problem: in the controversial arenas in which we work, some social scientists reject "privileging" science, education, and expertise; see Goven's (2006) critique of our work. Our strategy was to confront this criticism directly. Admitting that all sorts of biases are unavoidable, we seek to provide a variety of influences – including not only scientific information, but also social pressure and advocates as proxies for social norms – and measure their effect. This brings us to the need for experiments, which we discuss in Section 2.2 below, but first we should note how the scenarios themselves already stress test moral decision-making. Participants are put in a new situation, faced with technically and morally demanding issues they must decide. They may seek advice, but the advisors provided may not agree. They may be given feedback on other participants' choices and advisor usage, adding direct social pressure. Finally, later stages of the scenario reveal consequences of decisions taken, but a "ratchet" prevents participants from going back and correcting earlier decisions when these consequences are unwanted. A text input box allows participants to qualify or explain their choices. None of this guarantees more reflective ethical choice, but educational opportunities abound and we can record those who visit different sources. As we shall see, the resulting data is much richer than most public opinion surveys.

Our first sub goal is to provide significant amounts of this quality survey data, and it is important research data for our team's research on ethical mechanisms. These survey outputs are also important to our technology clients, to whom they provide a broad sample of ethical responses to various aspects of their technology thus the surveys have the indirect importance of motivating our collaborators. We need science and technology collaborators to provide expert knowledge of the various technologies we survey, as well as providing funding and access to participants. These collaborators include two large genomics projects: Genomics Research on All Salmonids Project (cGRASP) and Treenomix Conifer Forest Health.

20.2.2 Empirically Sound Experiments

Our second sub goal is to support empirically sound experiments. We build experiments not only to answer the criticism sketched above but to learn about the process of evaluation and to build better instruments for democratic ethics as well. Instead of bowing to vague metaphors about the social and political construction of science, technology, and ethics, we do controlled experiments on the mechanisms behind these "social forces". Experiments require large random samples for treatment and control; we need to survey large numbers of participants for our survey results to inform us about the morality of real populations and subgroups. Similarly, we need large numbers to make our experimental results significant and to allow us to test more hypotheses. Both sub goals (surveys and experiments) agree on the need for a cheap, extensible instrument.

We chose a web-based instrument for a number of reasons: Internet research sites have been remarkably successful in attracting public participation (Nosek et al. 2002); indeed, they may be the only effective research tool able to reach some previously hidden or underrepresented subgroup of the population (Rhodes et al. 2003); the web is (relatively) anonymous; reaches a broad international sample,[1] and is cheap compared to face to face methods; web users have the time to consult with – and we have the "space" to provide – a rich information context; our web platform is scalable and flexible; our content management system supports varied types of surveys (deep scenarios with complex advisor networks versus simple questions) and experiments; finally, we can collect a vast amount of both quantitative (choices, advisor use paths, timing) and qualitative (comments) data in a database available online to collaborators (selectively).

However, our two methods (surveys and experiments) clash on the issue of participant motivation. Serious moral reflection takes effort; it requires that participants be motivated. We have found that by offering rich scenario-based surveys, we can attract participants on the web to contribute high quality data (see Results below). This does, however, yield a self-selected sample, which undermines our experimental need for a random sample (Fishkin 2006). To meet Fishkin's criticism, we have built experiments on top of our surveys. In our scenario-based surveys, participants are randomly divided into two groups for different treatments (details below). This provides a random sample that is independent of the self-selection bias of the underlying survey.

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[1] Granted, there is a bias toward English, but we are now working on a remedy: our Animal Use in Research survey has been translated into Portuguese by Brazilian collaborators and is currently being translated into Japanese as well. The ease with which our content management system supports internationalization is another way a platform facilitates collaboration.

20.3 NERD Design and Results

20.3.1 Surveys

The first two NERD surveys were intentionally made as similar as possible, with parallel quasi-historical scenarios and advisors. In each scenario the second half introduces genetic and genomic technologies. Figure 20.1 shows the median participant responses on the 12 or 13 questions of the two surveys, respectively. These results are clear, if not surprising, on the two big substantive questions we set out to answer about areas of application of genomic technology. First, genomic technology is approved when used for human health, but not when used for (human) food; second, disapproval in the food case intensifies as the technology "goes genomic."[2] The indiscriminate disapproval in the salmon case surprised us, as participants rejected even upstream genetic modification of the fish food (instead of the fish) linked to substantial environmental benefits.

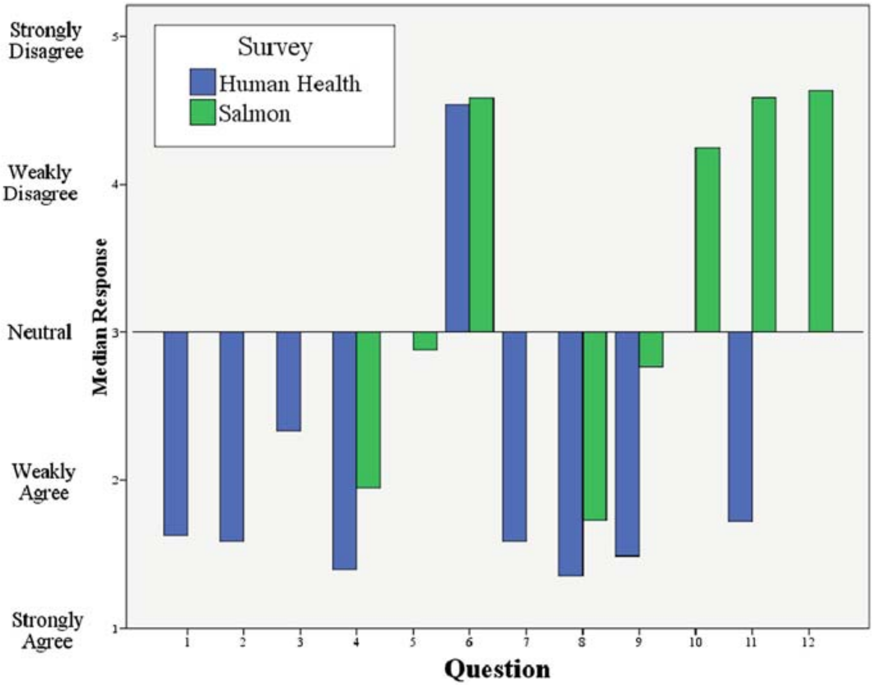

Fig. 20.1 NERD surveys 1 & 2: β-Thalassaemia in Cyprus and Salmon genomics and aquaculture

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[2] The slight upward – that is less approving – trend in the human case is obscured by representation of the neutral median, for question 10.

Our surprise led us to explore new surveys that would further inform these results. Partnering with the animal welfare research group in our Building a GE^{3}LS Architecture project, we constructed a survey about genetic technologies, similar to our salmon cases, but used on pigs instead. The Animal Use in Research survey replicated the non-genomic/genomic transition twice, beginning with a non-genomic technique for each of research on pigs for human health and environmental purposes. Figure 20.2 shows the results, in terms of those approving (selecting Strong Yes or Weak Yes) of the six options. Overall, 69% of respondents indicated that they would support research on pigs to reduce pollution, but this support declined to 55% when pigs were fed GM corn, and declined to 24% when a new line of GM pigs was created. Similarly for biomedical research, 55% of respondents indicated that they would support research on pigs to improve organ transplants, but support declined to 32% when a new line of GM pigs was created. Thus in both scenarios the level of support similarly declined when genetic modification was proposed. However, for non-GM pigs support was greater for research to reduce pollution. These findings agree with previous studies reporting greater public concern about genetically modifying animals than plants. Surprisingly, participants seemed similarly concerned about the genetic modification of animals destined for human consumption as for animals destined for medical research.[3] This confirms (shows the same

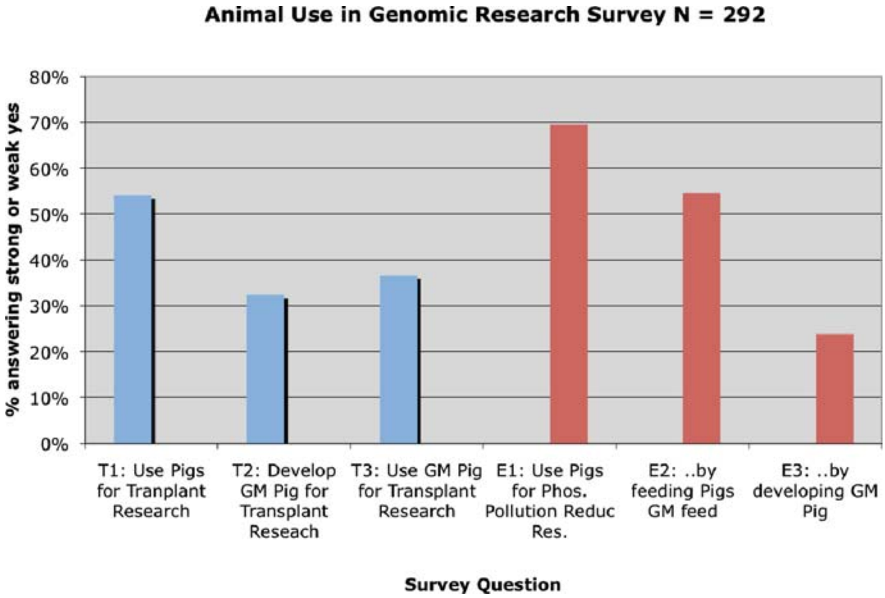

Fig. 20.2 Animal use in research approval: human health and environment

pattern as) the first Salmon survey but indicates more disapproval of genomic technology than the original human health survey that involved no research on animals.

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[3] Adapted from Schuppli and Weary (2007) to address a larger sample.

From a methodological perspective this is interesting because the four cases involved – genetic testing and transplantion on the one side salmon aquaculture and the enviro-pig on the other – fall under applied ethics done in very different traditions: bioethics and environmental ethics. Our methods allow us to compare evaluations made across these sub-disciplines. Indeed, the NERD 1.5 platform, under which the Animal Use in Research survey was run, enrolls participants in a continuing panel, so we can compare individually as well as in the aggregate, how moral judgments are made across these areas (which we will not pursue here).

The panel approach to recruiting participants also plays a role mitigating the self-selection problem with our sample. The Animal Use in Research survey was distributed as an educational device among teachers of courses on animal welfare and related topics in universities in North America and Europe. About one half of these student participants also took the Human Health survey, for which they were not recruited, broadening the demographics of its sample. Similarly, we expect our current surveys on public participation and salmon research, and forestry genomics, to increase the size and vary the demographics of the participant populations of existing surveys and each other. In this way we can increase the empirical significance of our scenario-based surveys while working within the limitations imposed by topics chosen by collaborators. Sharing the participant pool also has the benefit of keeping costs low; we have used very little paid advertising so far. Our low costs allow us to offer our platform to colleagues and students, in addition to well-funded research groups, which again increases the variety of our surveys and experiments and the participants recruited to them.

20.3.2 Experiments

We build our experiments on top of our surveys; while the surveys explicitly ask questions about the moral assessment of novel technologies, the experiments implicitly test hypotheses crucial to the ethical enterprise. Philosophical ethics assumes agents can sufficiently free themselves of social forces and cognitive biases to provide normatively significant evaluations while social science casts doubt on the availability of such ideal agents for applied work. Two general problems are social influence (Mesoudi and Danielson 2007) over an agent's choice by the other participants and the framing effect: cognitive biases induced by the contextual setting, or "frame" of the information presented. (Tversky and Kahneman 1981), showed how participants reverse judgments in equivalent ethical choices set in terms of lives lost or the complementary number of lives saved. However, these experiments do not provide an opportunity for serious ethical reflection. For example, Tversky and Kahneman's (1981) dilemmas are contrived choice problems in an experimental setting, not real issues. By building on our scenario-based surveys, we can experiment with participants making more realistic choices, which should be an environment more conducive for ethics.

To construct the first experiment on social influence we used social feedback as the independent variable. We randomly divided participants in the first two surveys into two groups, Feedback and No Feedback. There was no indication that there were two treatments. On each question members of the Feedback group were shown a graph of the aggregate choices made by members of this group and also text showing the percentage of the group choosing to consult each of the five advisors. Otherwise the two groups saw the same questions and alternatives and had access to the same advisors.

Figure 20.3 shows the results of the first NERD survey from a different perspective than Fig. 20.1. Now we focus on the two randomly partitioned groups, Feedback and No Feedback, and consider only the Likert scale questions. We see that there was a limited feedback effect. Four of the 6 Likert-scale questions – those marked with '$*$' – differ significantly. These results are discussed in Ahmad et al. (2006). We stress that the feedback experiment results are far stronger than the substantive survey results, as they are insulated from the self-selection bias of our sample. Our participants cannot sort themselves into feedback and non-feedback (control) groups. This random partition was imposed on them. We strive to match each scenario-based survey, with its morally rich but epistemologically weak (because self-selected) data, to an experiment with its stronger data.

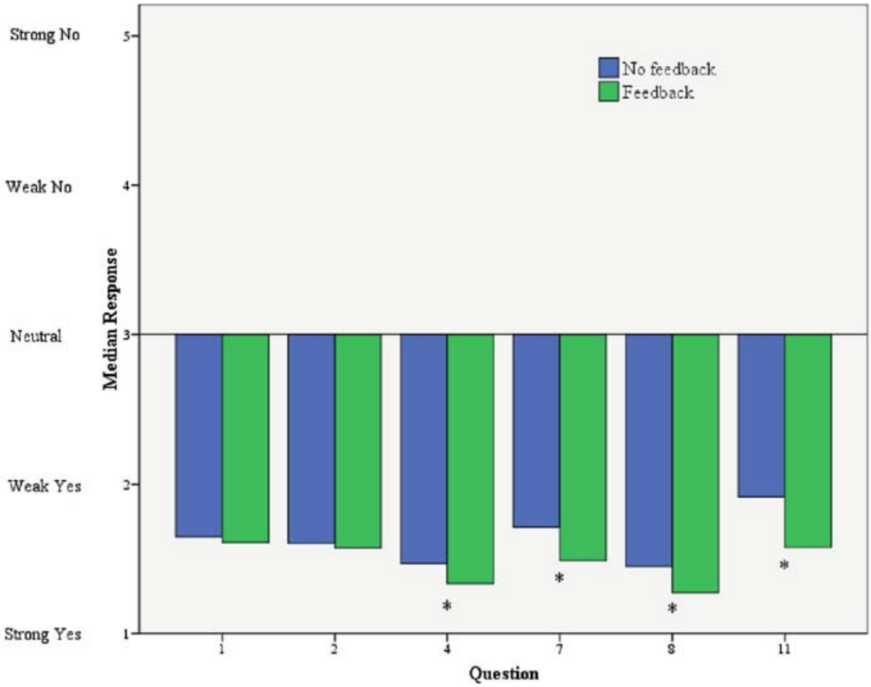

Fig. 20.3 Feedback effects in survey 1

Nonetheless, the form of feedback used in our first experiments is very mild. Our Parallel Ethical Worlds experiment will increase the pressure on participants in several ways. First, based on Salganik et al.'s (2006) experiment on non-moral group influence, participants are separated into small groups, which increases the likelihood of group divergence. Second, the survey questions are designed to provoke controversy: Instead of a scenario binding many questions together, we present a single question on each of five topics, selected to maximize controversy. Advisors, which would tend to unify the experimental groups, are removed. Third, the advisors are replaced with comments from other members of one's group. Fourth, participants are also allowed to publically comment on each other's comments. Salganik et al. (2006) suggests that social factors may cause these groups of randomly assigned participants to diverge in their evaluations due to conformity-driven founder effects and informational cascades. "We can compare the effect of group discussion and aggregate feedback (the 'intervention') by comparing between-group and within-group variation in Likert responses before and after intervention. If group discussion causes responses within each group to become more similar through conformity to the majority and/or the influence of a particularly influential individual, then we should see lower within-group variation after intervention than before. If a cultural founder effect causes each group to diverge in their responses, we should see greater between-group variation after intervention than before" (Mesoudi and Danielson 2007, p. 8).

Complementing these studies of social effects, we have also experimented with cognitive biases. In the Animal Use in Research survey, which we have already discussed, the experimental groups differ in the order in which they are asked the human health or the environmental questions. This experiment, still under analysis, tests for an anchoring bias effect of these beginning with one or the other of these two application areas. Preliminary analysis shows no significant difference between the two groups.

20.3.3 Exploratory Data

Our surveys provide a rich source of data, going beyond the substantive and experimental questions raised so far. For example, the Animal Use survey developed a network of advice in place of the single level of advice used in our first two surveys. This network allows one to measure whether participants went on to explore advice.

Figure 20.4 shows a pair of network graphs generated algorithmically from the data of two participants whose advisor use reveals a striking difference in path.[4] On the right side, participant #679 begins with a comment "It is ethically wrong to use animals in research" and proceeds simply to decide all six issues, regardless

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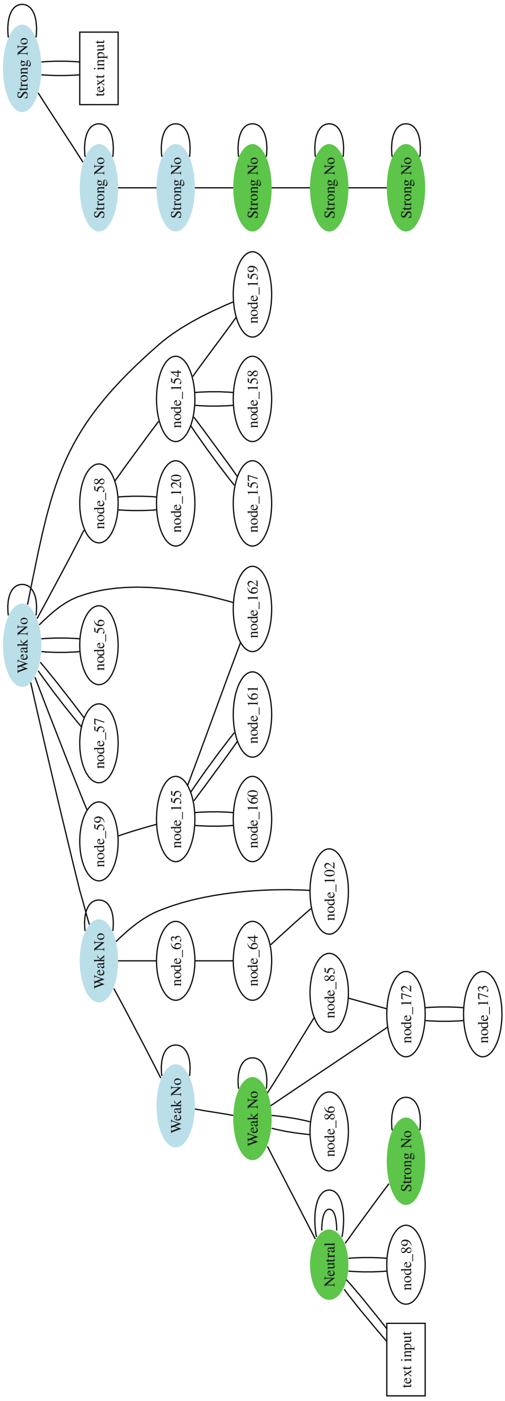
[4] The six filled nodes are the questions and the non-colored ovals are advice pages. The boxes are text inputs; both participants left one comment.


Strong No
text input
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node_154
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node_120
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node_160
Weak No
node_63
node_64
node_102
node_85
node_172
node_173
Weak No
Weak No
node_86
Strong No
Neutral
node_89
text input

Fig. 20.4 Paths of two moral decision styles

of their technical complexity with Strong No, without visiting any advisors at all. On the left, participant #268 is more typical. Although answering “Weak No” to four of the six question, he or she visits several advisors to some depth and leaves a comment explaining the one neutral answer: “Once testing was done to determine that the genetically modified corn was not toxic to the pigs and if they were house[d] in a natural setting, I don’t think I would have a problem with this.” These path networks indicate very different styles of moral decision-making; participant #679’s absolute stand evidently requires no access to additional information. This ability of our scenario based surveys to provide data on cognitive style as well as choices is another way our web-based approach is well suited for collaborative research on moral decision-making.

20.4 Conclusion: Stress Testing Ethical Decision Making and Assumptions

Summing up, we see our approach as a form of stress testing. An engineering idea that brings social science and philosophical ethics together in productive ways. On one level, participants are pressed to produce something normatively deeper than “public opinion”; on another, contending social scientific and normative approaches to the ethics of technology are experimentally tested against each other.

Our scenario-based surveys stress test individual decision-making. We demand a lot of participants and our results show that they respond well to our demands. One measure is the quality of the qualitative data they (optionally) contribute. See the comments from participant #268 above as a example of the general high quality.

The experiments have stress-tested ethical decision-making using social influence and the framing effect. Both experiments have been favorable to the assumption that people are capable of making independent, reflective evaluations. While there is some evidence of social influence, it remains small. On the cognitive side, we found no evidence that the order frame affects the outcomes. Of course, both were applied in mild forms; our current experiments increase the stress in both dimensions.

Finally, our notion of stress testing can be developed in a more normative direction. What sorts of stresses – such as comments from other participants or ranking of contributions by consistency – might further improve the quality of ethical decision making? We have deployed a new platform – NERD-Reasons – which you can explore at www.yourviews.ubc.ca.

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Part III
Reflection

Chapter 21
Why Philosophy? Why Now? Engineering Responds to the Crisis of a Creative Era

David E. Goldberg

Abstract This chapter asks why philosophers and engineers are now meeting together at international workshops and answers from an engineering perspective using an analogy to Kuhn. Specifically, the chapter suggests that engineers are now seeking conceptual clarification using philosophy in the technological crisis of a creative era in the same way that scientists sought conceptual clarification using philosophy in the scientific crisis that came in the wake of the discovery of relativity and quantum mechanics. The chapter starts by enumerating a number of ways in which philosophers and engineers are strange bedfellows. It continues with a cursory sociotechnical review of recent times. It carries on by making the connection to Kuhn, and it concludes with three specific ways in which philosophy can help engineers achieve greater methodological, pedagogical, and epistemological clarity. Although the chapter wonders whether newly philosophical engineers will persist in their reflections, it suggests that, regardless, the encounter should be productive for engineering and philosophy, both.

21.1 Introduction

On the occasion of the first *Workshop on Philosophy and Engineering* (WPE-2007), it seems useful to reflect on what may have caused such a gathering to come to pass and why it may have happened at the present time. After all, philosophers and engineers haven't had much use for each other over the years. Certainly philosophers have been reflecting seriously on technology for some time, and engineers have occasionally waxed philosophical (Mitcham 1994). Indeed there has been the occasional individual engineer turned philosopher (most notably, Wittgenstein), and the occasional philosopher turned engineer (for example, WPE attendee Mark

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Bedau), but – with the notable exception of engineering ethics – a formal meeting of engineering and philosophical minds is a rarity, and the occasion begs us to ask why this event has happened and to question why it has happened at this moment in history.

The purpose of this chapter is to consider these questions from the standpoint of an engineering educator and researcher in the opening moments of the 21st century. I start by considering some of the ways in which philosophers and engineers are odd companions. I continue by examining the unsettling creative imperative of our times, how it has been shaped by certain technological and economic forces, and how these forces may be spurring a reexamination of the nature and practice of engineering. This leads me to consider philosophy as a *crisis response tool* and to call for the injection of three elements of philosophical thought into the education of today's engineers.

21.2 Strange Bedfellows

That a meeting of philosophers and engineers should take place at all is particularly odd if we recount some of the differences between us. On the one hand, philosophers are humanists and engineers are technologists. Philosophers are contemplative and engineers are action oriented. Philosophers are articulate and engineers are sometimes linguistically naïve. Philosophers delight in the ambiguity and the rough and tumble of contradictory positions, and engineers eschew ambiguity with a vengeance. Philosophers pursue reflection in itself, and engineers use reflection as a tool.

With such a load of differences, it seems odd that those gathered at the workshop might have anything to talk about at all, but I hasten to add that generally philosophers and engineers do share a passion for *logic*. Moreover, it is probably safe to assume that the philosophers and engineers brought together at WPE-2007 share a greater interest in technology and philosophy, respectively, than we might find in corresponding populations at large. Nonetheless, the coming together of almost polar opposites deserves a better explanation than can be obtained by citing a single common interest or a fortuitously biased sample of individuals.

21.3 Then and Now

The Hegelian habit of seeking developmental explanations in countervailing forces in history may be useful in this regard. In particular, I see engineering as practiced today as a particular *paradigm* developed in response to the technological, governmental, and economic conditions following World War II. I then argue, as many others have, that our current times demand increased *creativity* and *inventiveness* particularly in the advanced economies in ways that recommend change in engineering patterns of thought.

21.3.1 World War II and Engineering Today

Engineering as taught today can be understood as largely a response to the technological and economic forces in place after World War II. At that time, economies of scale were dominant, large hierarchical organizations were the rule, and engineers became increasingly scientific in response to perceptions of the high and rising status of science after the war. Whether this status was deserved and whether the engineering reaction should have been as strong as it was can be debated (Goldberg 1996); however there is little doubt that these tendencies were reinforced by governmental actions that funded basic scientific research in post-war government labs and universities (Bush 1945), thereby encouraging academic engineers to join what was then a new money chase.

21.3.2 Missed Revolutions

Since the war, technological change has proceeded apace and in broad outline this has resulted in a number of revolutions in commerce and industry:

- Quality revolution
- Entrepreneurial revolution
- Information technology revolution

Even a cursory historical review is beyond the scope of this discussion, but the point at this juncture is to recognize that these revolutions resulted in extraordinary changes in the conduct of engineering as practiced and minimal influence on the teaching of engineering and engineering as researched. The revolutions are missed in the sense that quality methods, entrepreneurship, and information technology are taught in the academy, but they are not integrated into the fabric of universities and colleges in anything like the way they have been integrated into modern business organizations and commerce.

21.3.3 The Technoeconomics of Now

A long tradition in the philosophy of technology is to consider how technology and economics affect social institutions and interrelationships. Particularly important to the present era are transaction costs and increasing network returns and their interaction with the rise of speedy and pervasive transport and telecommunications.

The concept of transaction costs (Coase 1937) is helpful in understanding institutional change in our times. Transaction cost or institutional economics understands that a major factor in determining the size and structure of economic institutions is the *cost of using the market*. Put simply, using the free market is itself not free, and the larger the contracting and information costs of using the market, the more incentive there is for creating a large organization isolated from the market.

The idea of increasing network returns (Arthur 1996) is that certain goods and services, in particular network goods and services, become increasingly profitable when more people use them. This contrasts with many commodities that are subject to normal supply and demand and thus diminishing returns. For example, Microsoft Word is more useful as a medium of document exchange when more people own a copy, and many goods and services of our times have this network character to them.

The telecommunications and transportation improvements of the 20th and 21st centuries have made it possible to contract at a distance in ways that operationalize the smaller company logic of transaction costs. When companies now intone the mantra "stick to our core competence" they are reflecting a technoeconomic contingency of our times, not some newly discovered universal truth. Ironically, the same innovations in telecommunications and transportation make it possible for the beneficiaries of network effects such as Google and Microsoft to seed the globe with their particular products and services.

21.3.4 Friedman, Florida, Pink and All That

A number of current authors (Florida 2002; Friedman 2005; Pink 2005) have looked at the globalizing technological and economic changes around the world and concluded that returns to routine analytical work, including engineering, are diminishing, and returns to *creativity* are increasing. Friedman's *The World is Flat* (2005) has become a shorthand symbol for these thoughts, and flat worlds are almost everywhere remarked. *Pink's* analysis in *A Whole New Mind* (2005) has a number of useful clues for actionable change in curriculum, but a key distinction can be made between the *category enhancers*, workers who merely improve upon existing category of products, and *category creators*, those who are sufficiently creative to develop and market successful new products and services.

The point here is not to follow these analyses in detail, but rather to understand that the world of engineering has changed in a way that demands attention, and to observe that those who teach engineering continue their allegiance to a paradigm developed in earlier times.

21.4 Kuhn and the Response to Crisis

The use of the term "paradigm" in the previous paragraph was, of course, an allusion to the book that made that term famous. Kuhn's *The Structure of Scientific Revolutions* (1970) shook up both the philosophy and history of science in important ways, but here we are concerned with Kuhn's observations with respect to scientists, their response to crisis, and the role of philosophy (1970):

> . . .I think, particularly in periods of acknowledged crisis that scientists have turned to philosophical analysis as a device for unlocking the riddles of their fields. Some have not generally needed or wanted to be philosophers. Indeed, normal science usually holds creative philosophy at arm's length, and probably for good reason. . .But that is not to say that the search for assumptions cannot be an effective way to weaken the grip of a tradition upon the mind and to suggest the basis for a new one. (p. 88)

Kuhn is suggesting that scientists rarely turn to philosophy explicitly except in cases where old scientific paradigms are ripe to be overthrown because of an accumulation of anomalies that resist "puzzle solving" within the rules of the paradigm.

The analogy with the present circumstance is that, like physics at the turn of the 20th century, engineering is in considerable crisis because the paradigm of WW2 and the cold war is increasingly unsuitable to the demands of a postmodern creative age. The next section considers some of the tensions in engineering thought today and their alignment or lack of alignment with the postwar paradigm. The chapter continues by suggesting a few ways in which philosophy may be helpful in clarifying the situation.

21.5 Engineering, the Centripetal O's, and the Missing O

The reliance on science-push engineering unleashed at the end of WW2 continues unabated. Engineering deans like to talk about the O's of 21st century technology: nan*o*technology, bi*o*technology, and inf*o*rmation technology, and without a doubt nano and bio are members of the science-push club. For nano- and biotechnology, the engineering paradigm of the WW2 and the cold war work pretty well, except that the *pace of change* and the relentless push of new products and services into unfamiliar territory *does* up the ante along lines suggested by creative age theorists.

Having said this, information technology responds to both technological opportunity and human concerns in unprecedented ways. Where in the cold war, humans were error to be eliminated from the loop, today humans, in some sense, *are* the loop. Cursory reflection about Google, Ebay, Facebook, and other examples of information technology of our age reveals the integral nature of humans as part and parcel of the systems engineers must design today. Although the push for new categories is as fast and furious as in the other O's, the need to understand another O, *homo sapiens,* and to develop better soci*o*technology pushes engineering into areas where it has only made limited forays. Thus, the challenges of category creation and the challenge of *homo sapiens* in the loop help push engineers to reflect on the nature of their education, training, and occupation. The next section examines some of the ways in which philosophical reflection can be helpful in times where creativity is at a premium and when humans are integrally part of the loop.

21.6 Three Lessons of Philosophy for Postmodern Engineers

The demands of creative and human-centered technology can be particularly challenging for engineers trained largely in the efficient technical refinement of existing categories of goods and services. In this section, we ask whether philosophy can be helpful to engineers as they face the disorientation of the present era and answer by exploring three lessons of philosophy particularly appropriate to the times.

21.6.1 Socrates 101: Creative Times and Asking and Answering Good Questions

We start by turning back the clock to another creative era, the 5th century BC in ancient Greece. The accretion of knowledge human knowledge prior to this time was largely unsystematic and erratic. Socrates changed all that by teaching the world how to *ask* and *answer* good questions. Through this so-called *dialectic* method, Greek philosophers started the long journey of systematically accumulating useful concepts that carries on to this day. From a modern vantage point, Socratic questioning is such a commonplace that we scarcely notice it, and it is now usual to associate Socratic method with pedagogy or formal philosophical inquiry, but the key point is to recognize the importance of dialectic to *creative* endeavors generally.

This latter observation gives us a clue to the importance of Socrates to engineers in a creative era. In times of relative stability of the categories of technological product and service, the problems engineers face are ones of refinement in which largely *quantitative* analyses result in effective design solutions. In times of great change, the categories of product and service are themselves in flux, there is little agreement about what product should be designed, and precedents for what and how to do things are few and far between. In such unsettled times, the Socratic engineer is at a great advantage to the merely calculative one, to use Heidegger's term of derision, and systematic questioning and answering can help define and dimensionalize problems and opportunities in ways that make them more amenable to satisfactory solution. A recent article (Goldberg 2008) argues for the importance of all kinds of *qualitative thinking* to the education of engineers today.

21.6.2 Aristotle 102: Naming and Data Mining in Creative Engineering

The twin notions of categorizing and naming new concepts just alluded to are both critical at a time of creative flux. Returning to ancient Greece, Aristotle is the person we usually associate with the thorough examination of historical or observational data to create a systematic categorical scheme for new knowledge.

The use of such Aristotelian *data mining* and naming skills is also helpful to engineers in a creative era. In the same way that Aristotle dimensionalized his understanding of governments through his analysis of constitutions of his era, engineers can analyze the product offerings of their times to explore lacunae in features or product offerings to promote product innovation and new category creation.

21.6.3 Searle 103: Brute Facts, Social Facts and Postmodern Engineering

The juxtaposition of the strongly *material* engineering of the pre-cold war era and the *conceptual* engineering of our own times begs us to better delineate what we mean by the terms "material" and "conceptual" and thereby get a better grip on the ontology and epistemology of the panoply of things we routinely engineer in our times.

Here we reach, not to Greece, but rather to Berkeley, California and take a page out of Searle's (1997) playbook. The original text should be consulted for complete details, but here we borrow a number of important distinctions and terms as being useful for engineering clarity:

Epistemological vs. Ontological Subjectivity vs. Objectivity. A particularly important distinction Searle makes is that our knowledge of something (epistemology) and its existence (ontology) can both be either subjective or objective. For example, we can take the existence and knowledge of a mountain to both be objective. The existence of a pain in my toe is subjective but my knowledge of it is objective.

Brute vs. Social Facts. Things in the world can be *brute facts*, that is, their existence does not depend on an observer (e.g., mountains) or they can be social facts, that is their existence depends, at least in part, on the *assignment of function* by an observer (e.g., a screwdriver).

Certain Social Facts Depend on Large Numbers of Believers. Searle distinguishes between merely social facts and *institutional facts*. Institutional facts require assignment of function, collective intentionality, and constitutive rules of the form X counts as Y in Z. For example, money isn't money unless a bunch of us believe it is. The same is true about college degrees, marriage licenses, and even language itself.

What any of this has to do with engineering might not seem very clear, but the first thing to notice is an important demarcation between engineering and physical science. In Searle's terms, the usual object of engineering is to invent, manufacture, and maintain social facts, and the usual object of physical science is to understand brute facts.

This is a useful distinction and perhaps we could pause there, but taking another step leads us to recognize our own times as being quite full of engineered institutional artifacts. Searle gives a memorable example of institutional complexity by telling a short story about a patron in a French café. Here, we create a counterpart to the Searlean tale of the café by telling a story about a patron of an online bookstore:

> A young man goes on the Google search engine, searches for an online bookseller, and finds an AdWords advertisement for Amazon.com. Thereafter he signs into the popular online retail site, establishing a new account ID and password, and orders a book using a credit card stored in his user profile. Thereupon, he gets suggestions for new purchases from Amazon's recommender system ("people who bought this book, also bought X"), and he also orders two of those books with a five star rating and good online recommendations. Thereafter, the young man gets a confirmation message via his Yahoo e-mail account, and the books are delivered to his snail mail address by FedEx.

The story is filled with engineered institutional artifacts in a way that makes it clear how important these types of objects have become. Beyond seeking epistemological and ontological clarity about the nature of these items, the little story highlights an important gap in engineering knowledge. Institutional artifacts require a discipline of human-centered design that goes far beyond the usual concerns of human factors, engineering psychology, human-computer interface (HCI) design, or usability studies to better integrate broader sociotechnical systems concerns in a more systematic manner than is usually currently done.

21.7 Conclusions

This chapter started by asking why engineers and philosophers were meeting together as part of a formal workshop. It went on to observe that engineers and philosophers are intellectually and temperamentally quite different to the point of being strange bedfellows. The chapter continued by observing that the times have changed dramatically since the end of World War 2 and that the Internet, transaction costs, and network returns add up to a world that is as disorienting to engineering as Einstein's relativity was to science. Kuhn's argument about philosophy as a crisis response tool is raised by analogy to the case of science; the rise of concern by scientists for the philosophy of science coincided with unsettled scientific times in the same way that engineers are now turning to philosophy in unsettled engineering and technological times. The chapter closed by suggesting three specific elements of philosophical thought to help engineers cope with a fast-paced, creative, and human-centered era.

If the engineering analogy to Kuhn's argument about science is largely correct, we should predict two things. First, the engineering philosophical turn will be fruitful and reassuring to engineers, but the philosophical engagement by engineers will be relatively short lived; after mining the most useful results, engineers will be sufficiently reassured to return to their engineering and they will leave professional philosophizing to the philosophers. Second, the turn will boost activity by professional philosophers in matters of engineering epistemology and method in ways that will augment traditional concerns of the philosophy of technology; philosophers will carry the torch for these studies long after the engineers have returned to their benches and workstations, but the philosophers' studies will be permanently affected by their close encounter with engineering minds. Whether the interactions of engineers and philosophers are the predicted transient phenomenon or something more lasting remains to be seen, but at this juncture the interaction seems important to both groups and pregnant with interesting possibilities. Let the games begin.

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Chapter 22
A World of Things Not Facts

Natasha McCarthy

Abstract When one mentions philosophy of engineering, people often point out that Wittgenstein was an engineer – in order, perhaps, to quell their initial skepticism about the viability of the subject. Although Wittgenstein's engineering background may have had no direct influence on his philosophy, a comparison between a philosophy of engineering and Wittgenstein's later philosophical views can demonstrate the validity and value of the philosophy of engineering. In his later years, Wittgenstein turned to the world, to the context of real human interactions, in order to better understand mind and language and to shed light on previously intractable philosophical problems. If philosophers of science and epistemologists are willing to look at how knowledge is exercised in the world, through the application of knowledge to practical problems as it is carried out in engineering and beyond, they too will get a better understanding of their subject and will get new insight into problems they have wrestled with for centuries.

22.1 Wittgenstein the Engineer

When one broaches the idea of a philosophy of engineering, this perhaps unlikely area of study is often rationalised by the comment: "I suppose Wittgenstein was an engineer." This is not as glib a remark as it might seem, as echoes of his engineering past do run throughout Wittgenstein's philosophy. For a start, in the *Philosophical Investigations,* Wittgenstein opens his analysis of the nature of mind and language with a vignette set in a building site, and the work features recurring comparisons between words and language on the one hand and tools and controls on the other.

These examples in themselves do not, of course, prove any close connection between Wittgenstein's philosophy and engineering – Wittgenstein makes similar

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points through analogies he constructs between language and games. Moreover, straining this particular analogy risks misrepresenting the engineering profession which extends some way beyond the building trade or locomotive driving. Hence, I do not believe that there is, necessarily, some direct connection between Wittgenstein's relatively brief period of studying aeronautical engineering and his philosophy.[1] However, I intend to show that there are deep and enlightening resonances between the ideas that Wittgenstein developed in his later philosophy and the lessons of a philosophy of engineering; and that Wittgenstein's later approach to philosophy shares common features with both philosophy of engineering and engineering method itself. The point of making this comparison is to show that philosophy of engineering has a real contribution to make to the philosophical landscape and that it makes novel progress on philosophical questions that have persisted for some time.

22.2 Science, Engineering and the Two Wittgensteins

Philosophy of science has a relatively long and established tradition, but has generally excluded engineering from its compass. This could be attributed to the fact that science tends to be germane to philosophical reflection because the traditional methods of philosophy match well with the nature of scientific method.[2] In both science and philosophy analysis is the essential method and abstraction from reality and idealisation of the subject matter are permitted (and often necessary). Engineering is a practical pursuit, ultimately focussed on the real world, not the idealised conditions explored in the lab or the armchair. Its very nature and purpose requires that engineering deal with complexity, contingency and context. Thus it is not a natural bedfellow of traditional, a priori philosophising.

The methods in the *Tractatus Logico-Philosophicus* are very closely akin to traditional analytic philosophy and therefore to scientific method. The work traces out Wittgenstein's vision of logical atomism, and there is a clear and overt analogy with chemical analysis in the work. The opening statements of the Tractatus, which claim that "the world is the totality of facts, not of things" (Wittgenstein 1961, 1.1), set out the central idea of the *Tractatus*, that reality consists of true propositions and that the nature of reality can thus be discovered by analysis of propositions to find their ultimate logical form. This logical form will reveal the states of affairs that pertain in reality. This approach tempts one to say that the *Tractatus* was a work produced in lab conditions, where language is dissected outside its conditions of everyday use.

When Wittgenstein produced the *Philosophical Investigations* he broke free of the laboratory and moved away from this method of philosophy-as-chemistry. The main change of direction for him was to abandon the idea of analysis and to look instead at language in the context of its use. He sought only to describe the way that language functions rather than to dissect it to discover *how* it functions. The lesson of this new perspective is that language displays great variety – a point he illustrates with one of his first references to tools:

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[1] Indeed, Wittgenstein's study of aeronautics seems to have served mainly to furnish him with a swift route to Bertrand Russell's mathematical philosophy. See Monk (1990, Chapter 2).

[2] See Samuel Goldman (2004).

> Think of the tools in a tool-box: there is a hammer, pliers, a saw, a screw-driver, a rule, a glue-pot, glue, nails and screws. – The functions of words are as diverse as the functions of these objects. (Wittgenstein 1958)

He also seeks to diagnose the mistaken reasons for thinking that all words function in a like manner, that there is a single fundamental mode of functioning of language, and again he does this through an engineering-related analogy:

> It is like looking into the cabin of a locomotive. We see handles all looking more or less alike. (Naturally, since they are all supposed to be handled.) But one is the handle of a crank which can be moved continuously (it regulates the opening of a valve): another is the handle of a switch, which has only two effective positions... a third is the handle of a brake-lever, the harder one pulls on it the harder it brakes; the fourth, the handle of a pump: it has an effect only so long as it is moved to and fro. (Wittgenstein 1958)

As I suggested earlier, this analogy might be accidental (lots of things are various in nature, not just tools) except that the analogy between words and tools runs deeper than bringing out the variety in the kinds of words and the way that they work. An important lesson of the *Investigations* is that grasping the meaning of a word consists in knowing how to apply it and that understanding is, for the most part, an ability. Understanding is manifested by knowing *what to do* rather than having some introspectible mental state:

> The grammar of the word "knows" is evidently closely related to that of "can", "is able to". But also closely related to that of "understands". ('Mastery' of a technique) (Wittgenstein 1958)

Hence, in the Investigations Wittgenstein sees understanding and knowledge not as essentially states of mind, but as skills and techniques. Thus we can say that words and tools are similar not only because they both have a wide range of functions, but also because using them involves mastery of a technique, the development of a skill, rather than being in a particular state of mind or having something "in one's head". This view of knowledge or understanding of meaning has a strong resemblance to a popular analysis of what it is to have engineering knowledge.

22.3 Engineering Knowledge

One of the key questions a philosophy of engineering might ask concerns engineering knowledge. What is the nature and role of knowledge in engineering? Is the knowledge used in engineering simply scientific knowledge applied to practical problems? Do engineers create new knowledge?

The view that engineering is "merely" the application of scientific knowledge is to fail to appreciate the role of the engineer. Although engineering relies heavily on mathematics, physics, chemistry and increasingly biology, it is not a trivial matter to move from these scientific theories to the development of useful and reliable artifacts. This is well argued by Walter Vincenti (1990). There is a great deal of scientific and mathematical theory associated with the functioning of the products of engineering – e.g., fluid mechanics describes the physical processes essential to understanding the functioning of aeroplanes – but understanding the theory does not in itself give one the ability to master the processes that are needed to apply this theory in constructing a complex artifact. Nuclear science might be the foundation of nuclear engineering, but an appreciation of it alone does not impart the requisite knowledge to design a plant that will harness nuclear energy in order to generate electricity.

The distinctness of engineering knowledge is made clearer if one considers examples where it is exercised in the absence of any mathematical or physical theory to be applied. The development of the steam engine is the paradigm case – developed and perfected (most notably by Smeaton and Watt) in the absence of the theory of thermodynamics which describes its behaviour. It was only by observing functioning steam engines that Sadi Carnot developed his theories of their functioning, paving the way for a science of thermodynamics. Yet their existence was due to the exercise and refinement of engineering knowledge, knowledge of how to build, and to build better, the steam engine. This distinct engineering knowledge is not manifested in theory but in practical knowledge, in what is referred to as engineering "know-how". To understand the nature of engineering knowledge is thus to understand the nature and role of this "know-how".

Extending Wittgenstein's analogy with basic tools gives us a preliminary idea of engineering know-how: knowing how to tighten a nut just to the right point, without turning it too far, is a skill, more or less ineffable but based on experience and on learning what "feels right". Using a spanner to tighten a nut is not engineering, but many, probably most products of engineering depend for their success on people possessing just this tacit knowledge. A bridge design will be developed with use of mathematical analysis, much of which will concern how to build a bridge that is safe; but the safety and functionality is also crucially independent on the tacit knowledge of those who executed the construction of the bridge. Knowing how to bridge a bridge will include knowing how to do these essential aspects of construction. Vincenti has a particularly nice way of putting this:

> By the nature of things, some of what had been learned about flush riveting could only remain in the neuromuscular skills of the workers and the intuitive judgement of the engineers.[3]

Vincenti here includes both the experiential know-how of manual workers and hints at more sophisticated forms of tacit knowledge. Often complex and critical processes in engineering are dependent on tacit knowledge or intuition. It takes a great deal of engineering experience to be able to foresee and diagnose failures in a system – the uncertainty associated with possible failure (i.e., failures cannot always be simply predicted from given conditions) means that it is never possible to simply list potential failure modes and thus learn to identify them by rote learning of a set of rules. Even the process of breaking a complex engineering problem down into parts requires the exercise of intuition rather than the application of explicit rules simply because there are generally no ultimate "joints" in a complex system – it is a network of interdependent parts. Furthermore, engineers have to deal with situations that are always different from situations they have previously encountered – different clients, with different needs and different tolerances for risk and uncertainty, based in different geographical situations and so on. Hence, the experience engineers acquire cannot simply be reduced to a set of rules for decision-making that they have gleaned from previous experience. Much engineering knowledge is thus related to the basic kind of know-how described above, a sometimes painfully acquired ability to sense when something is right, and will work.[4]

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[3] Vincenti, *What Engineers Know and How They Know It*, p. 188.

On a deeper level, knowing how to use a tool is central to engineering because engineers use mathematics and physical theory as tools.[5] Mathematics and physical theory are not straightforwardly applied in that theories are developed which engineers then use in order to build something which instantiates a given theory. Rather, engineers make use of existing mathematics and physics in the process of designing and refining systems for which a need has been independently identified.

Engineers make use of these theories in pursuing their own ends. Thus an essential aspect of engineering knowledge is knowing *how* to apply mathematics and theory, knowing which theory is appropriate and what its limits are and how to adapt it for non-ideal situations. This know-how, rather than knowledge of the mathematics or theory itself, is what is essential to and characteristic of engineering. Engineers have the skill to do this precisely because they are accustomed to using tools in their work – to finding the right tool and using it correctly. It is this knowledge that differentiates engineering from pure mathematics or science, in which knowledge of how to identify situations in which a given model or theory applies is rarely required.

22.4 The Lessons of a Philosophy of Engineering

This analysis of engineering knowledge has revealed something interesting and distinctive about engineering and has shown that this resonates with Wittgenstein's views on understanding (understanding primarily, but not solely, of meaning). However, these findings also have application to wider philosophical problems. Applying them will reveal further correlations between Wittgenstein's philosophical method and philosophy of engineering.

First we can point out a match between Wittgenstein's approach to philosophical problems and the engineer's approach to a problem. Wittgenstein's view in the *Investigations* was that many philosophical questions are the result of misconceptions and that philosophy's proper job is to dissolve these problems by attacking the misconceptions. Thus, Wittgenstein suggests that investigation of the questions themselves, rather than the subjects of those questions (the nature of mind, or knowledge for example) will have greater results in philosophy. Wittgenstein writes:

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[4] I am grateful to John Turnbull FREng for discussion with him on this point.

[5] Samuel Goldman argues this point in his Goldman (2004).

> For the Clarity that we are aiming at is indeed *complete* clarity. But this simply means that the philosophical problems should *completely* disappear.
> The real discovery is the one that makes me capable of stopping doing philosophy when I want to. (Wittgenstein 1958, p. 133)

Thus a great deal of Wittgenstein's work involves undermining the assumptions that underlie traditional philosophical questions. His comments on the nature of mind seek to overturn the view, established by Descartes, that the mind is a private theatre and all mental phenomena is private, inner experience. His comments on knowledge seek to show that traditional epistemological problems like the difficulty of addressing fundamental sceptical arguments are not consistent with the way we understand and use the term "knowledge". In both cases, careful philosophical observation leads Wittgenstein to expose the assumptions underlying the questions that philosophers seek answers to. By so doing, he does not arrive at the answers, but solves the problems that lie behind the questions.

This echoes engineering's approach to problems. Although engineering does not seek to dissolve the problems it addresses, it does seek to overcome them. This contrasts with science where answers to questions are sought; where explanations, rather than resolutions are the goal. The engineer will do this by spending time ascertaining whether the right questions have been posed. The engineer knows well that a problem, or a specification for a solution to that problem, may well be based on preconceptions which, if put under pressure, show that neither the problem nor the proposed specification were properly conceived. Though the engineer is employed by a client to carry out the work bid of him, the good engineer will not simply deliver the solution that the client requests (if the client does so) but will work with the client to devise the best solution.

Secondly, and at the meta-level, we can show that a philosophy of engineering can be used to interrogate the premises of traditional philosophical problems and potentially overcome them. Two examples follow to show this.

22.4.1 Engineering and Cartesian Doubt

Expanding our concept of knowledge to include engineering knowledge can provide a new perspective on fundamental epistemological questions. An important aspect of engineering knowledge in addition to its status as "know how" (as described above) is the fact that it is most often *shared* knowledge – shared by researchers, design teams and even whole corporations. Complex engineering projects are on such large scales that many people work on them in disparate locations, yet work together to find a result. Take, for example, the development of the Airbus A380, the current largest passenger plane. Developing, testing and constructing an aircraft of this size was not simply a matter of copying what had been done before on a larger scale, but posed novel challenges due to the new services that Airbus planned to incorporate into the plane. The fact that there were novel challenges involved was evidenced by the fact that the project hit upon (sadly common) delays in delivery. Learning how to solve these problems resulted in new knowledge and understanding that will be of value to future projects. However, this is not knowledge held by any one person or team, for many of those people would only have worked on a limited aspect of the whole. But the whole project generated new knowledge, much of which is know-how, or tacit knowledge dispersed amongst people, held in various records, designs and so on (and even gained by competitors).

Looking at engineering knowledge in this way reveals that a great deal of important knowledge does not reside in individuals' heads. Realising this can be of great relevance to addressing sceptical arguments aimed at scientific knowledge and knowledge generally. Keiron O'Hara (in O'Hara 2002) argues that the sceptical questions that are raised within the philosophical model of knowledge as justified true belief have less purchase in a world where much knowledge is held by organisations rather than individuals: in different peoples' heads, in databases, in records and on the internet. O'Hara points out that this is not just the case for technical knowledge; there is all manner of data in various locations, which can potentially be retrieved and can function as useful knowledge – data on the web in particular.[6] Once we appreciate the extent to which the knowledge we possess is like engineering know-how or organisational knowledge, the justified true belief model of knowledge is undermined, and so, very importantly, are the sceptical arguments to which it is vulnerable. For example, Cartesian doubt about the external world – the kind of doubt centred on the possibility that all our experiences mislead us – is based on the assumption that to have knowledge is to be in a certain state of mind, or to have a belief, which may or may not match the external world. However, a look towards engineering reveals that some knowledge is a matter of skill rather than belief or state of mind, and some knowledge is shared and thus not open to individual doubt. Understanding that knowledge is often practical and communal eludes this kind of philosophical doubt.

This is to espouse a form of externalism about knowledge. Externalism, very broadly, is the view that having knowledge does not depend on being in a certain introspectible state of mind but consists in a relation between a knower and the physical world or a knower and a wider epistemic community. Looking at the nature of engineering knowledge, and the nature of knowledge made possible by the products of engineering, gives concrete and sophisticated substance to this externalist viewpoint. This supports an externalist rejection of the Cartesian model of knowledge and the sceptical doubts that it struggles to refute.

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[6] For example, a computer program such as a machine learning program can trawl through vast databases to find generalisations – Amazon might use such a program that would, by analysing the vast amounts of data generated by Amazon everyday, a generalisation such as philosophers tend to spend more money on Amazon than dentists, perhaps. This is a useful generalisation that Amazon can act on. O'Hara argues that we should see this as knowledge possessed by Amazon, even thought it is not knowledge in anyone's head, hence it is not a belief and cannot then be characterised as justified true belief.

22.4.2 Engineering and the Pessimistic Induction

When questions arise about the reliability of scientific knowledge, examples are given of its failure in the past. The pessimistic induction – the conclusion that scientific theories are most likely to be rejected as false on the premise that theories previously held true have been – is offered to undermine the claim of science to present us with knowledge of the world. However, as Joseph Pitt points out in his paper "What Engineers Know" (Pitt 2001), engineering knowledge is less vulnerable. Whilst engineering is improved upon continuously, improvements cannot show that previous designs failed to work. The construction of a new bridge does not make older bridges collapse nor render them useless. Engineering know-how is thus straightforwardly cumulative, whereas science's claim to progress is more contestable.

Now, this might be taken to show a difference between science and engineering's respective claims to knowledge, but the more important lesson is a general one about progress and cumulatively in our shared knowledge of the world. It is difficult to extract engineering and scientific knowledge one from the other, and it is thus difficult to say, based on the pessimistic induction or other arguments, that one or the other makes a greater claim to reliability or veracity. The topsy-turvy (compared to the standard view) way that thermodynamics followed what might otherwise be called its application in developing steam engines shows how this area of knowledge is a complex mix of scientific theory, engineering analysis and know-how. In areas such as electronics, where learning, making and experimenting are almost impossible to extricate, it too is difficult to say what is engineering and what is science. Thus it is difficult to partition engineering from scientific knowledge.

If we appreciate this and take Pitt's point about the pessimistic induction, the lesson to learn is not that engineering, as opposed to science, delivers dependable knowledge, but the lesson is that we should be broader in what we include in knowledge of the world. If we include engineering "know how" as well as theoretical understanding of the world in our shared canon we can easily make sense of what is self-evident in common sense, that we have made progress from our epistemic state in previous centuries and that our knowledge of the world has grown. Practical knowledge as exploited by engineering provides a thread of continuity throughout theory change. Thus it gives us reason to believe that current knowledge is not on entirely shaky ground.

Looking at engineering knowledge, the way it persists through time and the ways that it is inextricably linked with other bodies of knowledge shows us that the pessimistic induction is based on a mistaken premise. This is the premise that all knowledge is theory-bound, and that all knowledge is lost when theories change. Thus another philosophical concern is overcome, at least in part, by learning from philosophy of engineering.

22.5 Conclusion

In sum, there are clear resonances between Wittgenstein's later philosophy and both engineering itself and the philosophy of engineering. These resonances demonstrate the value of a philosophy of engineering. Wittgenstein gained a great deal philosophically when he turned from the laboratory of the *Tractatus* to the real world. His was a turn to an anthropological philosophy, but similar gains can be made by turning from a philosophy based on knowledge conceived of as theories to looking at knowledge in application, knowledge manifested in human built artifacts or processes and knowledge held within the organisations and communities that develop those artifacts and processes. By turning to the world of things and away from that of facts and theories important epistemological lessons can be learnt. This can allow philosophers to reframe intractable philosophical questions, and even discover some answers to them.

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Chapter 23
Architecting Engineering Systems

Joel Moses

Abstract We discuss approaches to the overall design of large scale engineering systems, such as planes, cars and large software systems. Such approaches are usually called design methodologies. We discuss the top-down structured methodology, the layered or platform-based methodology, and the network-based methodology. Such design methodologies are associated with organizational structures or architectures, such as tree-structured hierarchies, layered hierarchies and generic networks. We discuss the relationship of these approaches to Aristotle's approach to the organization of Greek city-states and his logic-based problem solving, to Plato's organization of the Just Society, and to Darwin's use of evolution as an approach to design. We point out how these design methodologies relate to cultural attitudes toward engineering. We also point out that different engineering fields make different fundamental assumptions about properties of engineering systems, such as flexibility. We believe that undergraduate engineering education would be greatly improved if we taught design methodologies and their relation to philosophy. Similarly, engineering education would be improved if we taught foundational concepts regarding properties of engineering systems and the differing built-in assumptions regarding such properties found in various engineering disciplines.

23.1 Introduction

Design is the soul of engineering. Much of engineering analysis relies on mathematics and science, but design usually differentiates engineering from these fields. Our interest is in how one approaches the design of large scale and complex engineering systems, such as planes, cars and large software systems. It is difficult to teach the design of large-scale systems to undergraduates. Undergraduate design projects

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often simply emphasize getting a project done at all, given the limitations of time, staff and money. It is assumed that most issues related to large scale design will be learned by a practicing engineer on the job, often relying on approaches to design taught by his or her engineering firm.

General approaches to the design of large-scale systems are called design methodologies. Design methodologies, when they are taught at all to undergraduate engineering students, go by names such as systems engineering. We will discuss the advantages and disadvantages of several methodologies and how different methodologies relate to philosophical differences between Plato, Aristotle as well as others, such as Darwin. Of course, we make no claim that Plato and Aristotle were engineers. Our hope is that by analyzing different philosophical approaches and their relationships to design methodologies future engineers will be able to design better engineering systems.

We discuss the relationship of the design methodologies and organizational structures to different cultures. We indicate that there is a relationship between attitudes toward engineering as a field and the popularity of certain design methodologies.

Finally, we discuss the reasons for the development of the graduate program System Design and Management at MIT. One of the lessons learned in SDM is that individuals in different engineering fields make different assumptions about key system properties, such as flexibility and robustness. We believe that an analysis of such assumptions for each engineering discipline will greatly benefit all of our undergraduate engineering students.

23.2 Tree Structures

Design methodologies are not simply ways of architecting and designing technical systems, but are closely related to the structure of human organizations as well as general ways of attempting to solve problems. I believe that the first written description of a hierarchical structure for a human organization occurs in the Bible in *Exodus*. Jethro, Moses' father-in-law, visited him at the foot of Mount Sinai, just before the giving of the Ten Commandments. He watched Moses spending all his time judging. He told him that this is not good. Moses ought to appoint a judge for every thousand, every hundred, every fifty, and every ten. Then Moses would only need to judge the most difficult cases.

What Jethro is suggesting is a tree-structured organization of judges with Moses at the top, followed by a number of judges for every thousand, each followed by a number of judges for every hundred, etc. This is what I call a pure tree-structured hierarchy. Every judge has exactly one judge above him to whom he would deliver the most difficult cases he has. Such an organizational structure is very general and quite common, so much so that many people think all hierarchies are necessarily tree structured. Jethro's description is top-down, from Moses to the judges for every thousand, then to the level of judges for every hundred, etc. His description suggests that the cases to be judged are passed from the bottom up to the top. Aristotle used a similar tree structured organization for administrating Greek city-states in *Politics*. He assumed that the tree-structured organization for a given city-state can have the number of its levels increased as the city-state increases in population.

Jethro's idea is in retrospect quite obvious. Why did Moses not think of it? My answer is that Moses had a different mind-set from Jethro, one that favored a very different organizational structure. In *Numbers* we find Moses creating the structure for the Israelite religious hierarchy. He places Aaron as the high priest at the top node of the hierarchy. He then places Aaron's sons (and eventually their male descendents) as priests at the top layer of the hierarchy. The rest of the tribe of Levi forms the middle layer, and the remaining tribes form the bottom layer. Layered hierarchies are different from tree structured ones is several respects. A judge in Jethro's structure has exactly one judge to whom he reports, and presumably he'll report to that judge for some time. The Levis, on the other hand, served whichever priests needed their support at any given time, and these priests could change from one day to the next. Priests worked in teams. So did Levis. In contrast, Jethro's judges likely were not intended to work in teams.

The structure of the Israelite religious hierarchy in *Numbers* is similar to Plato's Just Society in *The Republic* with a philosopher king instead of high priest, and a layer of guardians instead of the layer of priests. There are important differences. Moses has people born into their rank. Plato relies on testing to determine someone's final rank. I call such hierarchies layered hierarchies.

The two types of hierarchy can also be associated with approaches to problem solving. The tree-structured hierarchy is associated with the "divide and conquer" approach to problem solving. This approach works as follows: Given a problem, if you can solve it, do so and you are done. If not, break it up into parts and attempt to solve each part in turn as a subproblem. If you can solve a subproblem, do so and go to solve one of the remaining subproblems. If you cannot solve a subproblem break it also into parts and keep doing so until you either solve all the subproblems or you give up.

A treasure trove set of examples of top-down problem solving is in mathematical logic. Consider proving a theorem in Russell and Whitehead's *Principia Mathematica*. This process was actually automated in the 1950 s in an AI program by A. Newell, J. Shaw and H. Simon called the Logic Theorist (Newell et al. 1957). The approach taken by that program is a top-down one. I associate analytic philosophy, especially Bertrand Russell's version of it, with the top-down approach.

The design methodology associated with the top-down tree structured approach is the systems engineering approach, which became popular in the US in the 1950 s, largely in the aerospace field. Classic systems engineering is a reason for the success of the Apollo moon project in the 1960 s. A key reason for the success of systems engineering in the Apollo project was that the design was frozen early on. This avoided a weakness of the methodology, which shows up when changes are made to the design requirements in the midst of the design process or later on during the lifetime of the system. This weakness arises from the relative inflexibility of this approach.

23.3 Platform-Based Architectures

In a tree structure each node has exactly one parent node, and the parent node remains fixed for a long time. In a layered or platform-based system architecture, the parent node can change readily, and the members of a layer can be viewed as members of a team or set of teams. Current examples of human organizations that are structured this way include large partnerships, such as law firms or consulting firms. These are often structured in three layers – senior partners, junior partners and associates. Associates may be asked to work on a team with different partners in different engagements. Universities have vestiges of this structure – full professors, associate professors and assistant professors. Getting tenure is akin to making partner. In this sense, a university is a partnership of the faculty. A president who ignores this aspect of the organization of a university can get into serious difficulties with his faculty.

An example of a platform-based engineering system is an automobile platform. The bottom layer or the platform of the automobile is relatively fixed, and the top layer can vary to create different automobile models. The advantage of this approach to design is that it is usually cheaper to design a new car model based on an existing platform than it is to design the model from scratch. I claim that the relative ease of making such changes is a result of the flexibility of the platform-based design. Another advantage of the approach is that one can improve the platform over time due to its longer lifetime, which results in greater experience for the manufacturing firm, and thus the possibility that its processes can be improved over time. A disadvantage of the approach is that the initial design of the platform is more expensive than a specialized one for a new model. Another disadvantage is that the approach is somewhat restrictive. In general, all design methodologies have advantages and disadvantages. The choice of a methodology ought to depend on properties of the system being designed and its environment.

Automobile platforms are examples of power or energy-centered systems. It appears relatively difficult to create a hierarchy of platforms containing more than two layers in an energy-centered system. Hierarchies with three or more layers are easier in information- or communication-centered systems. We define the internal flexibility in a system to be related to the number of paths in it from a top node to the bottom nodes. Three layers are, in general, far more flexible than two using this metric. The architecture of the AT&T telephone system with area codes, regional numbers and local numbers indicates a three-layer architecture with a total of ten digits for each phone number. Each layer was originally implemented with a different architecture. The area code in the number indicates a node in a national telephone network, whereas the last four digits represent one of ten thousand possible phone lines in a local switch.

Software and mathematics provide many examples of layered or platform-based architectures. Consider a polynomial in x, y and z with integer coefficients. Any such polynomial can be written as a polynomial in x with coefficients that are polynomials in y, with the latter having coefficients polynomials in z with coefficients that are integers. Of course, the order of the variables can be changed. The order of the layers will then change as well, although a polynomial expressed in one layered structure will be equivalent to one expressed in such a reordered structure. Plato was an idealist and close to mathematics, especially geometry. Although algebra was not well developed in his time, the algebraic examples would have been well appreciated by him.

Platform-based software systems abound. Consider a high level programming language, such as Fortran, the first popular programming language. Consider a system written entirely in Fortran, but one that runs on a particular microprocessor. The microprocessor does not actually run Fortran code. Fortran is usually translated to the machine language of the microprocessor through a series of steps. Thus we can say that Fortran provides a platform that separates the Fortran program from the actual bits of the machine language used by the microprocessor. Such a high-level-language-based platform provides expressiveness and flexibility to the system. An argument leveled against high-level languages is that their use loses some space and increases run time relative to a hand optimized machine language code. Such losses have been greatly reduced over the years as compilers have become better than most human programmers.

In fact, many software systems are currently based on a number of platforms, some of which are on top of each other creating a hierarchy of platforms that correspond to levels of abstraction. For example, data base systems, operating systems and special user interfaces can all be considered to be platforms. Given the prevalence of this approach to the architecture of large scale software systems, it is surprising that the methodology associated with platform-based design is not normally taught to computer science undergraduates. Such a methodology would have the architect of a new system spend significant time determining a new platform that would make it easier to design a new large-scale system. Most such platforms would be placed on top of existing platforms. Sometimes, especially when efficiency is a major consideration, new platforms could be interspersed between or below existing platforms.

In recent centuries the multi-layer architecture in the social and behavioral sciences was most popular in German speaking countries. In particular Marx and Freud can be said to use multi-layer architectures in their thinking. Freud emphasized the conscious and subconscious layers, but as a medical doctor he certainly could not ignore the physical layer of the brain underlying them both.

German speaking countries are not the only ones where can see a layered or platform-based approach to organization, problem solving or design. Japanese firms also use such an approach, and it is a reason why they were so successful in manufacturing relative to the US for decades. The Japanese used platforms in automobile design well before it became the norm in the US. Large Japanese firms tended to rely on an organizational hierarchy, which is partly based on age and provides little salary differentials for many years. They also rely on teamwork at each level. An advantage of this approach is that, within limits, it is very flexible. A disadvantage is that it does not work well outside of certain limits. Hence the appropriateness of the book on Japan entitled *Flexible Rigidities* (Dore 1986).

Management thinkers often emphasize the top level of a firm (especially the CEO). Japanese firms recognize the importance of middle management levels. Middle managers can play key roles that Americans often do not fully appreciate. One of their roles is to promulgate the firm's culture to their staff. Another key role is to get their staff to work well in teams. A related role is to build trust in the staff in employees in other parts of the organization. Then when new teams need to be formed, the team members can begin to work with each other relatively quickly and effectively. For an analysis see (Ouchi 1981).

Let us summarize some of the strengths and weaknesses of design methodologies that are associated with tree-structured and layered hierarchies. Tree structures are quite general. Most problems can be attempted with a top-down design approach. The approach is very logical. It works best when problems are relatively small or do not change much. It does not work well when the rate of change is relatively high since tree structures are quite inflexible. Flexibility in an organization occurs when there are alternative paths to a solution. Tree structures, unfortunately, have exactly one path from the top node to any particular node at the bottom. We associate Aristotle with this approach. According to my late colleague, Thomas Kuhn, even Aristotle's physics relied on tree structures with the Unmoved Mover at the top of the hierarchy.[1]

Layered hierarchies can cope with changing environments better than tree-structured ones due to their increased flexibility. This flexibility arises partly through increased cooperation and interaction between members of the same layer. Components of a layer can also have more than one parent node at a higher layer. The approach, however, is not nearly as general as the one associated with tree structures. It is relatively easy to break most problems into parts, although the break-up may not be unique, and a given break-up may not be best in the long run. It is harder to design a new platform because many issues or trade-offs must be taken into account. Thus greater attention must be paid to each such new platform design, and system architects need to be both experienced and creative. On the other hand, a platform can provide greater flexibility and expressiveness, as we noted earlier. We associate the layered approach with Plato, although he clearly did not emphasize the need for a capability for change in complex systems in his writings.

23.4 Network-Based Architectures

In recent years we have lived with technologies, such as the Internet, that undergo many changes all the time. Although the architecture of the Internet is based, at least initially, on the International Standards Organization seven-layer model, the topology with which we as users are most familiar is that of a network. A network-based architecture with nodes and edges is very general. All tree structured hierarchies and layered hierarchies can be modeled as particular networks, yet most networks are not hierarchies at all. The physical and biological worlds can be modeled using networks. Networks are extremely flexible, even exponentially so as a function of the number of nodes. As a result a number of physicists and biologists have gravitated to the modern network theory. Watts (2003) gives an overview of this approach.

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[1] Kuhn T., personal communication.

Networks are in general highly decentralized. This can be an advantage and a disadvantage. Decentralization gives a system great freedom and flexibility. The economy of a market-oriented nation can be modeled as a decentralized network of interacting actors. Centralization, such as that of the military, can give a fair amount of control over the actions of the various actors, more control than would be the case in a general network.

Networks are associated with problem solving approaches, just as hierarchies are. The determination of the price of a commodity in a market economy is a result of a multiplicity of actions of actors in a network. The open software movement in recent decades relies, in part, on actions of many programmers over the Internet. Wikipedia relies on a similar approach in its articles.

A related change to problem solving and design is due to the great success of modern biology. Evolution can be viewed as an approach to design that is related to a network-based architecture. The structure of relations of species to each other can be viewed as a tree structure, as Darwin noted. Whether the tree grows bottom-up or top-down is not of great importance here. Paths within a cell or an organism violate tree-ness and hierarchy sufficiently that the overall structure is best considered a network.

23.5 Attitudes Toward Engineering in Various Cultures

One of my concerns over the years, especially when I was Dean of Engineering, was why engineering was viewed differently in various industrial countries. The typology presented above of design methodologies and their relation to organizational structures and philosophy helped me understand some of these differences. Japan did not become a modern nation state until the Meiji restoration in 1868. Germany was finally united in 1870. These two countries thus have a better memory of their medieval past than Britain, for example. Layered organizations were relatively common in the Middle Ages, and became less so during the Enlightenment. The US was founded by people who were strongly opposed to a layered class structure, and the Founding Fathers were strongly influenced by the Enlightenment.

Science relies on logical arguments and tends to emphasize competition as well as specialization. A tree structured approach to problem solving fits rather well in science. Britain holds science in very high esteem. Engineers in Britain are often thought to be people who operate engines. Engineering usually relies on science, but also relies on teams to implement designs. Combining layered structures in addition to the tree structures works well in engineering. Thus I am not surprised that attitudes toward engineering are better in Germany and Japan than in Britain and even the US.

Hofstede and Hofstede (2005) analyzed the attitudes of IBM employees in sixty different countries. Geert Hofstede notes differences in the respective roles of the individual and the collective in different cultures. Tree structured organizations can be said to emphasize the individual, whereas layered ones tend to emphasize the collective. While he does not discuss the typology of organizational structures we use, the differences we note in national cultures show up in his work.

23.6 The System Design and Management Program

In my career I spent many years in the 1960 s and 1970 s arguing against the strong attraction that top-down tree-structured approaches to problem solving and design had to fields, such as Artificial Intelligence, Computer Science, Systems Engineering, and Management Science. In the 1980 s I found the Japanese approach to such issues a welcome endorsement of an alternative I had postulated in the 1960 s, namely layered or platform-based design. It was then that I realized that these differences in approach go back thousands of years, and that they are now deeply embedded in national cultures. In the late 1980 s American industry began accepting elements of this alternative approach as a way of coping with the Japanese success in manufacturing. Womack et al. (1990) analyze this approach, usually associated with Toyota. Yet I found that this acceptance of the Toyota approach was limited in scope. Toyota remains the best automobile manufacturer in the world today.

Just as it seemed that US firms were "getting it," the success of the Internet and modern biology led to the emphasis in the US on network-based methodologies. In my view, there is no methodology that is ideal under all circumstances. Each of the major methodologies has advantages in some situations. Networks are to be preferred when the environment changes very quickly or when the number of actors is extremely large. Layered systems are to be preferred in situations which are in middle range in size and rate of change. How to account for the quick skipping of the layered approach in the US? It cannot be that everything suddenly was getting very large and undergoing great change. Is it a surprise that Adam Smith, Charles Darwin and Bertrand Russell were British and that Marx and Freud were German and Austrian? I think not. Would it not be useful if one could encapsulate the various approaches to design, problem solving and organization of such thinkers so that future generations can use the appropriate approach in differing circumstances?

At MIT we had successfully introduced the Leaders for Manufacturing program in 1988 as a response to the Japanese success in manufacturing. LFM grants students two masters degrees, one in management and one in engineering. When I became dean of engineering I felt that LFM did not sufficiently address the issue of design in large scale engineering systems. This eventually led to the creation of the System Design and Management program, which grants a single masters degree in engineering and management. SDM has a core that includes a graduate course on system architecture. I had hoped to co-teach it, and make some of the points in this chapter about the architecture of engineering systems. Then I became the provost of MIT, and the teaching plan fell through. What happened is that the aeronautical engineers, great teachers all, taught the subject and began with a base of systems engineering. They broadened the classic approach to systems engineering to include discussions of systems properties, such as flexibility. Yet the issues related to alternative design methodologies, such as platform-based design, were not addressed very well.

What I realized is that different engineering fields, not just national cultures, had different biases about systems issues. For example, a civil engineer would be happy to design a structure that had a single alternative in its design (e.g., a parking garage with four floors with the possibility of adding two more floors at a later point if demand so warranted). Computer scientists might not be interested unless a system had a billion alternatives in its operational use. Hence flexibility means different things in different engineering disciplines. In my recent courses on engineering systems I start with defining my national background, and that of my parents. I also describe the biases that I believe were introduced in my education in the fields of mathematics, AI, computer science and engineering. I think it would be wonderful if we had a deep analysis of the foundational assumptions of every engineering discipline. Our students would then have a far better notion of what they were getting into in their choices of engineering discipline. Likely engineering faculty members are too close to these issues. They could use help in such discussions from faculty in the humanities and social sciences.

23.7 Summary

Three major approaches to the architecture and design of large scale engineering systems are discussed. These are the tree-structured hierarchy, the layered or platform-based hierarchy and the network architecture. These architectures are related to approaches to the structure of human organizations. We indicate the relationship of these organizational structures to ones used by Aristotle and Plato. Evolution is considered as a design methodology in networked systems.

We note that national cultures have a closer relationship to some of these approaches to design than to others, although no single approach is ideal under all circumstances. We also note that different engineering disciplines make different assumptions regarding fundamental properties of systems, such as flexibility and robustness.

Ideally an undergraduate engineering education ought to discuss all these issues. Engineering faculty members are likely too close to these issues, and could use the help of other faculty members in such discussions.

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Chapter 24
Bits Don't Have Error Bars: Upward Conceptualization and Downward Approximation

Russ Abbott

Abstract How engineering enabled abstraction in computer science. Engineering and computer science are both constructive disciplines: both fields build new artifacts. Computer science has evolved to focus primarily on abstractions: what aspects of a construction can be factored out and used elsewhere and more generically? Engineering has evolved to focus primarily on approximating physical reality: how close does one have to come to the underlying physics so that the construction is successful? The primary reason for this difference is that computer science builds on the foundation of the bit, a physically implemented symbol.

24.1 Turning Dreams into Reality

> What has been is what will be, and what has been done is what will be done; there is nothing new under the sun. Is there a thing of which it is said, "See, this is new"? – Ecclesiastes 1:9-10

Although Ecclesiastes says "No," engineers and computer scientists say "Yes, there are things that are new under the sun – and we create them." Where do these new things come from? They start as ideas in our minds. A poetic, if overused, way to put this is that we – and I'm writing as a computer scientist – turn our dreams into reality. Trite though this phrase may be, I mean to take seriously the relationship between ideas and material reality. Engineers and computer scientists transform subjective experience into phenomena of the material world.

The previous statement notwithstanding, this chapter is not a theory of mind. I am not claiming to explain how subjective experience comes into being or how we map subjective experience to anything outside the mind. I do plan to talk about the relationship between ideas and material reality. Section 24.2 provides more detail

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on the approach to consciousness I'm adopting. It also provides an introduction to the notion of a level of abstraction and its significance.

Section 24.3 returns to thought externalization, the ways in which engineers and computer scientists turn ideas into material reality. As Ferguson (1992) says, "The conversion of an idea to an artifact ... is a complex and subtle process that will always be far closer to art than to science." Section 24.4 discusses both the bit, the fundamental level of abstraction, and the price computer science pays for working at the bit level and above. Section 24.5 describes the different approaches engineering and computer science take to design.

Much of this chapter talks about how computer scientists and engineers think. For computer science I rely my own intuitions and self-awareness (Abbott 2008a). To a great extent I rely on Ferguson (1992) for the thought processes of engineers.

24.2 Subjective Experience and Levels of Abstraction

A reader of an earlier draft wondered whether I intended to embrace dualism by talking about transforming ideas into physical reality. This section explains why not and goes on to discuss levels of abstraction in general.

24.2.1 The Hard Problem of Consciousness

Subjective experience seems to be universal among human beings.[1] Yet we don't know how it comes about. Presumably it arises from brain activity, but we have no way of explaining how brain activity results in subjective experience. Chalmers (1995) calls this "the hard problem of consciousness."

> The really hard problem of consciousness is the problem of experience. ... When we see, ... we experience visual sensations: the felt quality of redness, the experience of dark and light, the quality of depth in a visual field. Other experiences go along with perception in different modalities: the sound of a clarinet, the smell of mothballs. Then there are bodily sensations, from pains to orgasms; mental images that are conjured up internally; the felt quality of emotion, and the experience of a stream of conscious thought. ... It is widely agreed that experience arises from a physical basis, but we have no good explanation of why and how it so arises.

Chalmers was echoing a problem described much earlier by Leibniz (1714).

> Supposing there were a machine, so constructed as to think, feel, and have perception, It might be conceived as increased in size, while keeping the same proportions, so that one might go into it as into a mill. On examining its interior, we would find only parts which work one upon another, and never anything by which to explain [subjective experience].

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[1] Dennett (1988) denies the existence of qualia on "eliminative materialism" grounds. I don't understand that argument. As I discuss later in this chapter – and in more detail in (Abbott 2009) – that something can be reduced to physical primitives doesn't demonstrate its eliminability.

24.2.2 Levels of Abstraction

Leibniz and Chalmers are describing emergence, a problem more general than subjective experience. Here's how O'Connor and Wong (2006) put it.

> [Emergent entities and properties] 'arise' out of more fundamental entities and yet are 'novel' or 'irreducible' with respect to them. (For example, it is sometimes said that consciousness is an emergent property of the brain.)

I argue (2006, 2007, 2008b, 2009) that emergence is what is known in computer science as a level of abstraction. A level of abstraction is a collection of types (categories of entities) and operations on entities of those types. Every level of abstraction has two important properties. (a) It can be characterized independently of its implementation – the (emergent) entity types, properties, and operations can be described abstractly. (b) When implemented, it is reducible to pre-existing levels of abstraction.

Consider any computer program, say Microsoft Word. It implements a level of abstraction that has such (emergent) entities as words, paragraphs, documents, etc. These entities have such (emergent) properties as font size and style, margins, etc. If one looks at the code that implements Microsoft Word one will not see words, paragraphs, documents, or their components or properties. But we do not consider it mysterious that words, paragraphs, etc. "emerge" from that code.

A specification pins down the entities and properties on a level of abstraction. One may require of Microsoft Word, for example, that when one double clicks the text one "selects" a "word," and when one triple clicks one "selects" a "paragraph." These requirements define (abstract) relationships among paragraphs, words, and click operations. They don't define what a word is in terms of simpler physical elements such as bits or electrons.

That's how it should be. A level of abstraction may be implemented by software in any number of ways. There is no necessary relationship between words and bits or electrons. All that matters is that words behave as expected with respect to the other elements on its level of abstraction. It's up to the implementation to decide how to implement words.

Searle (2004) invented a nice phrase to describe entities and entity types on a level of abstraction. He called them causally reducible but ontologically real. Higher-level entities are causally reducible because when a level of abstraction is implemented one can see how it works by looking at the implementation.

Higher-level entities are ontologically real because their functioning can only be described in terms of the entities themselves. When the entities are man-made, that description is a specification. But naturally occurring entities must also be described in terms of themselves. Biological organisms, for example, have the properties of being alive or dead, and they perform functions such as eating, sleeping, seeing, moving, and reproducing. These concepts apply only at the biological level; they make no sense at the level of chemistry or physics. The reality of higher-level entities and entity types inheres in their specifications.

24.2.3 Functional Decomposition vs. Stigmergic Design

Where did we get the idea that higher level entities and properties must be reducible to lower level components? Well, how could it be otherwise? If an entity is composed of lower level elements, how could it not be that those lower level elements serve as the components of the higher level entity? This idea is so natural and intuitive that it has been adopted as the design strategy known as functional decomposition. Using functional decomposition one designs a system as a collection of independent component subsystems so that the system's functionality is a composition of the functionalities of the subsystems. Applied recursively this leads to a hierarchy of functional units. The result is a system whose physical (component) structure corresponds to its functional structure – a very clean design.

But as Microsoft Word illustrates, the functionality that software produces can result from an interaction among elements that do not have any of the properties of the resulting entities. In fact, most software does not lend itself to functional decomposition. (See Section 24.5.) Yet according to O'Connor and Wong (quoted above) that's why emergence seems so mysterious. Even the brilliant Leibniz was misled. After concluding that one wouldn't find the components of subjective experience in the mechanical workings of a mind, he wrote the following.

> Thus it is in a simple substance, and not in a compound or in a machine, that [subjective experience] must be sought for.

In other words, Leibniz concluded that since subjective experience is not composed from lower level elements, it must be primitive, i.e., a "simple substance."

The design strategy that produces emergent functionality – and that contrasts with functional decomposition – might be called stigmergic design.[2] Software developers use it all the time.[3] Nature uses it in biological and social entities. What is philosophically important is the realization (a) that stigmergic design is a valid design strategy and (b) that it can produce entities and properties from apparently unrelated lower level entities and properties. Had this concept been available to Leibniz, he might not have drawn the conclusion he did. I return to the discussion of stigmergic design in Section 24.5.

24.2.4 Subjective Experience as a Level of Abstraction

It seems reasonable to assume that consciousness is implemented as a level of abstraction by physical processes in the brain. Here's how Searle (2004) puts it.

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[2] The term *stigmergy* was coined by Pierre-Paul Grassé (1959) to explain how social insect societies operate. Social insects interact in part by leaving markers in the environment.

[3] Related software terms include object-oriented design, service oriented architecture, tiered design, platform-based design, and (of course) levels of abstraction.

> [Conscious states] are real phenomena in the real world. ... [They] are entirely caused by lower level neurobiological processes in the brain. ... You can do a causal reduction of consciousness to its neuronal substrate, but that reduction does not lead to an ontological reduction because consciousness has a first person ontology, and you lose the point of having the concept if you redefine it in third person terms.

The problem is that we don’t know how the brain does it. We can explain how Microsoft Word produces words, paragraphs, and documents, but we can’t yet explain how brain functioning produces subjective experience. Nonetheless, from here on I will assume (a) that subjective experience is a level of abstraction implemented by the brain, (b) that we each have the experience referred to as having an idea, (c) that we are aware of ourselves as having ideas, and (d) that we understand in more or less the same way what it means to say that one has an idea.

Given the preceding, I will refer to the phenomenon of having an idea non-dualistically and without further explanation or apology and will return to the perspective that engineers and computer scientists turn ideas into material reality.[4] Although engineering and computer science are similar in that way, there is a difference in the kinds of realities created. Computer scientists create (physically implemented) symbolic reality. Engineers create material objects that act in the physical world.[5] The consequences of this difference are far-reaching.

24.3 Thought Externalization: Engineering is to Sculpture as Computer Science is to Music

If I could say it in words there would be no reason to paint. – Edward Hopper

The first step in turning an idea into reality is to externalize the idea. By externalizing an idea I’m referring to the conversion of the thought from something completely subjective to an external representation – a representation outside the mind in a form that allows the thought to be examined, explored, and communicated. The pervasive example is natural language. Most disciplines use natural language to externalize thought. Diagrams and equations are other examples.

Most externalized thought is intended for human consumption. Expressions in natural language as well as equations and diagrams are meaningless except to other human beings. An externalized thought has the same intentional property as thought itself. It is about something, and for an externalized thought to be about something requires that it be re-internalized, i.e., understood and converted into (intentional) thought. Here’s how Ferguson puts it.

> Engineers start with visions of the complete machine, structure, or device. ... [They first] convert the visions in their minds to drawings and specifications, [which] are expressed in

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[4] Mitcham (1978) made this point 3 decades ago. He also noted that science turns reality into ideas. Debora Shuger (personal communication) added that humanists turn reality into dreams. And Paul Erdos is widely quoted as saying that mathematicians turn coffee into theorems.

[5] In this chapter I won’t be discussing hybrid systems – physical systems with embedded software.

> a graphic language, the grammar and syntax of which are learned through use [and which] has idioms that only initiates will recognize.

But as illustrated by Hopper's remark, sometimes the thought is transformed directly into the thing itself. A Hopper painting is the thing itself. No intermediate form can adequately represent the idea – or there would be no reason to paint. Along the same lines Ferguson distinguishes between engineers and artisans.

> If the idea [of the thing to be made] is in the head of an artisan, he can make the thing directly. ... If the idea of the thing to be made is not in the artisan's head but in the engineer's, the engineer [uses] drawings to convey to workers what is in [his] head. ... The difference between the direct design of the artisan and the design drawing of the engineers are differences of format rather than ... conception.

Thought externalization in computer science is different. Computer scientists externalize thought as software. Software has the important property that it is both intentional and the thing itself. It refers in the same way that expressions in natural language refer: one can read it and understand it as having meaning. Software is also the thing itself – almost. With the help of a computer, software acts without the need for human understanding. (See Abbott 2008b.) To the best of my knowledge, music is the only other discipline that can externalize thought in a form (a) that is intentional/symbolic and (b) that may be actualized without further human participation. Even before computers, player pianos were able to convert the symbolic expression of musical thought into music. Engineering is approaching this capability, but it isn't there yet. A fully automated computer aided manufacturing capability – insert a design; get a product – would be equivalent.

24.3.1 The Bit: Where Thought and Matter Meet

The term bit is used in three overlapping ways.

1. Bit can refer to a binary value, i.e., either *true* and *false* as in Boolean logic. A bit in this sense, i.e., as the notion of true or false, is a thought, an idea in our minds just as *true* and *false* are.
2. Bit can refer to a mechanism or means for recording such a value. A bit in this sense is part of the material world, typically a unit of computer storage. It is a physical device that (a) is capable of being in either of exactly two states and (b) can be relied on always to be in one of them.
3. Bit can to refer to a unit of information as in information theory. I'm not using bit in this sense in this chapter – although a bit in the second sense can be used to represent a bit in this third sense.

The bit is a fundamental example of externalized thought. It is both a Boolean value (a thought) and a physical device (a part of the material world). Circuits that when run can be understood as performing Boolean operations provide a way to glide gracefully back and forth between bit as thought and bit as material device. Bits and the physical machinery that operate on them enable us to externalize

Boolean operations and values (thoughts) and to manipulate them in the material world. The bit is where thought and matter meet, an extraordinary achievement.

Engineering is a physical discipline. Physical disciplines involve physical devices and materials, which are never perfect and never the same from one instance to another. To determine how a physical device behaves, one measures it – often multiple times. The resulting sets of data points typically contain ranges of values. Such data sets have average values and error bars.

The physical devices used to store and manipulate bits have the same properties as any other physical device. In particular, they have error bars. Yet computer scientists don't see these aspects of physically implemented bits. Machinery built by engineers hides the reality of analog values and error bars from those of us who use bits. It is because of this machinery that as far as computer science is concerned bits don't have error bars. As the interface (a) between engineering and computer science and (b) between thought and matter the bit serves as the foundation upon which all other levels of abstraction can be implemented.

As externalized thought, the bit also externalizes the forbidden fruit of the tree of knowledge. Like thought itself it both gives us a way of gaining leverage over reality while at the same time separating us from it. Because every conceptual model implemented in software is built on bits, every software-based conceptual model has a fixed bottom level, a set of primitives. Whatever the bit – or the lowest level in the model – represents, those primitives serve as the model's floor. It's not possible to decompose them and model how they work–unless one builds a new, more detailed model.[6]

Because software models have a fixed set of primitives, it is impossible to explore phenomena that require dynamically varying lower levels. A good example of a model that needs a dynamically varying lower level is a biological arms race. Imagine a plant growing bark to protect itself from an insect. The insect may then develop a way to bore through bark. The plant may develop a toxin – for which the insect develops an anti-toxin. There are no software models in which evolutionary creativity of this richness occurs. To build software models of such phenomena would require either that the model's bottom level be porous enough that entities within the model are able to develop capabilities that sabotage operations on that lowest level or that the lowest level include all potentially relevant phenomena, from quanta on up. Neither of these options is currently feasible.[7]

Another example of a model that needs a dynamically varying lower level involves the gecko, a macro creature, which uses the quantum van der Waals force to cling to vertical surfaces (Kellar et al. 2002). Imagine what would be required to build a computer model of evolution in which that capability evolved. Again, one would need to model physics and chemistry down to the quantum level.

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[6] One might object that when bits are used to represent numeric values that are derived from an equation-based model, they don't represent primitive elements. I wouldn't dispute that. But equation-based models are science and engineering models, not computer science models.

[7] This poses a nice challenge to computer science: develop modeling mechanisms in which the lowest level of the model can be varied dynamically as needed.

The inability to develop models with dynamically varying lower levels is not limited to software. It is a problem with any finite conceptual model. We don't seem capable of building models that at the same time (a) have a lowest level and (b) can be extended downward below that lowest level. Yet engineering continually extends its models downward. How? The next section answers that question.

24.4 Static and Functional Structures

To a first approximation most systems may be understood from two complementary perspectives: static and functional. A static view describes the system's fixed skeletal structure – if it has one. A functional view describes how the system's functionality is implemented by the functioning of and interactions among its components. In medicine, for example, these two views are referred to as anatomy (structure) and physiology (functioning).

Although structure vs. function makes a nice division of labor, most systems are not so easily decomposable. Biological organisms may have what we think of as an anatomy, but most of the atoms making up that anatomy are regularly replaced. Part of the physiology of biological organisms is to repair and replace their anatomical structures. The same is true for social organizations. The anatomy of an organization such as a government consists of its institutional organs – a legislature, a judicial system, etc. But these are composed of people, who are replaced regularly. In addition, even the constitutional structure of most social organizations is subject to change – although usually with significant constraints.

24.4.1 Stigmergic Design and Upward Conceptualization

The rest of this section continues the discussion of functional decomposition and stigmergic design begun in Section 24.2.

What about software? Does it have a static structure? The static structure of interest is the structure in place when the software executes. Krutchen (1995) suggests that it is useful to understand software from 5 perspectives. Only the Process View – what happens during execution, including the creation and destruction of variables, objects, stack frames, tasks, etc. – captures the static structure of executing software. Clearly this is not static. Yet at any instant, it is those elements and their interrelationships that make up the static structure of the executing software.

A good way to think about executing software is as a continually changing collection of interacting entities – variables, objects, tasks, etc. The job of a software developer is to write software that creates and controls software entities. Software creates functionality through the interaction of these entities. Section 24.2 referred to this as stigmergic design. Since each software entity exists on some level of abstraction, computer scientists tend to understand software as the art of using one level of abstraction to implement another. Just as multi-celled organisms result from the patterned interactions of individual cells and social organizations result from the patterned interactions of biological organisms, much of software grows in an equally organic manner. The result is a series of upwardly conceptualized levels of abstraction – starting with the bit.

24.4.2 Functional Decomposition and Downward Approximation

Unlike computer science, engineering builds objects whose design must work in the material world. Ferguson quotes the definition of engineering from the 1828 charter of the British Institution of Civil Engineers. "Engineering is the art of directing the great sources of power in nature for the use and convenience of man." Petroski (1996) adds, "[Although] engineering is the art of rearranging the materials and forces of nature, the immutable laws of nature are forever constraining the engineer as to how those rearrangements can or cannot be made."

Engineering is both cursed and blessed by its attachment to physicality. It is cursed because in molding and modeling physical reality one can never be sure of the ground on which one stands. All engineering models are approximations. But engineering is also blessed by its attachment to physicality. For any issue one can decide how deeply to dig for useable physical bedrock. Engineering design rests on two techniques: physical approximation and functional decomposition.

Physical approximation. To reduce model complexity, engineers choose models that provide the necessary assurances on as high a level as possible – a civil engineering model may include the load bearing properties of a steel beam rather than the chemical bonds that produce those properties. Ferguson puts it this way.

> The engineering sciences . . . differ from pure science in that they have an array of abstract concepts, independent of science, that serve as a framework within which technical problems can be analyzed. . . . Informed judgment must decide to what extent calculations involving idealized processes can be depended upon . . . because mathematical models are always less complex than [nature].

But engineering is also blessed by its attachment to physicality. If the accuracy of a model is inadequate, engineers can replace it with one that models more primitive physical phenomena. The secret of engineering's ability to dig beneath the floor of its models is that as humans engineers can create new models when needed.

Functional decomposition. Functional decomposition works well when functional design can be mapped to static structure. Many engineered systems may be decomposed into component subsystems. If the subsystems can be modeled independently, then the system as a whole can be modeled as the collection of subsystems along with a model that ties the subsystems together. This often works quite well. But it is not infallible. To paraphrase the Commission on Engineering and Technical Systems of the National Academy of Engineering (2000),

> When engineering systems fail it is often because of unanticipated interactions (such as acoustic resonance) among well designed components that could not be identified in isolation from the operation of the full system.

Problems often arise (a) at a level below the system primitives (approximation fails) and (b) only when the system components are joined to make the entire system (functional decomposition fails). So engineering design is often a continuing search for models of reasonable complexity that provide an acceptable approximations to reality. Engineering is continually approximating downwards.

24.5 Summary

Engineers and computer scientists say there are new things under the sun. Nature agrees – new viruses, new bacterial, new species, lots of new things. Is nature a blind engineer or a blind computer scientist? Engineers build systems top-down. But like computer scientists, nature builds phenomena bottom-up, level of abstraction by level of abstraction. Nature is a blind programmer.

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Chapter 25
Metaphysics of Engineering

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Abstract The central questions of this chapter are: What is the setting of a learned work of engineering? Is that setting unique to engineering? The chapter argues that there are at least two settings: one, the real world in which engineering employs methods that seem to simulate the methods of mathematics and science; the other, the hyperreal world known as the assigned world in which engineering employs no simulations. While the question of uniqueness invites a more exhaustive inquiry into many learned disciplines than ventured herein, it can be said that when engineering is done in the real world it is done differently in some ways from mathematics and science, and that neither mathematics nor science is done in a hyperreal world whose natural laws are made from authoritative imperatives.

25.1 Introduction

Philosophers, mathematicians and scientists are often called scholars inasmuch as many of them are members of the academy or academic community. However, like lawyers and physicians, some engineers are scholars while many others consider themselves practitioners and members of professional communities. Let us say learned works are works composed by learning at the highest degrees, and that learned works of philosophy, mathematics and science are scholarly works while learned works of engineering may be scholarly or practical. Some learned works are systematic while others are *ad hoc*. The latter include the celebrated works of intuitive mathematicians, like Leibniz and Ramanujan, and ordinary works of surgeons, trial lawyers, improvisational musicians, and field engineers. Hereinafter, all learned works are said to be rigorous whether systematic or *ad hoc*.

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In his book *Patterns of Discovery* (1979) R.N. Hanson says, "The visitor must learn some physics before he can see what the physicist sees." Said differently, learned works may exhibit storied terms, e.g. point of view and setting, and the natures of these terms may vary with learned discipline. In a minimalist sense, point of view and setting constitute a world view. What is the setting of a learned work of engineering? Is that setting unique to engineering? These are the central questions of this chapter.

The main ideas of this chapter are as follows. Learned works of engineering are different from those in the sciences and the humanities. Learned works of science are systematic and thus said to be worthy of belief. Learned works in the humanities often exhibit a narrative style. Most learned works of engineering are non-systematic and thus are said to be at best intuitive, at worst *ad hoc*, but nonetheless believable. Herein, *ad hoc* learned works of engineering are translated into systematic learned works by speculating the hyperreal world known as the assigned world. The latter are worthy of commitment.

25.2 Background

In his book *Thinking Like An Engineer* (1998), Michael Davis observed that the first course of university study in engineering was taught in 1794 at L'Ecole Polytechnic du Paris, and that its teachings engaged military engineering with the then new calculus and Newtonian physics. Often, then, the problem statements in learned works of modern engineering are clashes between its legacies. The clashes are between the authoritative imperatives (Ferguson 1979) handed down to engineering in its military, civilian and artisan traditions, and the reasoning handed down to it from the calculus and classical mechanics. Such imperatives often mean that engineers should perform novel deeds at affordable costs, and before all the facts are in. This chapter considers two ways engineers navigate the so-called impossible dream. The argument goes as follows.

Engineers answer their problem statements with learned works whose rigors simulate mathematical and scientific rigors (Gorman 1992). The simulation is a learned work that would be mathematically and scientifically rigorous if it were not fraught with discrete gaps in their sorts of rigor, but whose gaps are bridged by rhetorical devices Billy Koen (2003) calls heuristics. Whereas mathematical and scientific works are said to be worthy of belief, albeit not always believed, the resulting simulated works are said to be believable. Likewise, literary critics are known to say this or that work of fiction is or is not believable. However, the consequences of putting learned works of engineering into action can be lethal and otherwise costly on societal and environmental scales. Thus, an engineer's work remains undone until engineers commit to its implementation regardless of any foreseeable consequences.

To get that commitment engineers engage in discourses having the same structures as some learned discourses in psychology, theology, literature, mythology and poetry. For example, if a person has a problem and seems unable to solve it because part of its solution is hidden in his unconscious, the task of finding that solution and bringing it to consciousness may require a visitation to a world in which dragons actually exist (Campbell (1973)). This visitation can be rigorous if it obeys the natural laws of that world. The main challenge of this chapter is to capture the hyperreal world known as the assigned world (Broome 1985) often visited by engineers when discoursing among themselves about their problems.

25.3 Wittgenstein

> Like everything metaphysical the harmony between thought and reality is to be found in the grammar of the language.–Wittgenstein (1970)

What might we do to conduct a metaphysical inquiry into engineering? The artist Laurent de la Hyre (1606–1656) responds with his painting *Allegory of Grammar* (1650). One of the seven liberal arts, grammar is represented as a woman. Let us think of her eyes as windows to her mind. Then the tape, loosely wrapped around her right hand and arm with the Latin words on it saying “A meaningful and literate word spoken in a correct manner,” tells that her thinking can be found in grammar. The allegory tells, moreover, that psycho-motor skill is required to pour water from a vase onto a pot of delicate flowers. Inasmuch as the allegory depicts the simultaneity of her thinking and acting, harmony between thought and reality is conveyed to the viewer.

For some, harmony between thought and reality is to be found in a grammar made by embedding symbolic logic in a so-called meta-language, i.e. a natural language such as English. We seek to compare harmonies in learned works composed by pure mathematicians, empirical scientists and engineers. Of course, these composers are preconditioned by their disciplines to seek harmonies in their works where they may or may not lie. Pure mathematicians seek harmony among thoughts. This is the mental world. Empirical scientists and engineers seek harmony between thought and the real world. Herein, however, the possibility is considered that engineers may not always find harmony there. Instead, they may find it between thought and the assigned world, a hyperreal world or enlargement of the real world. Dream states, the speculated spiritual world, the imaginary worlds of artists, all are instances of such an enlargement. Accordingly, harmony may be found in the grammars of these works. Focus is put on works whose grammars are made by embedding abstract algebra in English.

25.4 Peirce and Brunner

For Charles Sanders Peirce (1839–1914), a grammar consists in signs, syntactics, semantics and pragmatics (Morris 1938). For Jerome Seymour Bruner, the human brain is wired, so to speak, to think in storied terms: beginning, middle and ending; point of view; setting; etc. (Bruner 1990). Of course, Bruner takes one side of a variously sided argument that seeks general propositions about thinking. Herein, focus is on cases that fall to Bruner's side. Herein, a work is a grammatical composition exhibiting storied terms, and a learned work is a work that only an expert can compose.

Some of the signs in the learned works of interest herein reference a number; others reference a number and another concept; or they reference a number, a thing and one or more properties of the thing. Some of these signs are algebraic while the others belong to the English language. Of particular interest herein are signs appearing in triplicates, e.g. x_T, x, δx, where: x_T references a fixed but unknown number said to be the truth about some concept, thing or property of the thing; x references any number said to be knowledge about that concept, thing or property of the thing; and δx references an unknown number corresponding to the number referred to by x, and is thus called the error in x.

Signs may be organized together in accordance with rules called syntactics. Algebraic rules are syntactics. In an algebraic expression such as $x + \delta x$, the signs x and δx represent only the numbers they reference; their other referents are understood to tell which numbers they reference, or if they reference a specific number or kind of number. Thus, "+" belongs to the grammar of arithmetic, and it belongs there independently of whether the non-numerical referents of x and δx are artifacts of interest to engineers, heuristics, or ideals of interest to mathematicians or scientists.

A certitude equation of the first kind brings the signs of a triplicate into a coherent whole, e.g. $x_T = x + \delta x$. A certitude equation of the second kind brings the truth signs of two or more triplicates into a coherent whole, e.g. $y_T = f(x_T)$. When we say a story is structured with a beginning, middle and an ending, and that the middle is a causative sequence of signs, we are saying the rules of causation are syntactics. Normally, we think of such rules as being systematic, whether logical or poetic; but cases arise in which these rules are intuitive, i.e. spontaneous or *ad hoc*, i.e. case-dependent and either speculative or imaginative.

When the story's beginning, middle and an ending are compared with a simple sentence's subject noun, transitive verb and object noun, respectively, the middle is said to have a mood, i.e. indicative, imperative or subjunctive. Works composed by mathematicians and scientists have an indicative mood; works by engineers, an imperative mood; and works by artists and musicians often have a subjunctive mood.

It is in the beginning of a story where its point of view is identified. "Call me Ishmael" are the first words in Melville's *Moby Dick*. Herein, works are studied whose points of view are those of their composers, namely, mathematicians, scientists and engineers. While the middle of the story is a causative sequence, the first cause initiating the sequence is called the story's problem. It is here, in the beginning, that the story's problem is laid down:

> If all of the certitude equations in a set of two or more triplicates are stipulated, and if something is known about some of the errors in the set, then what can be known about the rest of the errors in the set?

Works of interest herein address the above problem and attempt to solve it by claiming that errors are, or that they behave as, so-called "small" numbers.

Learned works have settings. Their settings are identified by their semantics, particularly certitude equations. The purpose of this essay is to find and compare the settings of the learned works discussed herein. The thesis of this essay is that a setting heretofore undiscovered will be found in certain works composed by engineers, and that a recent algebraic structure will facilitate this finding.

While the middle of the story is a causative sequence, the effect terminating the sequence is called the story's solution. It is in the ending that the story's solution is arrived at. The solutions arrived at in the works of interest herein are all terms of art in the disciplines of their composers. As such, these solutions are called pragmatics.

25.5 Grammar of Certitude in Infinitesimals

Isaac Newton (1643–1727) and Gottfried Wilhelm Leibniz (1646–1716) are jointly credited with independently inventing the calculus. Both invented methods that "worked" for scientists seeking better ways of predicting the movements of the heavens, and for military engineers seeking better ways of predicting the trajectories of their cannon balls. I shall use Leibniz's conception of and signs for infinitesimals inasmuch as they are retained to this day.

Signs. Leibniz divided the real numbers into two categories: zero; and the rest which are called finite numbers. We shall use the signs x, y, z, etc., to reference real numbers. Then he introduced new numbers among the real numbers which he called infinitesimals, i.e. fixed numbers which are smaller than every finite real number and yet are not zero. We shall use the signs dx, dy, dz, etc., to reference infinitesimals.

Syntactics. Let =, +, • be the relations of ordinary arithmetic unless overruled by Leibniz's *ad hoc* rules for manipulating infinitesimals. These rules are:

$$\text{If } \mathrm{x_T} = \mathrm{y_T} \text{ then } \mathrm{x} = \mathrm{y} \text{ and } \mathrm{dx} = \mathrm{dy};$$
$$\text{If } \mathrm{x_T} = \mathrm{y_T z_T} \text{ then } \mathrm{x} = \mathrm{yz} \text{ and } \mathrm{dx} = \mathrm{ydz} + \mathrm{zdy}.$$

The second rule is a contradiction: $\mathrm{dy} = 0$ and/or $\mathrm{dz} = 0$ *v.* $\mathrm{dy} \neq 0$ and/or $\mathrm{dz} \neq 0$. Physicists and military engineers were impressed with the utility of results obtained from appeal to these rules, but mathematicians were generally less enthusiastic about infinitesimals. Bishop George Berkeley (1685–1753), a well-known mathematician, came to the rescue of reason calling Leibniz's infinitesimals "ghosts of departed entities." Berkeley was astonished that anyone would put forward an argument in which an infinitesimal was said to be non-zero but later said to be zero. Then Berkeley was attacked for being a man of the cloth who would appeal to faith on Sunday but who would not tolerate thinking beyond reason on Monday.

Semantics. The certitude equations for this grammar are as follows:

$$\mathrm{x_T} = \mathrm{x} + \mathrm{dx}, \quad \mathrm{y_T} = \mathrm{y} + \mathrm{dy} \quad \text{and} \quad \mathrm{y_T} = f\,(\mathrm{x_T})$$

Leibniz and Newton were concerned about ratios of infinitesimals and their references to real-world events. They used infinitesimals merely as means to these ends. Thus, the idea of an infinitely small error would have seemed rather bizarre to them.

Pragmatics. After the invention of the limit by Cauchy, et al., scientists and engineers would invoke Leibniz's rules as they deduce from the third certitude equation that

$$\mathrm{dy} = f'(\mathrm{x})\mathrm{dx}$$

where the prime indicates the derivative. This reads, "The change in y is the product of the derivative and the change in x." Then, they would write

$$\|\mathrm{dy}\| = \left|f'(\mathrm{x})\right| \|\mathrm{dx}\|$$

and say, "The maximum possible change in y is the product of the absolute value of the derivative and the maximum possible change in x."

Language. Mathematicians never spoke this grammar. Scientists and engineers speak it; but when they speak it they often, perhaps most often, introduce a new *ad hoc* device into it – they equate an infinitesimal to a real number. They have written $\mathrm{dx} = 0.2$ cm. Are they are misspeaking this grammar, or correctly speaking another grammar?

25.6 Grammar of Certitude in Engineering Mesofinitesimals

Leibniz's infinitesimal and his *ad hoc* rules for manipulating it have persisted in science and engineering. However, close inspection of some uses of dx in science and engineering betrays meanings for dx that Leibniz never intended for his infinitesimal. Recalling that Leibniz's infinitesimals are neither finite nor zero, we are surprised to find discussions in science and engineering literatures putting $\mathrm{dx} = 0.2$ or $\mathrm{dx} = 0.0$, but manipulating the sign dx in accordance with Leibniz's *ad hoc* rules. To distance these practices from Leibniz's intentions, we shall use $\Delta\mathrm{x}$, $\Delta\mathrm{y}$, etc., to reference numbers that may be zero or finite but which may submit to Leibniz's *ad hoc* rules. We call them engineering mesofinitesimals (Broome 2004).

Signs. Let $\mathrm{x_T}$, x, $\Delta\mathrm{x}$, etc., be real numbers which may be finite or zero.

Syntactics. Let =, +, • be the relations of ordinary arithmetic unless overruled by Leibniz's *ad hoc* rules for manipulating infinitesimals.

Semantics. The certitude equations for this grammar are as follows:

$$\mathrm{x_T} = \mathrm{x} \pm \|\Delta\mathrm{x}\|, \quad \mathrm{y_T} = \mathrm{y} \pm \|\Delta\mathrm{y}\| \quad \text{and} \quad \mathrm{y_T} = f(\mathrm{x_T}).$$

When concerned about certitude, scientists and engineers use mesofinitesimals to reference mental and real-world objects and events.

Pragmatics. J. R. Taylor documents ways scientists and engineers define error *qua* uncertainty (Taylor 1982). This is a survey of practices, not a theory attributable

Table 25.1 J.R. Taylor's error formulas

Formulas in *R*	Formulas in *E*
$x_T = y_T \Rightarrow x = y$ and $\|\Delta x\| = \|\Delta y\|$	$\hat{x} = \hat{y} \Rightarrow x = y$ and $\|\Delta x\| = \|\Delta y\|$
$x_T = y_T + z_T \Rightarrow x = y + z$ and $\|\Delta x\| = \|\Delta y\| + \|\Delta z\|$	$\hat{x} = \hat{y} + \hat{z} \Rightarrow x = y + z$ and $\|\Delta x\| = \|\Delta y\| + \|\Delta z\|$
$x_T = y_T - z_T \Rightarrow x = y - z$ and $\|\Delta x\| = \|\Delta y\| + \|\Delta z\|$	$\hat{x} = \hat{y} - \hat{z} \Rightarrow x = y - z$ and $\|\Delta x\| = \|\Delta y\| + \|\Delta z\|$
$x_T = y_T z_T \Rightarrow x = yz$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = \frac{\|\Delta y\|}{\lvert y\rvert} + \frac{\|\Delta z\|}{\lvert z\rvert}$	$\hat{x} = \hat{y} \bullet \hat{z} \Rightarrow x = yz$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = \frac{\|\Delta y\|}{\lvert y\rvert} + \frac{\|\Delta z\|}{\lvert z\rvert}$
$x_T = \frac{y_T}{z_T} \Rightarrow x = \frac{y}{z}$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = \frac{\|\Delta y\|}{\lvert y\rvert} + \frac{\|\Delta z\|}{\lvert z\rvert}$	$\hat{x} = \frac{\hat{y}}{\hat{z}} \Rightarrow x = \frac{y}{z}$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = \frac{\|\Delta y\|}{\lvert y\rvert} + \frac{\|\Delta z\|}{\lvert z\rvert}$
$x_T = By_T \Rightarrow x = Bx$ and $\|\Delta x\| = \lvert B\rvert \|\Delta y\|$	$\hat{x} = B\hat{y} \Rightarrow x = Bx$ and $\|\Delta x\| = \lvert B\rvert \|\Delta y\|$
$x_T = {y_T}^N \Rightarrow x = y^N$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = N\frac{\|\Delta y\|}{\lvert y\rvert}$	$\hat{x} = \hat{y}^N \Rightarrow x = y^N$ and $\frac{\|\Delta x\|}{\lvert x\rvert} = N\frac{\|\Delta y\|}{\lvert y\rvert}$
$y_T = f(x_T) \Rightarrow y = f(x)$ and $\|\Delta y\| = \lvert f'(x)\rvert \|\Delta x\|$	$\hat{y} = f(\hat{x}) \Rightarrow y = f(x)$ and $\|\Delta y\| = \lvert f'(x)\rvert \|\Delta x\|$

to Taylor. His formulas detailing solutions to problems addressing various *f* are derived from the above equations. Using standard notations, namely, **R** to reference the set of ordinary real numbers and ***R*** to reference **R** together with the relations =, +, •, these equations are shown in Table 25.1: Formulas in ***R***.

Language. Mathematicians never spoke this grammar. However, the language made from it by scientists and engineers has two dialects: one spoken by empirical scientists; the other, engineers.

Scientific works are written in the indicative mood. Thus, scientists can justify their uses of the formulas by reference to Peirce's notion of an unlimited community of researchers. For example, if y and z are empirical quantities, then, say, the second row in "Formulas in ***R***" can be stated in terms of data. If several such statements are made over time with ever increasing precision in the instrumentation and procedures used to generate data on a given fixed object or phenomenon, then the resulting sequence would exhibit convergences of x, y, and z to, respectively, x_T, y_T and z_T, and $||\Delta x||$, $||\Delta y||$ and $||\Delta z||$ would approach zero in the limit. According to Peirce, the current values of x, y and z in the sequence would qualify as knowledge.

Engineers cannot always justify their uses of these formulas by reference to Peirce inasmuch as the given object or phenomenon is not always fixed. Whereas scientists say one atom of oxygen is the same as another and that an atom of oxygen does not change over time, engineers say that no two automobiles, whether of the same make, color, etc., are the same and no one of them remains unchanged during its use (Broome 2002). Nonetheless, inasmuch as engineering works are written in the imperative mood, engineers can justify these formulas as parts of a tradition of responding to situations judged complex, exigent and lethal. In the USA, these formulas are coded into civil law as legal means of designing engineering systems. As such, these formulas and the *ad hoc* rules which were used to derive them are instances of engineering heuristics.

25.7 Grammar of Certitude in Engineering Numbers

Definition 1: *signs*. Let $\mathbf{E} \subset \mathbf{R}^2$ such that $\hat{x} = \langle x, \Delta x\rangle \in \mathbf{E}$ as well as $\hat{y} = \langle y, \Delta y\rangle \in \mathbf{E}$, etc. Thus, knowledge and error are captured in **E** as one number.

Definition 2: *syntactics*. For every $\hat{x} = \langle x, \Delta x\rangle$ and $\hat{y} = \langle y, \Delta y\rangle$ in **E** let:

A. $\hat{x} = \hat{y} \Leftrightarrow x = y$ and $\Delta x = \Delta y$;
B. $\hat{z} = \hat{x} + \hat{y} \Rightarrow z = x + y$ and $\Delta z = \Delta x + \Delta y$ in **E**; and
C. $\hat{z} = \hat{x} \bullet \hat{y} = \hat{x}\,\hat{y} = \langle x,\Delta x\rangle \bullet \langle y,\Delta y\rangle \Rightarrow z = xy$ and $\Delta z = y\Delta x + x\Delta y$ in **E**.

Then, $\hat{x}$ and $\hat{y}$ are called engineering numbers (Broome 2004) and **E** is the set of engineering numbers.

The motivation for **E** is as follows. It is possible to look at the signs "x_T" and "x" and have two very similar but different visual experiences with two objects, and yet look at the sign "Δx" and have no visual experience at all but take it as a computation of the difference. However, it is possible to look at the sign "$\hat{x}$" and have a visual experience with a fuzzy object surrounded by an aura, and then look at "$\langle x,\Delta x\rangle$" and have no visual experience at all but take it as computations of properties of the object and its aura.

The reason for the name "engineering numbers" is that ***E*** is a grammar that accounts for a hyperreal world in which only engineers live. Others can learn enough about engineering to visit this world, but while visiting it they are limited in what they can say scientifically. For example, when x_T is translated to $\hat{x}$ something is lost in translation inasmuch as $\hat{x}$ references a different sort of number than the real number referenced by x_T.

The quadruple (**E**, =, +, •) is the space ***E*** of engineering numbers. Thus we see that the formulas arrived at *ad hoc* in ***R*** by Leibniz are arrived at systematically in ***E***. Specifically: mesofinitesimals are equated only to mesofinitesimals; the sum of two mesofinitesimals is a mesofinitesimal; the product of an ordinary real number and a mesofinitesimal is a mesofinitesimal; and the product of two mesofinitesimals does not exist in **E**.

Proposition 1: The set ***E*** = (**E**, =, +, •) is a ***ring***, i.e. for every $\hat{x}$, $\hat{y}$ and $\hat{z}$ in **E**:

1. Addition is commutative: $\hat{x} - \hat{y} = \hat{y} - \hat{x}$;
2. Addition is associative: $(\hat{x} - \hat{y}) - \hat{z} = \hat{x} - (\hat{y} - \hat{z})$;

3. Multiplication is commutative: $\hat{x} \bullet \hat{y} = \hat{y} \bullet \hat{x}$;
4. Multiplication is associative: $(\hat{x} \bullet \hat{y}) \bullet \hat{z} = \hat{x} \bullet (\hat{y} \bullet \hat{z})$;
5. Multiplication is distributive over addition: $\hat{x} \bullet (\hat{y} - \hat{z}) = (\hat{x} \bullet \hat{y}) - (\hat{x} \bullet \hat{z})$;
6. The additive identity exists in **E** and is unique: $\hat{0} = \langle 0,0 \rangle$;
7. The multiplicative identity exists in **E** and is unique: $\hat{1} = \langle 1, 0 \rangle$;
8. The additive inverse of every $\hat{x} = \langle x, \Delta x \rangle$ in **E** is $-\hat{x} = \langle -x, -\Delta x \rangle$ in **E**; and
9. Multiplicative inverse:

   a. To every $\hat{x} = \langle x, \Delta x \rangle$ in **E** where $x \neq 0$ there exists a unique multiplicative inverse

   $$\hat{x}^{-1} \equiv \frac{\hat{1}}{\hat{x}} = \left\langle \frac{1}{x}, -\frac{\Delta x}{x^2} \right\rangle; \text{ but}$$

   b. To every $\hat{x} = \langle 0, \Delta x \rangle$ in **E** there is *no* multiplicative inverse.

Thus, ***E*** is not a field but an algebraic ring. We shall see, however, that ***E*** exhibits all of the properties of a field when used to replicate mathematical operations performed in ***R***.

Semantics. The certitude equations for this grammar are as follows:

$$\hat{x} = \langle x,\Delta x \rangle, \quad \hat{y} = \langle y,\Delta y \rangle \quad \text{and} \quad \hat{y} = f\left(\hat{x}\right).$$

The engineering numbers $\hat{x}$ and $\hat{y}$ reference the assigned world (Broome 1985). This is a hyperreal world. A Gestalt of "$\hat{x}$" has a hard core named "x" and an aura named "Δx."

Pragmatics. Taylor's formulas detailing solutions to problems addressing various *f* are derived from the above equations. Using **E** to reference the set of engineering numbers and ***E*** to reference **E** together with the relations =, +, •, these equations are shown in Table 25.1: Formulas in ***E***.

Language. This grammar promises to become a language generally spoken by engineers and others with some training in engineering.

25.8 Summary and Conclusions

The central questions of this chapter are: What is the setting of a learned work of engineering? Is that setting unique to engineering?l The chapter argues that there are at least two settings: one, the real world in which engineering employs methods that seem to simulate the methods of mathematics and science; the other, the hyperreal world known as the assigned world in which engineering employs no simulations. While the question of uniqueness invites a more exhaustive inquiry into many learned disciplines than ventured herein, we can say that when engineering is done in the real world it is done differently in some ways from mathematics and science, and that neither mathematics nor science is done in a hyperreal world whose natural laws are made from authoritative imperatives.

The terms "*ad hoc*" and "systematic" were used here as antonyms, and "*ad hoc*" was applied to the way engineering is done in the real world while "systematic" was applied to the way it is done in a hyperreal world. Nonetheless, varieties of the word "rigor" were applied to learned works of mathematics, science, and engineering whether set in the real world or hyperreal world.

Agreement was found between the *ad hoc* certitude formulas used in various learned works of engineering, and the systematic counterparts of these certitude formulas that could have been used in these works. Thus, these learned works may constitute a compelling call to a great adventure, a hero's journey that is worthy of commitment regardless of the consequences.

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Chapter 26
Engineering Determinacy: The Exclusiveness of Technology and the Presence of the Indeterminate

Albrecht Fritzsche

Abstract The 20th century shows a general pattern of change in the attitude towards indeterminacy. Various different experiences have made us accept the continuous presence of the indeterminate without stopping to look for determination. If technology is understood as determinate operation, this attitude towards indeterminacy makes it possible to accept technology as the essence of being in the world and at the same time keep an outside perspective to discuss it. However, this perspective does not allow us to introduce an alternative to technology, since it is limited to denial.

26.1 Introduction

Traditionally, we think about technology in a pair of opposites like technology and humanity, technology and nature or technology and science. In a time in which we experience technology as a ubiquitous phenomenon, the elements of these pairs lose their contrasting quality. When we allow technology to execute calculations and conclusions for us and at the same time rely on technology to access the world, everything seems to be technologic. To cope with this situation, a different approach to technology is necessary. On the one hand, such an approach should acknowledge the fact that technology is everywhere; on the other hand it must leave us with a perspective to look at technology without producing self-referential expressions. In other words: we have to find out how we can allow technology to be unlimited and at the same time proclaim that an outside still exists. In this article, I suggest that the answer to this problem is already hidden in the philosophy of the twentieth century and that it can be brought to light by using the guiding difference of determinacy and indeterminacy.

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26.2 Indeterminacy as a Key to the 20th Century

The German philosopher Gerhard Gamm marks the conclusion of the modern age by the change of attitude towards missing determinacy (Gamm 1994). Experiences of indeterminacy have always been part of human life. During the 20th century, however, these experiences gained another quality. The preceding centuries left the possibility open that the role of indeterminacy in human life might one day change. There was some reason to believe that science, technology, society and even art were on their way to reach full determinacy in their own domains. The 20th century brought many disappointments that shattered these beliefs. In science, set theory was not able to cover all groups of objects that can be intuitively described; incompleteness appeared in logics and quantum mechanics were based on relations of uncertainty. In sociology and politics, visions of perfect societies and eternal piece were swept away by worldwide wars and totalitarian regimes. Even in art, classical ideas of perfection and clarity were given up for the sake of momentary, impulsive work, arbitrary influence and unreadable outcome. Along with these disappointments the attitude towards indeterminacy changed. Indeterminacy is no stain on clear thinking any more. It has gained a positive quality. Thinking, as Gamm puts it, has escaped the categories.

It is important to keep in mind that Gamm introduces the notion of indeterminacy as a general pattern. In each single aspect of human affairs in which we detect it, it will appear in a different way and it will probably have a different name. What Gamm addresses is the basic structure of all these experiences in which they express the denial of the possibility for determination. As such, indeterminacy is not limited to a special topic or a specific rationality, but a fundamental quality of life. The argument is situated on the same level as, for example, the French contributions to the study of nothingness and negation in the 20th century: e.g. Sartre's relation of the experience of the individual as being for oneself to the insight into ones own deficiencies; Lyotard's understanding of the modern as uncovering what is not described in the modern and post-modern as the awareness of the indescribable; Michel Foucault's shadow of the unthinkable in the relation between subject and object (Sartre 1962; Lyotard 1990; Foucault 1971). In the course of these works, the notion of a denial emerged that is not a limitation to human existence, but in the contrary a part of its condition: an essential unreachable vanishing point, opening up the kind of perspective we need for our study of technology.

26.3 The Role of Technology

Technology offers another way to describe the modern age. In the last century, technical applications have penetrated human life with increasing speed. Technology has become deeply involved in everything we do. It has shaped the environments in which we exist and it has determined the procedures of our operations by the tools we use. Today, it is woven so deeply into our existence that we can hardly identify it any more. Tools like newspapers, telephones, cars, television and the computer have covered our lives like different layers of technology which have become just as natural to us as wearing clothes. In consequence, it is hard to keep up the traditional material descriptions of technology as available means in separation from the objective of an operation and the actor himself. We cannot distinguish any more between the physical tools in the world and, as Cassirer expressed it, the symbolic forms which shape our thinking as the tools of our mind (Cassirer 1998, p. 158; Schwemmer 2007, p. 54). In the modern world, we cannot avoid accepting the fact that we, our tools and our objectives are interrelated.

A more suitable notion of technology can be based, for example, on the works of the Spanish philosopher Ortega y Gasset. He describes technology as effort to avoid effort (Ortega y Gasset 1978, pp. 24–34). With technology we can perform actions in such a way that we do not have to face some of the effort that we would have to face without it. This happens when technology allows us to leave a part of the action on its own, so that we do not have to bother with it. Using a hammer, we do not have to care about how to gather the momentum to transfer the necessary kinetic energy to the nail. Putting clothes and detergent in a washing machine, we do not have to take care about watering and rubbing the fabrics until they are clean. Technology avoids effort by establishing relations and procedures that can be left alone, because we can be sure about the output when we know the input. In this way, we can develop Ortega y Gasset's notion of technology towards a general pattern of operations with clear outcome, for which we might use the word determinacy.

26.4 Technology and Determinacy

The change of attitude towards indeterminacy and the development of technology in the 20th century can now be related to one another. The denial of the possibility of determination can be understood as a reaction to experiences with technology. And in fact, the disappointments of the expectation of determinacy in the 20th century are all based on specific technological progress: physical experiments accessing single particles which are found to behave strangely, formal representations in mathematics which make it possible to express fundamental contradictions, photography and other techniques of image processing which perfect the reproduction of any visual experience, information technology which makes it possible to organise complete systems and makes clear that we might still be unable to control them etc.

The change of attitude towards indeterminacy caused by these disappointments is easily misunderstood. At first sight, it may seem as if someone who accepts indeterminacy as inevitable would hardly be interested in determining things any more. The appearance of indeterminacy in set theory and logics gives a fine example to show that this is not true. When the belief that the axiom of comprehension could bring full determination to set theory was shattered, people soon started to call this event the crisis of the foundations of mathematics. Most Mathematicians, however, are very hesitant to use this expression, because the practical usage of mathematics never was in the state of a crisis. The disappointment was only caused by the expectation that a universal determined representation of the mathematical universe was possible (Hilbert 1922, p. 157). It did not inhibit the development of mathematical structures, formulas and conclusions. The same is true for any aspect of human affairs where indeterminacy was experienced. Technological development continues. Determination remains the bait to drive progress. The only thing that has changed is the topography of the space in which the progress takes place.

26.5 How Technology is Made Possible

It is now time to study the relation between indeterminacy and technology in more detail. For this, we have to look at the specific patterns in which indeterminacy appears in technological operations. Since Aristotle, the structure of technological operations is defined by the practical syllogism of intention and means that allow its realization. The relation of intention and means in technology is determined (see e.g. Hubig 2007, pp. 121–129). A means is a means for a certain intended outcome, and a means works as a means when the transformation from input to output by the usage of this means is determined. Thus the structure of technological operations does not allow any indeterminacy; it is essentially determination. However, Aristotle himself already introduced the principle of appropriateness of action in a given situation (see e.g. Nic. Ethics, 1094b). Considering technology only as an application of what is provided by nature, he did not claim that technology needs to be appropriate. Today, the situation is clearly different. Appropriateness is an important aspect of technology and it leads us to the vanishing point of indeterminacy.

In present technology, we can distinguish two different ways of dealing with the problem of appropriateness; one of them can be called classical, the other post-modern. For instance, technological operations are appropriate in the classical way if they comply with given norms. Norms define the extent to which objects and procedures are determined; beyond the boundaries of the norms, we cannot rely on the means and the outcome of the operations. Another way is the introduction of stochastic objects. In a factory, it is appropriate if less than a given percentage of the production is defective. Any single operation of the machines in the factory may fail. This does not matter as long as 99% (or whatever the threshold is) of the operations is successful.

A post-modern way of dealing with the problem of appropriateness is, for example, heuristic optimization. In complex search spaces where analytic approaches fail, search methods like Genetic Algorithms can be used to optimize solutions by continuous improvements of small samples of the given space. In practical applications, there is no way to prove that the output is indeed an optimum. Still, it is appropriate to use this result since it will most certainly be the best solution that can be identified. The post-modern label seems to be justified in this application because such technology is based on the acceptance of restricted knowledge of the outcome and missing analytic representation to justify it. For similar reasons, Chaos Theory and new approaches in Artificial Intelligence can be called post-modern, too.

Appropriateness does not restrict the power of technology. Saying that an operation has to fit to the circumstances does not set up any limitations of what can be done. Quite in the contrary, appropriateness is what makes technology possible in the first place. Without using normed objects and procedures, without the acceptance of a certain probability of error and without renouncing the claim of full knowledge and representation, none of the applications we discussed would be working. So, if we say that technology covers every aspect of human affairs, we can still establish a point of view outside of technology when we state that technology has to come into being. Technology as determinacy is established on a background of indeterminacy; and the actor who does this is the one we call engineer. Engineering, we could say, is always engineering determinacy.

26.6 The Question of Exclusivity and Heidegger's Answer

Engineers consider themselves problem solvers. Being asked what the most important step in problem solving is, every practitioner would probably answer: the understanding of the problem, which means nothing else than establishing the determinate background on which we can put together a solution. As seen before, there are different ways to establish an appropriate background, just as there are different concepts of rationality. All of them result in determinacy and all of them can be called technology. Engineers can use various different strategies to solve problems. The specific quality of being an engineer is not based on a certain kind of rationality, but on the fact that in the end, a problem structure is introduced and solved. In other words: being an engineer describes a specific mindset where human affairs are approached as problems. Obviously, the question if technology covers everything is now divided into two parts: even if we accept without further discussion that everything can be approached in technological terms, we can still ask whether technology is exclusive in doing so. While the mindset of an engineer treats every aspect of human affairs as a problem, there still might be other mindsets that can serve as alternatives. As far as we know, technology stands only for one type of reflection. We cannot say whether the way an engineer thinks is identical to reflection itself or not.

Martin Heidegger's answer to this question is quite clear (Heidegger 1962, p. 16). According to him, the modern techno-scientific society is the culmination point of a long process of forgetting that there is a difference between the pure being and the way we can determine things as being in the world. In the modern society, the engineer's mindset appears to be exclusive. It dominates thinking in a way that does not allow any alternatives beside it. Heidegger even suggests an alternative: He compares the modern notion of technology to Aristotle, where technology is integrated into binding natural environment. Within this environment, technology could not assume the dominant role for thinking that it has today. At a closer look, however, it has to be said that Heidegger's alternative is not an alternative to the mindset of an engineer (see Hubig 2007, pp. 102–104): The fact that the freedom of an engineer to introduce an application in order to solve a problem is somehow bounded does not mean that there is anything that could replace engineering. Heidegger shows an alternative source for appropriateness, maybe a different concept of rationality, but not a different type of reflection.

26.7 Logical vs. Transcendental Reflection: Janich and Hubig

The question whether the engineer's mindset is irreplaceable in human life or not can be developed as a question about the level on which the types of reflection are characterized. Peter Janich has lately distinguished different types of reflection on a "logical" level (Janich 2006, p. 15). On this level, the different types sort the means to gain insight into the world as predicative expressions. Janich uses this approach for the discussion of culture and method on nature and technology. For him, technology refers to a mindset in which expressions are used to refer to all kinds of proceeding action. Nature is a different mindset, because is uses expressions to refer to events and experience with action. In this way, the distinction of different types of reflection in the logical sense classifies predicative expressions on a higher level again as predicates. Such types of reflection can exist next to each other and it is necessary to negotiate between them.

With reference to Kant, Christoph Hubig contrasts the logical types of reflection with transcendental types of reflection, following the path of the argument in the Critique of Pure Reason in which Kant offered a solution to the dispute between Locke and Leibniz. Asking for the conditions of the possibility of reflection, Kant came to the introduction of transcendental terms. In contrast to the "logical" terms of Empiricism and Rationalism, they bring together ideas and intentions with the powers of insight that make them come into being. Transcendental types of reflection are situated on a much more elementary level of thinking where the background upon which they may be compared is missing: Since the condition of its possibility is part of the definition of this type of reflection, the reflection has an absolute quality (Hubig 2006, p. 229).

Hubig translates Kant's work from the theoretical relations of the world into practical relations to the world. He constructs technology as a transcendental type of reflection. Technology subsumes all potentials for action. It is the embodiment of doing things, and in this sense, it has no alternatives. In contrast to Janich, nature is for Hubig the embodiment of determinate structure in the world being at our disposal for action, while culture is the embodiment of determinate operational structures of means and objectives for operation. Both are obviously defined on a technological background in Hubig's sense. Understanding technology as determinacy and the engineer's mindset as reflection on the world in technological terms, Janich's distinction between nature and technology as alternative types of reflection does obviously not fit. We clearly have to vote for Hubig's transcendental type of reflection.

26.8 The Absoluteness of the Negation

With these premises, we now have to look for a different transcendental type of reflection than the one that is given by technology. As we have seen, Heidegger's suggestion for an alternative did not fit to our notion of technology. In fact, we can use Heidegger's work itself to show why it could not fit and why it is very unlikely to find any alternative at all. The answer is given in Heidegger's reading of Kant (Heidegger 1967).

Heidegger does not object the structure of Kant's arguments. He evaluates its ontical meaning. According to Heidegger, the transcendental method assumes to talk about being while at the same time it refers to objects and reasons in the world. In consequence, objects and reasons falsely appear to be true being, which made it possible that rational thinking spread itself out to cover human affairs exclusively in structures of reason. In this way, Heidegger says, the transcendental method by itself gains exclusivity against other constructions (Heidegger 1967, p. 137). Now, it seems fairly easy to make the step from objects and reason to determinacy. Doing so, the transcendental method itself becomes part of a closed system in which reason, rational thinking, determinacy and technology are interconnected. Then, of course, the engineer's mindset is already built into the transcendental method and the other way around. An alternative could only be found if we stepped beyond the whole system, renouncing reason, objects and determinacy.

From this we can conclude that our true being is not being an engineer, but when we try to abdicate our role as an engineer, we have to give up the whole way in which we can think about the world. So, all that we can say is that there is more than being an engineer, but than we can only express this statement as a denial. This leads us back to the term of indeterminacy which we started from.

26.9 Conclusion

In order to find out what happens when we tear down all limitations to the notion of technology, we have introduced the guiding difference between indeterminacy and determinacy. At the present time, this approach seems rather natural, since the experiences that shaped the 20th century can be interpreted as disappointments of the expectation of determinacy, which led to a change of attitude towards indeterminacy. The driving power behind these experiences was the development of technology. Based on the ideas of Ortega y Gasset, we have developed an understanding of technology as determinacy. There certainly would have been other ways to achieve this goal. For example, a review of the theory of action and the concept of means and objectives could have lead to a similar result. With technology as determinacy, indeterminacy becomes the vanishing point that remains outside of the scope of technology. In fact, we have found traces of such a vanishing point in the ways how technology comes into being: for any technological structure the scope of determinacy has to be established appropriately. Determinacy is not a given, it is the result of a process which we described by the word engineering.

The idea that every aspect of human affairs can be approached from an engineer's point of view seemed plausible enough to accept it without further discussion. What remained was the question whether the engineer's mindset was exclusive in this. As we have seen in short glimpses on the work of Heidegger and Janich, the answer to this question depends on the notion of technology. The way we have understood technology, the alternatives given by Heidegger and Janich did not make sense. We have not verified if they made sense with other notions of technology, but there may be cause to doubt that, for the simple reason that a consistent notion of technology is not so easy to find when the scope of technology is restricted. With Christoph Hubig, we have identified the mindset of an engineer as a transcendental type of reflection which assumes exclusiveness. With Heidegger, we can say that our notion of technology is so closely related to our access to the world that there is probably no other way to express ourselves than the mindset of the engineer. The only thing that remains is denial.

The conclusion from this little study is that anything we say without the mindset of engineer will by necessity have the quality of a denial. As soon as we start to specify the denial and change its negative meaning into something positive, it will become something we can interpret as technology. So, technology will never be everything, but as soon as there is something, we can consider it technology.

Acknowledgments Special thanks to Christoph Hubig for his remarks on my ideas and to Joe Pitt and Billy Koen for their interest and encouragement.

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Chapter 27
Quo Vadis, Humans? Engineering the Survival of the Human Species

Billy Vaughn Koen

Abstract Since life first appeared on Earth some 3.8 billion years ago, 99.9% of all species have gone extinct. What is the future of the human species confronted with these almost insurmountable odds? This paper defines Universal Method as a generalization of the Engineering Method and, in effect, develops a combined *philosophy–engineering framework* to engineer the survival of the human species. In so doing, it serves as a modest example of the importance of an applied philosophy of engineering.

27.1 Introduction

> Since life first appeared on Earth some 3.8 billion years ago, it has been estimated that more than 99.9% of all species have gone extinct (Raup 1991). Today, all the extant (living) species on Earth may represent less than one-tenth of 1% of all the species that have ever existed. Billions of species have gone extinct throughout geologic history (Sawicki).

***Quo Vadis*, Humans?**[1]

The objectives of this paper are (1) to develop a philosophically defensible framework for answering this paramount question with examples of its use and (2) to serve as a first, though modest, example of an *Applied Philosophy of Engineering*.

> You and I are participating in a magnificent experiment to see whether Nature's latest wrinkle, the *human species* armed with its new weapon *intelligence*, has survival value.

So begins my book *Discussion of the Method: conducting the engineer's approach to problem solving* that forms the basis of this article (Koen 2003). It will be referred to by the acronym *DOM* in what follows.

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[1] *Quo vadis* is Latin for "Where are you going?" and a proverbial phrase from the Bible (John 13:36).

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DOM defines the Universal Method for solving any problem based on the method of the engineer. Method once in hand: what more important problem is there to tackle than that of our own *precarious* existence suggested by the statistics just cited? In effect, we seek to *engineer the survival of the human species*. I invite you to weld with me our species' unique weapon *intelligence* in the form of Universal Method to beat the almost insurmountable odds that confront us.

This chapter is divided into four parts. In Part 1, we must reprise the engineer's approach to solving problems and then in Part 2 generalize the engineer's method to Universal Method. They cover familiar territory for those who have read DOM but are included here because they are essential background for those who have not. In Part 3, the promised preliminary framework for attacking the survival of the human species is proposed. Finally, Part 4 gives specific examples of the application of the theory developed and concludes with a personal invitation to you.

The claims made in the two initial parts are sufficiently complex and novel, perhaps even audacious, that it is almost impossible to make them compelling in the limited scope of an article. They have, however, been treated in greater detail in previous publications. Those interested in investigating this background information in more detail are referred to Koen (2003, 2005a,b, 1985, 2007, 2008).

27.2 Definition of Engineering Method

In DOM (Koen 2003, p. 28) I propose the following definition of the engineering method:

> The engineering method (often called engineering design) is the use of *heuristics* to cause the best change in a poorly understood situation within the available resources.

This definition contains important words that are being used in a sense peculiar to the engineer and are highly charged philosophically. Let us focus attention on two of the most important to the task at hand: the *heuristic* and the engineer's notion of *best*. In addition to this definition an important additional auxiliary engineering concept, the *state-of-the-art*, must be understood before developing the framework for human survival we seek.

27.2.1 The Heuristic

My *first cut* at the definition of the word *heuristic* in the definition of engineering was given in a presentation in 1971 (Koen 1971) as

> A heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible.

A heuristic has several characteristics that help to distinguish it from a scientific law: (1) it does not guarantee a solution; (2) it may contradict other heuristics; (3) it can reduce the search time for solving a problem; and, (4) its acceptance depends on the immediate context instead of on an absolute standard.

Engineering heuristics run the gamut from very simple *rules of thumb* to some of the most philosophically sophisticated concepts imaginable. Representative engineering heuristics include:

- those that aid in the allocation of resources such as the admonition to *Allocate resources to the weak link*,
- others that control the amount of risk to be assumed such as the admonition to *Always give yourself a chance to retreat*, and
- still others that indicate the appropriate attitude for an engineer to take when encountering a problem such as the admonition to *Work at the margin of solvable problems*.

It is worth noting in passing that the first sample engineering heuristic given *Allocate resources to the weak link* is the prime motivator for this article as was alluded to in the introduction. If we claim a universal method for solving *any* problem, what more important problem or "weak link" can there be than that of promoting our own survival?

In addition to the sample heuristics just given, the definition of an engineering heuristic includes all of the orders of magnitude, graphical correlations, factors of safety, and mathematical equations used throughout engineering practice.

Two specific examples of engineering heuristics, one a simple rule of thumb and the other a more sophisticated heuristic, will help with an understanding of the notion. Remember them well. They will be needed again momentarily.

A professor at the US Coast Guard Academy gave his students the following rule of thumb: if a *first cut* estimate of the cost of a building in the United States is needed, (1) estimate its size, (2) calculate the equivalent weight of concrete it would contain, and (3) then multiply by the cost of hamburger meat per pound to get an approximation to the cost. At the time of his lecture, construction cost in the US scaled as the cost of hamburger meat. He would then continue: if the building is to have an abnormal amount of electrical components, use the cost of sirloin instead of the cost of hamburger meat.

At the opposite end of the spectrum, consider Fig. 27.1 by Dr. Barry Bebb,[2] (Sullivan 1986) formerly of the Xerox Corporation.

This figure compares the graphs of the number of *change orders* in the design of an automobile in Japan and the United States. A change order occurs when a major change is made in the design of a product during its development. The number of change orders versus time for Japan is plotted as the curve on the lower left and the

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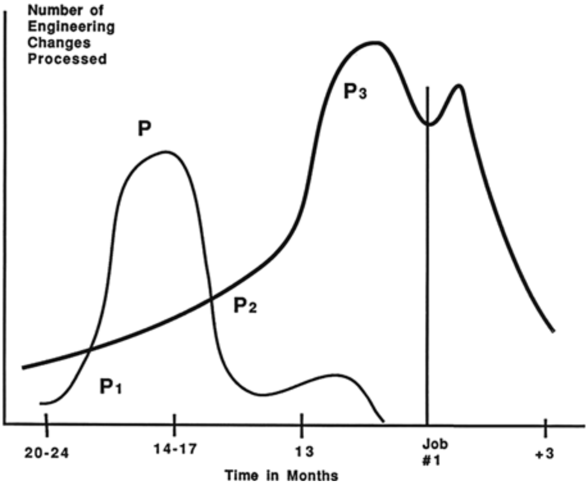
[2] Reference quoted by Bebb, H. Barry, in a presentation entitled "Quality Design Engineering: The Missing Link in U.S. Competitiveness." The figure has been approximately redrawn for this chapter.

Fig. 27.1 Japanese vs. USA changes



one for the United States is the higher curve on the right. The vertical line labeled Job 1 indicates the time when the automobile is released for sale to the general public.

It is immediately obvious that Japan and the United States differ in the number of prototypes, indicated by the letter P. According to the article cited by Dr. Bebb, the Japanese use only one prototype during the design process; Americans typically use three. In addition, the Japanese automotive engineer distributes cars to employees for the final debugging (which accounts for the final hump in the number of change orders) before distributing it to the general population. On the other hand, the American engineer releases the automobile directly to the population when the change orders begin to decline.

No implication should be drawn here that one of these heuristics is necessarily better than the other. The point is that different heuristics are used in different countries and that some of them are very sophisticated. Which heuristic to use in a specific instance may depend on context.

The word *heuristic* was not used first in conjunction with solving engineering problems. Many historians attribute the concept to Socrates about 469 B.C. and it has been used throughout the centuries by a very large number of philosophers including Pappus, Descartes, and Leibnitz. What is important is to note that the word is being used here in a slightly different, but important, sense than the historical one. As usually understood, a heuristic offers a chance to arrive at an approximate solution to a difficult problem with the implication that another, true solution exists. To quote Polya (1945):

> Heuristic reasoning is reasoning not regarded as final and strict but as provisional and plausible only, whose purpose is to discover the solution to the present problem.. . . We shall attain complete certainty when we shall have obtained the complete solution, but before obtaining certainty we must often be satisfied with a more or less plausible guess.

When the word *heuristic* is used in the definition of engineering, it is not to imply that the engineer uses heuristics only from time to time to aid in the solution of particularly intractable problems as might be said of a mathematician. The specific claim made in this paper is that *the engineering method* and the *use of heuristics* is an absolute identity. Absolutely everything the engineer does is based on a heuristic and, contrary to the conventional wisdom, there is no "absolute truth hidden beyond the veil" that the engineer simply explores by using heuristics. This engineering notion of the heuristic represents a radical departure from all other uses of the word in the literature in 1971.

27.2.2 The Best

The second word in the definition of engineering method chosen for study is the word *best*. What is to be taken as good by the engineer and the one thought to be used by the layman, undoubtedly derived from Plato, are strikingly different. Both must be considered here and then they will be compared. What we will find is that in actual practice we universally implement the engineer's concept although pledging allegiance to that of Plato.

27.2.2.1 The Engineer's Good

Recalling the technical terms used in optimization theory and borrowing the figures given in DOM (Koen 2003, p. 17) will help us define *best* for the engineer.

Consider a television set with one control as shown at the top of Fig. 27.2. We will assume that turning this knob to a higher number will produce a better picture but at the same time worsen the sound; turning the control to a lower number will

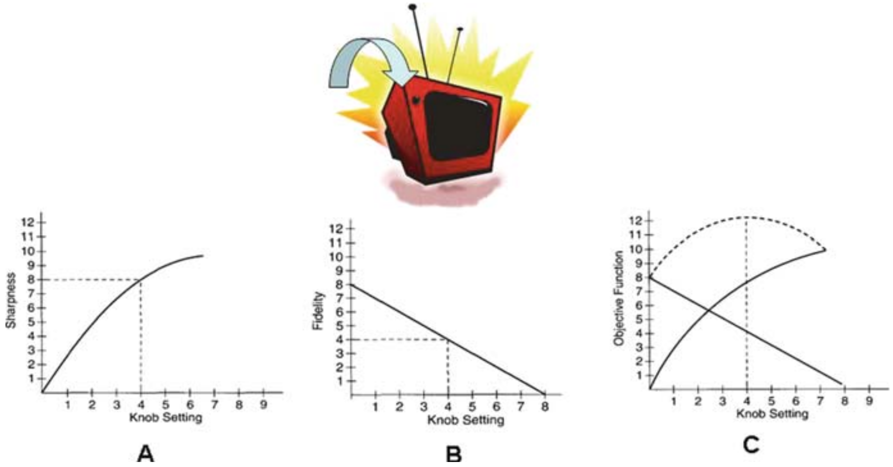


Fig. 27.2 Best knob setting

worsen the picture but improve the sound as shown by the graphs at A and B. It is relatively easy to adjust the knob for your personal preference as you balance the relative importance of picture and sound.

To represent pictorially what a person does instinctively when she selects her preferred setting, the two return functions must be combined or superimposed on the same graph; they must be put on the same basis; or, technically, they must be made commensurate. What the engineer needs is the relative importance of sound and picture to the owner of the television set.

The upper dotted curve at C is the sum of A and B under the assumption that an improvement in picture and sound are equally desirable. This dashed curve is the common measure of goodness for the problem. It is sometimes called the objective function or measure of system effectiveness.

We want the largest or maximum value of the objective function. This number is called the *optimum* or *best* value. For this television set, the optimum setting corresponds to a control setting of the knob or independent variable of four. This balancing of multiple criteria is what an engineer calls a *trade-off*.

This example can be put on a mathematical basis and generalized. In the appendix a simple mathematical derivation is given that was prepared by professors from the Operation Research and Business areas of The University of Texas at Austin to give a brief introduction for those unacquainted with the theory. Admittedly it omits many important considerations, but it will serve as an introduction.

Optimization Theory is a very important and actively researched area in engineering. The particular version chosen here to make ideas more concrete is called *Multi-attribute Decision Theory*.[3]

The design of a more complex engineering project such as an automobile will have an optimization space with a much larger number of conflicting technical criteria such as fuel economy, power, safety, comfort, and style. As a result, a large computer and sophisticated numerical strategies would be needed to obtain the optimum if we wanted to calculate it analytically.

Except in rare instances, engineers do not seek the optimum mathematically, but they always do it implicitly. They commensurate the incommensurables – *heuristically*.

In conclusion, *best* for an engineer is the optimum in a rich *multi-variant* space including technical, ethical, aesthetic, and humanistic criteria. The choice of criteria and their weightings are determined by the context which is also determined heuristically.

The complex axes system used by the engineer in a typical engineering problem is impossible to represent accurately on a planar surface, but it is easy to treat mathematically as we can see in the appendix. Figure 27.3 will be used symbolically to

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[3] Some researchers would classify this as an example of Multiple Criteria Decision Making (MCDM) instead of Multi-attribute Decision Theory. See the appendix for a more technical discussion and relevant references.

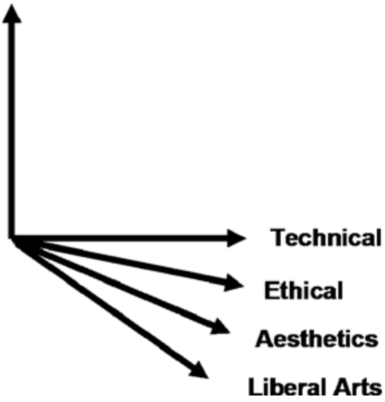

Fig. 27.3 Engineering optimization space

remind us of the engineer's notion of *best* and to allow us to compare the engineer's best with Plato's best.

27.2.2.2 Plato's Good

The Greek philosopher, Plato, saw things differently. His view of the good is complex and forms a major part of introductory courses in philosophy. We cannot do it justice in this chapter, but since it colors the nonengineer's view of engineering, a brief gloss of it is essential.

Plato hypothesized (I would say "proposed the heuristic") that Ideal Forms of such concepts as a circle, justice, beauty, the good, etc. actually exist in a realm inaccessible to the ordinary person and what we take to be these concepts in our world are pale shadows of these Ideal Forms.[4]

To quote one author [retaining his emphasis]:

> A general idea or concept, according to this new doctrine, is immutable, timeless, one over many, intellectually apprehensible and capable of precise definition at the end of a piece of pure ratiocination ***because it is an independently existing real thing or entity.*** ... As our everyday world contains people, trees, stones ... so a second and superior, or transcendent world contains concept-objects (Edwards 1967, Vol. 6, p. 322).
>
> Only later did Plato see that the arguments for taking Justice, say, and Unity as Forms would establish Tree, Silver, Knife and Sour as Forms too (Edwards 1967, Vol. 6, p. 323).

Based on this analysis, a disciple of Plato would surely feel justified in adding the Ideal Forms of a freshly baked apple pie to the list.

Figure 27.4 is only a crude depiction of the Platonic world, but it is sufficiently accurate for the present purpose. These Ideal Forms were ordered in a hierarchy culminating in the ultimate form of the Good. This is depicted in Fig. 27.4 by the top line slanting to the right. (The order of the items on this line have no historical significance.)

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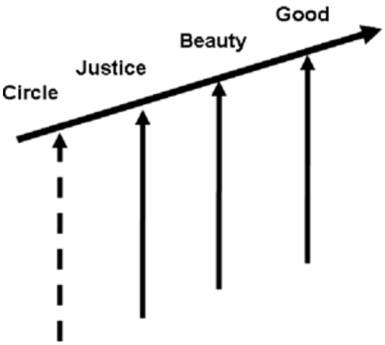
[4] Plato's Theory of Forms was first fully developed in the Platonic dialogue, *Phaedo*.

Fig. 27.4 Plato's notion of the good



Now consider the ideal form of a circle in the figure and focus on the dotted vertical line below it. This is the realm where we live. We move upwards along this line from *good* to *better* to *best*. And, for a follower of Plato, so goes the evaluation of other concepts such as an apple pie.

The crucial thing to notice is the progressions along the dotted line and the slanted one are along mono-variant lines. There is no influence and certainly no commensuration between separate Ideal Forms.

27.2.2.3 Comparison of the Engineer's and Plato's Notions of Good

A comparison of the engineer's and Plato's worlds is instructive. Contrast Figs. 27.3 and 27.4.

The engineer lives in a heuristic world the goodness of whose concepts are evaluated as the optimum trade-offs in a multi-variant space; Plato lives in a dual world of Ideal Forms and shadows the goodness of whose concepts are evaluated in a combination of distinct mono-variant spaces.

A practical example will illustrate the difference in the two worlds.

Assume that you have been invited to a dessert party at the home of a person who is widely celebrated by all for her succulent pies – let us call her, Mrs. Goldberg. When you arrive, arrayed before you are ten or fifteen pecan, apple, lemon, etc. pies with a cheese cake thrown in for good measure from which you are invited to choose. They differ in flavor, texture, color, crust, and there are multiple examples of each. Unfortunately, you can only choose one, so certainly you want to choose the *best* piece. In my case I would want the best (and largest) piece of Mrs. Goldberg's pecan pie.

The best strategy for making this decision is subject to much research in modern decision theory. It can be placed on a complex theoretical basis – something Plato could not have foreseen.[5]

---

[5] One of the major issues is technically called R-transitivity or its weaker form, P-transitivity.

It is also worth noting that there is no Ideal Pie apart from context. If you had eaten pecan pie several times over the last week, you might not want to choose a piece of pecan pie at the dessert party even if it were your favorite kind of pie. In effect, weighting coefficients in your optimization space have changed and the optimum has shifted.

We all do the equivalent optimization of the choice of Mrs. Goldberg's pies everyday. And, one thing is certain, there is no "ideal pie in the sky." Furthermore I will bet even Plato would not forgo choosing a piece of Mrs. Goldberg's delicious pies because he was unable to commensurate the multiple criteria of taste, appearance, flakiness of crust, smell, and size.

I consider the engineer's notion of *best* one of the major gifts the engineer has to give to philosophy.

In summary, the engineer uses heuristics to find the best solution in a resource constrained, uncertain situation. The important lesson to be learned from an analysis of the engineering method is that a problem can be satisfactorily solved in a multivariant space in the complete absence of the concept *certainty* by using heuristics.

We have now completed the two principal words in the definition of engineering method and it is time to consider the last, auxiliary term promised, the *state-of-the-art*.

27.2.3 The State-of-the-Art

The term *state-of-the-art*[6] is a valuable concept that allows us to understand what the engineer does and how he or she does it. It can be generalized for use outside of engineering to great effect. We will need it in a general sense throughout the remainder of this paper, but in this section we consider its use in engineering.

27.2.3.1 Sota$|_{\text{individual, time}}$

Engineers learn the engineering heuristics they use every day from books, in school, and by observing the actual world around them. It is convenient to use the symbol, sota$|_{\textit{individual, time}}$, to represent the set of heuristics, the state-of-the-art or – to use an acronym – the *sota* to refer to the engineering heuristics available to a specific individual at a specific time.

A circle representing the sota for the engineer we will call Mr. A or sota$|_{A,\ time}$ is shown as the first image at the top of Fig. 27.5. It represents the totality of all the concepts, mathematics, correlations, and other specialized knowledge, helpful in engineering design that is available to A at a specific time. This engineer only has knowledge of the heuristics in this set. For example, if he or she has never studied the calculus, it is hard to see how the calculus could be used in an engineering project.

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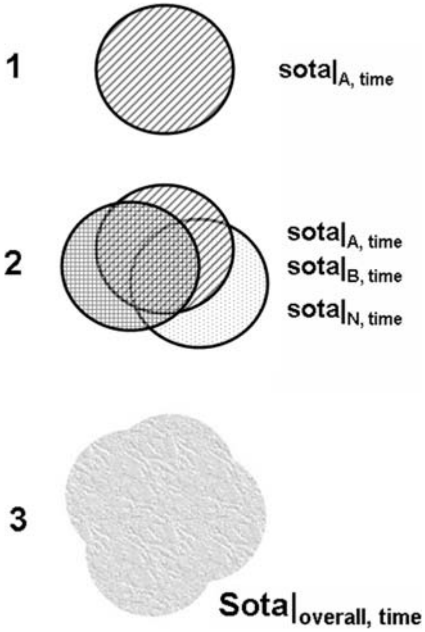
[6] Its present form is cited as early as 1910 in an engineering manual on gas turbines (Cockle 2006).

Fig. 27.5 Individual sotas



Obviously, an engineer cannot use an unknown heuristic. The sota of an engineer both confines and restricts the range of the possible in engineering design.

Sota| $_{individual,\ time}$ proves to be an extremely valuable notion that can be shown to help define *all* human concepts. To demonstrate its effectiveness in the case of one specific concept, attention turns to defining what an engineer takes as *best engineering practice*. We will return to sota| $_{individual,\ time}$ and the rest of Fig. 27.5 repeatedly in what follows when the concept of *human survival* is to be considered.

27.2.3.2 Sota| $_{\text{best engineering practice, time}}$

All engineers do not have the same state-of-the-art or sota. They differ in the universities they have attended, the courses they have studied, the conferences in which they have participated, and the countries in which they have lived. Not unexpectedly engineers differ in the heuristics they have available for use. Therefore, sota| $_{B,\ time}$, for engineer B is different from the one given for engineer A as is sota| $_{N,\ time}$ for an arbitrary engineer, N. Since sotas are not the same, they are not congruent, but overlap as shown by the middle image indicated by the 2 in Fig. 27.5.

If the sotas of all engineers living today were combined in this way, all possible heuristics available for engineering would appear as in the bottom section of the figure. This overall collection of heuristics would represent *best engineering practice* or sota| $_{best\ engineering\ practice,\ time}$. It is against this sota that a specific engineering design should be evaluated (Koen 2003, p. 50). Thus it is not unreasonable to speak of a state-of-the-art stereo system as one that is designed based on the current best engineering heuristics for stereo design.

A final note: the individual sotas of all engineers are not equally appropriate in solving a specific problem and best engineering practice is in actual fact a weighted average with *best*, of course, being used in the engineering sense instead of that of Plato.

The important thing to remember is that sota always refers to a collection or set of heuristics and the subscripts tell us which set we are considering and at what time.

The concept of a sota and Fig. 27.5 are two of the most important, yet under appreciated, concepts in engineering.

I consider the engineer's notion of a sota as a collection of heuristics the second major gift the engineer has to give to philosophy.

This completes the analysis of the engineering method as promised. Part II will generalize it to Universal Method. Then, at last, we will be in a position to develop a framework for human survival.

27.3 Universal Method

> If there is to be a universal method—and there is—at a minimum it should be, well, universal. Whether we look to philosophy, to science, to the arts, to engineering, or elsewhere, any method that claims to be universal must subsume all of its competitors. Perhaps surprisingly, the engineering method will emerge as the prototype in our search for the universal method. (Koen 2003)

Defining the *engineering method* as based *exclusively* on heuristics is not a great threat to philosophers. The thrust of the next part of this article – is.

27.3.1 Expanding the Scope of the Heuristic: All is Heuristic

Part 2 now insists that not just all of engineering is based on heuristics, but that everything is. In effect, the central claim of this part is that

All is heuristic.

By *All* is meant *All*. *All* includes this claim itself, the words from which it is composed, and the grammar and logic it uses. If its *self-referential* nature is worrisome, just remember that *self-reference* is also a heuristic in a world in which *All is heuristic*. In fact, the central claim is not even that *All is heuristic* is true, because, of course *true* is itself also a heuristic. What is being claimed is something like *All is heuristic* is the *best* heuristic (using *best* in the sense of the engineer).

The immense extent of the universe and its unfathomable age make it highly unlikely that anything we claim to know now has eternal standing. If you were a betting person aware of the short time humans have been on this earth and the number of things we have thought to be true that turned out not to be so, what odds would you give that there cannot and will not be changes in the future that will wipe out all things we now think to be true?

Also, throughout our short history on this planet, there has been a group of very active philosophers (the skeptics) who have been dedicated to showing that everything we think is true is in actual fact, false.

But maybe these arguments are unconvincing. Instead, even though the universe is large and the odds are infinitesimally small, perhaps we could have just been lucky and stumbled on a sure way to know the world. Some think we have done so and they call it the scientific method.

27.3.1.1 Science as Sota$|_{\text{Science, time}}$

Let us now turn to science, a notion that makes strong claims that it gives true knowledge, and insist that *Science is just a collection or set of heuristics* and that *sota science, time* is itself just one more good heuristic. Figure 27.5 will, once again, aid us in this endeavor.

Scientists do not agree on what science really is: For example, we see (1) one opinion in the work of the Ionian philosophers (Thales, Anaximander, and Anaximenes) where many feel the germ of the scientific method was first planted in the 6th century B.C.; (2) another by Aristotle in the *Organum*; (3) still another by Bacon in the *Novum Organum*; (4) yet another by Descartes in the *Discours de la Mèthode*; (5) yet another by Popper in The *Logic of Scientific Discovery*; and, finally, (6) another by Kuhn in the *Structure of Scientific Revolutions*.

This disagreement among experts suggests that at the very least, each of their opinions should be treated as heuristics, each of these views should be represented by a distinct circle at 2 in Fig. 27.5 on page 10.

The notion that science gives us true knowledge is actually very tenuous for

1) remembering that *Gödel's Proof* is a constructive proof that demonstrates that *arithmetic* (the axioms that give us the fact that $2 + 2 = 4$), indeed all of *mathematics*, and all *deductive systems* sufficiently rich to encompass the expressive power of arithmetic are either incomplete or inconsistent;
2) remembering that the *Einstein-Podolsky-Rosen (EPR)* thought experiment and *Bell's experimental confirmation* of it cast doubt on *causality* (Or as the celebrated physicist, Planck, has characterized it, "Causality is neither true or false. It is a most valuable *heuristic* principle to guide science in the direction of promising returns in ever progressive development.");
3) remembering that there are many *logic* systems: Including the Laws of thought, Aristotelian logic, Symbolic logic, Multivalue logic, Quantum logic – just to stick with those in the Western tradition. With such a multitude of logic systems from which to choose, how are we to select one to use in a specific instance – surely not logically? Heuristically, then?
4) remembering that hypnotism and its ability to make people see things that are not there, not see things that are present, and forget that they were ever hypnotized casts serious doubt on *perception*; and, finally,

5) remembering that the Heisenberg Uncertainty Principle attacks our knowledge and certainty of the two sets of conjugate variables, (*position* and *momentum*) and (*time* and *energy*), and that Schrödinger's cat questions our knowledge of *physical reality*;

we are left to conclude that sota science, time is just one more good heuristic.

We are forced to admit that the bottom section of the Fig. 27.5 might just as well be labeled sota$|_{\textit{science, time}}$.

If science fails as dispositive in understanding our world, perhaps ratiocination or the process of reasoning will prevail? The self-professed experts in this area are the philosophers. Let us hear from them.

27.3.1.2 Philosophy as Sota$|_{\textbf{philosophy, time}}$

In his classic textbook, the late Robert Solomon counsels, "the nature of philosophy is itself among the most bitter disputes in philosophy" (Solomon 1977, p. 18).

He then gives telling examples of disagreement: (1) Many philosophers feel that [philosophy] is a science, in fact, the "Queen of the Sciences." (2) It has also been argued that the main business of philosophy is a matter of definitions – finding clear meanings for such important ideas as truth, justice, wisdom, knowledge, and happiness. (3) Other philosophers would insist that philosophy is rather closer to morality and religion and its purpose is to give meaning to our lives and lead us down the "right path" to "the good life." (4) Still others insist that philosophy is an art, the art of criticism and argument as well as the art of conceptual system building. (5) There are philosophers who place strong emphasis on proof and argument. (6) There are others who place their trust in intuition and insight. (7) There are philosophers who reduce all philosophizing to the study of experience. (8) There are philosophers who take it as a matter of principle not to trust experience. (9) There are philosophers who insist on being practical, in fact, who insist that there are no other considerations but practicality. And, finally, (10) There are philosophers who insist on the purity of the life of ideas, divorced from all practical considerations.

Dr. Solomon then concludes that "philosophy cannot, without distortion, be reduced to any one of these preferences." None of these ideas are what "Socrates was willing to die for."

27.3.1.3 Engineering as Sota$|_{\textbf{engineering, time}}$

The notion of a sota can be used to define other concepts as well, even engineering. This chapter is based on the preferred definition of engineering method as "the use of heuristics to cause the best change in a poorly understood situation within the available resources" as extracted from Koen (2003) and given on page 2. In essence this definition is equivalent to sota$|_{\textit{overall, time}}$ in Fig. 27.5 since *engineering method* and the *use of engineering heuristics* has been taken as an absolute identity.

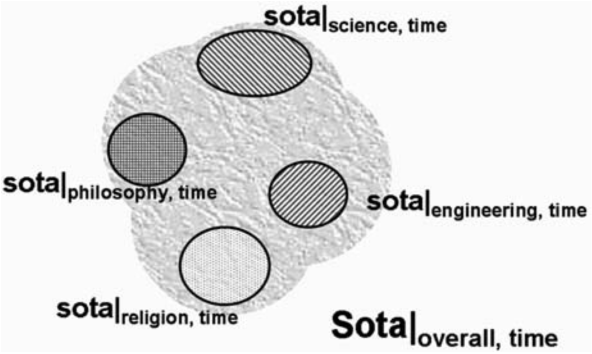

$\text{sota}|_{\text{science, time}}$
$\text{sota}|_{\text{philosophy, time}}$
$\text{sota}|_{\text{engineering, time}}$
$\text{sota}|_{\text{religion, time}}$
$\text{Sota}|_{\text{overall, time}}$

Fig. 27.6 $\text{Sota}|_{\textit{overall, time}}$

This is not the only definition of engineering that appears in the literature, of course. Many engineers agree with the definition in terms of heuristics proposed here, but some engineers do not. Consider only a few of the competitors.

Engineering is (1) a morphology or structure though which the design process is assumed to pass (Dixon and Poli 1995), (2) a set of axioms (Suh 2001), (3) a branch of science called "Design Science" (Hubka and Eder 1996), (4) a process of "trial and error" (Petroski 1994), and, of course, the ubiquitous (5) "Applied Science" used erroneously by the general population, news media, and nonengineers.

Since all of the definitions given involve heuristics, Fig. 27.5 can be reused, once again, to represent the definition of engineering in general with $\text{sota}|_{A,\ time}$ as the preferred definition, $\text{sota}|_{B,\ time}$ the first on the list above, and so forth. As a result the bottom section of the figure could be labeled $\text{sota}|_{engineering,\ time}$.

Science, philosophy, engineering – what are we to make of this array? An earlier paper argued for the consilience of engineering and the humanities (Koen 2005a). Surely with more time, we could demonstrate that $\text{sota}|_{religion,\ time}$, $\text{sota}|_{art,\ time}$, $\text{sota}|_{humanities,\ time}$, etc. exist in an analogous way as shown in Fig. 27.6 and argue for the consilience of all knowledge until at last we are compelled to conclude that *All is heuristic*, that an overall sota, $\text{sota}|_{overall,\ time}$ exists, and that *Universal method as the Use of heuristics* are good heuristics based on analogy with engineering method and a preponderance of the evidence.

Figure 27.6 or its generalization as the bottom image in Fig. 27.5 will be invaluable in the next section where the framework for human survival will be considered.

27.4 Framework for Engineering Human Survival

Of particular interest to us now is the sota that defines the human and the one that defines survival. Attention turns to each of these to develop the framework for engineering human survival.

27.4.1 Survival of the Human Species

What is to be taken as *human*? What *thing* do we want to survive? What do we mean by *to survive*? Unexpectedly these questions turn out to be surprisingly difficult to answer.

27.4.1.1 Sota$|_{\textbf{human, time}}$

Throughout history many definitions have been proposed for the concept *human*. Let us, once again, try the same strategy that has served us so well in the past.

The human is defined by a subset of all heuristics and defined differently depending upon who decides which heuristics to include in this subset. At one time or another, definitions have ranged from: (1) the rational animal, (2) the featherless biped, (3) the image of God, (4) the intellectual lifeform, (5) the animal with language ability, (6) an illusion created by the heuristics of division, categorization, and space – to name but a few candidates from a long list that appears in the literature (Koen 2003, p. 209).

Ultimately, the definition of *human* is human-made by the person choosing which heuristics to include in the subsota to define human. Taken as a whole, the concept *human* is a subset composed of weighted subsets from the overall set of all heuristics. Unfortunately, the heuristic *modern science* suggests that each of these individual proposals has a very small weighting coefficient in sota$|_{\textit{human, time}}$ as we will soon see.

27.4.1.2 Sota$|_{\textbf{survival, time}}$

Perhaps we will have better luck looking for the *thing* we want to survive, the so-called unit of evolution, sought by the advocates of the heuristic *evolution*.

Many candidates have been proposed for this unit of evolution. At one time or another (1) the breeding individual, (2) the taxon[7], (3) a portion of the gene pool, (4) DNA-in-the cell, and (5) the flexible organism in its environment has been advocated as the basic element that survives or is selected against in the process of evolution.

Each of these concepts is a heuristic, of course, depending for its definition on other heuristics that have been taken from the Western scientific tradition (Koen 2003, p. 248).

Unfortunately, the heuristic *science* is currently rendering all of these classic suggestions for the definition of both the human and the unit of evolution obsolete and we must look elsewhere to define what we would like to see survive. Let's quote a very small sample of what is being reported:

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[7] A taxonomic category or group, such as a phylum, order, family, genus, or species.

Fig. 27.7 Ancient chimera

- Scientists have begun blurring the line between human and animal by producing chimeras—a hybrid creature that's part human, part animal. [See Fig. 27.7[8]]
- Chinese scientists at the Shanghai Second Medical University in 2003 successfully fused human cells with rabbit eggs. The embryos were reportedly the first human-animal chimeras successfully created. [Or as one headline screamed: Scientists are planning to create a "frankenbunny" by fusing together human cells with a rabbit egg (Thisislondon.co.uk).
- In Minnesota last year researchers at the Mayo Clinic created pigs with human blood flowing through their bodies.
- At Stanford University in California an experiment might be done later this year to create mice with human brains. (Mott 2005)

To make matters worse in trying to define what it means to be human, the near future may bring new competitors onto the field,

- Scientists in Maryland have already built the world's first entirely handcrafted chromosome—a large looping strand of DNA made from scratch in a laboratory, containing all the instructions a microbe needs to live and reproduce. (Weiss 2007)

27.4.2 Promised Framework for Human Survival

In view of the problems associated with these past efforts to define what it means to be *human* or what we want *to survive*, I feel obligated to propose my own contribution.

We cannot predict what heuristics will define the human in the future, but one thing is certain *snuff out* $sota|_{overall,\ time}$ *and you snuff out any possible definition of what it takes to be human*. This chapter takes $\text{sota}|_{overall,\ time}$ as the unit of survival. It is a reasonable definition of the entire human race. We want it to remain on the main line of evolution.

---

[8] In Greek mythology, the Chimera is a monster, depicted as an animal with the head of a lion, the body of a she-goat, and the tail of a dragon. Photograph of an ancient Etruscan statue of a chimera found in north-central Italy by Ugo Bardi, Permission granted to use. See http://www.unifi.it/unifi/surfchem/solid/bardi/chimera/bronzino/index.html

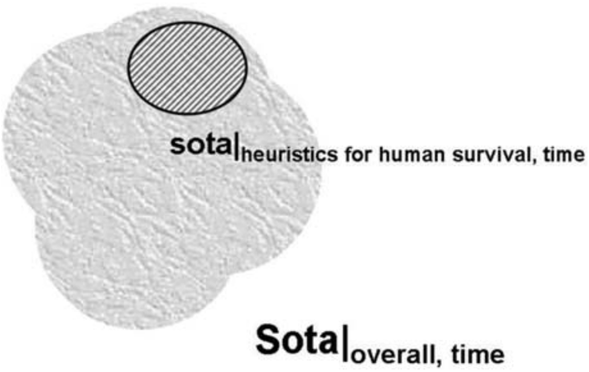
$\text{sota}|_{\text{heuristics for human survival, time}}$
$\text{Sota}|_{\text{overall, time}}$

Fig. 27.8 $\text{Sota}|_{\textit{heuristics for human survival, time}}$

Only one last component of the framework for human survival remains. We must carve out the $\text{sota}|_{\textit{heuristics for human survival, time}}$ from the overall sota. It is the *best* set of all heuristics from all nations, races, religions, families, and individuals to make $\text{sota}|_{\textit{overall, time}}$ persist in time.

Figure 27.8 is the theoretical climax of this paper that was promised in the introduction. It represents the *framework for human survival* we have sought.

27.5 The Framework: Characteristics and Sample Heuristics

The Blind men and the Elephant[9]

It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
(Though all of them were blind),
That each by observation
Might satisfy his mind.
. . .

This verse goes on to say that each of the blind men chances upon and feels a different part of the elephant such as the trunk, tail, or side and concludes that an elephant is like a hose, snake, or wall (See Fig. 27.9). The point of this very old parable is that each person sees and interprets the world from his or her own unique perspective or, as I would say, sota.

Our goal for engineering human survival based on Universal Method may now be precisely stated. We seek the $\text{sota}|_{\textit{heuristics for human survival, time}}$ that will make the $\text{sota}|_{\textit{overall, time}}$ persist in time.

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[9] This modern version is attributed to the American poet, John Godfrey Saxe, but Jainist, Buddhist, Sufi/Hindu, and Discordian versions exist. The original parable originated in China sometime during the Han Dynasty (202 B.C.–220 A.D.) (Robertson 2008). Permission to use image granted by John Robertson.

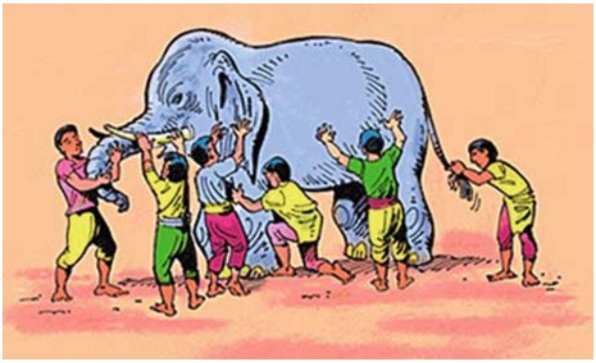

Fig. 27.9 Blind men and the elephant

This final section has two objectives: (1) to examine some of the important characteristics of $\text{sota}|_{\textit{overall, time}}$ and (2) to propose a special kind of heuristic, the meta-heuristic, that the $\text{sota}|_{\textit{heuristics for human survival, time}}$ should contain.

27.5.1 Some Important Characteristics of Sota$|_{\textit{overall, time}}$

As previously noted, Fig. 27.6 may be divided into a wide variety of sometimes overlapping, sometimes disjoint sotas. As with the blind men and the elephant, sotas representing individuals, nations, races, sports teams, religions, genders all see the world differently, sometimes radically differently – sometimes even radically differently enough to go to war and kill.

In fact, there is a sota representing *you* at this moment, $\text{sota}|_{\textit{You, time}}$, contained in the overall sota and, of course, one for me. As with the blind men of Indostan, *You* and *I* each see the world differently based on the heuristics we find in our own personal sota as in Fig. 27.10.

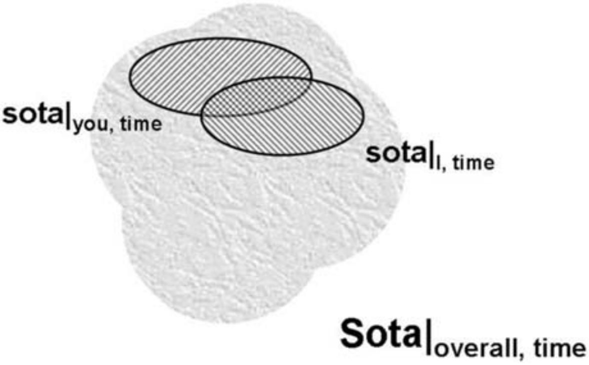

Fig. 27.10 Overlap of $\text{sota}|_{\textit{You, time}}$ and $\text{sota}|_{\textit{I, time}}$

It is worthy of note that this discussion depends on the intersection of these two sotas and could not take place at all if *You* and *I* did not share some heuristics such as language, culture, etc. And, there are inevitably some heuristics outside of the intersection that we do not have in common and cause dissention.

Incidentally, the philosophical dependency of this paper on sota$|_{I,\ time}$ is the reason that it has consistently used the ubiquitous first person pronoun, I. It is based upon my sota and not an assumed or implied external truth.

Now some of the more important characteristics of sota$|_{overall,\ time}$ are examined.

27.5.1.1 Sample Vulnerabilities and Specific Heuristics of Sota$|_{\textbf{overall, time}}$

Let us now examine a small sample of the kinds of vulnerabilities sota$|_{overall,\ time}$ has or what attacks we must ward off to survive. For each vulnerability, sample heuristics we might use will be considered. Each entry is worthy of a complete book.

[SINE QUA NON or "That without which nothing."] Some vulnerabilities are such that if they are not ameliorated, nothing else matters. Two examples immediately come to mind: the possibility of the impact of an asteroid or comet and the eruption of a supervolcano such as the one at Yellowstone National Park in America. Consider each.

Sample vulnerabilities:

- Asteroid Impact

  In our darkest dreams we see the crater-pocked moon or remember the terrestrial meteorite crater in Arizona and become aware of the possible total annihilation of the human species by an asteroid or comet. When the sun rises, we conveniently return to a state of denial. To ensure that the current scientific sota is not misrepresented, a quotation from the literature follows:

  > Since life began on earth, several major mass extinctions have significantly exceeded the background extinction rate. The most recent, the Cretaceous-Tertiary extinction event, occurred 65 million years ago, and has attracted more attention than all others because it killed the dinosaurs. In the past 550 million years there have been five major events when over 50% of animal species died (Extinction event 2008). [See also. (Raup and Sepkoski 1982)]

  Keeping in mind that about 2,000 objects massive enough (1 km diameter) to cause global catastrophe are known to cross Earth's orbit and that such an impacting object would wipe out 25% of humanity (Steel and Clarke 1995) consider the frequency of objects that are known to impact the earth as shown in Fig. 27.11.
- SuperVolcano Eruption

  The situation is somewhat different in the case of a supervolcano. The average person sleeps peacefully unaware that the possibility of an eruption exists. Again, we take an extensive quotation from G. Williams working for National Geographic.

Pea-size meteoroids - 10 per hour
Walnut-size - 1 per hour
Grapefruit-size - 1 every 10 hours
Basketball-size - 1 per month
50-m rock that would destroy an area the size of New Jersey - 1 per 100 years
1-km asteroid - 1 per 100,000 years
2-km asteroid - 1 per 500,000 years
A "nemesis" parabolic comet impactor would give us only a 6-month warning.

Fig. 27.11 Frequency of impactors

> Hidden deep beneath the Earth's surface lie one of the most destructive and yet least-understood natural phenomena in the world—supervolcanoes.. . . The last supervolcano to erupt was Toba 74,000 years ago in Sumatra. Ten thousand times bigger than Mt St Helens, it created a global catastrophe dramatically affecting life on Earth.. . .
>
> It is little known that lying underneath one of America's areas of outstanding natural beauty—Yellowstone Park—is one of the largest supervolcanoes in the world. Scientists have revealed that it has been on a regular eruption cycle of 600,000 years. The last eruption was 640,000 years ago. . . so the next is overdue.. . . Scientists have very few answers, but they do know that the impact of a Yellowstone eruption is terrifying to comprehend.. . .
>
> And it would devastate the planet. Climatologists now know that Toba. . . blasted so much ash and sulphur dioxide into the stratosphere that it blocked out the sun, causing the Earth's temperature to plummet. Some geneticists now believe that this had a catastrophic effect on human life, possibly reducing the population on Earth to just a few thousand people. Mankind was pushed to the edge of extinction. . .and it could happen again. (BBC 2000). [See also Williams (2007)]

Sample heuristics:
Sometime ago, a colleague teaching in the liberal arts honors program, who was also a world class cello player,[10] asked me to give one reason to justify engineers interest in going into space when we had so many problems on earth? I asked him if he had ever played a Stradivarius to which question he answered *yes*. And then I reminded him that an asteroid had hit the earth destroying the dinosaurs and that a supervolcano had nearly destroyed the human race completely in the past and might do so again. In which case, I continued, the universe would never again hear a Stradivarius. With a noticeably misty eye, he replied, "Maybe we should go to the moon."

Stephen Hawking appears to agree. To quote him (Highfield and Hawking 2006):

> The survival of the human race is at risk as long as it is confined to a single planet. Disasters such as an asteroid collision could wipe us all out. Once we spread out into space and establish independent colonies, our future should be safe.

I accept Hawking's premise, but remain wary of his comforting last sentence because of the next category of vulnerability we face as a species.

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[10] Professor Paul Olessky

[FATAL FLAW] It is possible that there is a fatal flaw inherent in the human species that will lead to the ultimate demise of $\text{sota}|_{\mathit{overall,\ time}}$. Some specific individual sotas demonstrably have such a flaw. For example there is a religion called the United Society of Believers (Shakers) in New England. As reported in the New York Times in 1992: Because members choose to remain celibate, only one community remains and the extinction of the communities is only a matter of time.[11]

There is some evidence that $\text{sota}|_{\mathit{overall,\ time}}$ contains flaws that might cause it to self-distruct also. The issue here is whether or not there are fatal flaws that have evolved in the species that no amount of *engineering* can remove.

Sample vulnerabilities:

Consider *The Tragedy of the Commons* and the related *Prisoner's Dilemma.*

- The Tragedy of the Commons (Tragedy of the commons 2008)

> The Tragedy of the Commons is a type of social trap, often economic, that involves a conflict over finite resources between individual interests and the common good. The term derives originally from a comparison noticed by William Forster Lloyd with medieval village land holding in his 1833 book on population (Lloyd 1833). It was then popularized and extended by Garrett Hardin in his 1968 Science essay "The Tragedy of the Commons" (Hardin 1968). However, the theory itself is as old as Thucydides (1950) and Aristotle (1885).

Hardin uses the following situation to illustrate the Tragedy of the Commons:

Assume a village with a central common area on which the villagers may graze their cattle much like the Boston Commons in Massachusetts. When a farmer adds a head of cattle to the commons he individually derives the full benefit from it, but the common resources are only slightly depleted. Under those conditions, the rational thing for the farmer to do is to add an extra animal, then another, and another. Every farmer reasons in the same way until the commons degrades from overgrazing.

We all succumb to the Tragedy of the Commons in small ways when we cut across the grass ultimately leaving a barren path, turn in a paper or project after the deadline, or fail to return a library book on time. But we also fall victim to it in large ways when we pollute the environment, increase population over replacement levels, or horde resources. It certainly appears that this is a fatal flaw embedded in the organization of human society – but is it irrevocably fatal?

---

[11] Ethel Hudson, the last surviving member of New Hampshire's Shaker colony, died on Monday at her home in this town 13 miles northwest of Concord. She was 96 years old. Miss Hudson's death leaves only one Shaker community remaining in the United States. It is in Maine, where nine Shakers live in the town of New Gloucester on Sabbathday Lake. The denomination, whose members are celibate, once numbered 6,000 people in 24 communities around the country. But in 1965 the elders and eldresses who governed these communities decided to abandon the practice of accepting converts as new members. Since then the extinction of the communities has been only a matter of time (Ethel Hudson 1992).

- The Prisoner's Dilemma[12]
  Closely related to The Tragedy of the Commons is The Prisoner's Dilemma. An extensive literature has built up around it and its application to economics, political science, and game theory (Prisoner's dilemma and public choice theory 2008). It is easy to explain, but difficult to resolve.

  > Two people are arrested for robbing a bank and placed in separate isolation cells. The district attorney makes the following offer to each. "You may choose to confess or remain silent. If you confess and your accomplice remains silent[sic] I will drop all charges against you and use your testimony to ensure that your accomplice does serious time. Likewise, if your accomplice confesses while you remain silent, he will go free while you are sent to prison. If you both confess I get two convictions, but I'll see to it that you both get early parole. If you both remain silent, I'll have to settle for token sentences on firearms possession charges. If you wish to confess, you must leave a note with the jailer before my return tomorrow morning."

  The "dilemma" faced by the prisoners here is that, whatever the other does, each is better off confessing than remaining silent. But the outcome obtained when both confess is worse for each than the outcome they would have obtained had both remained silent.

  For engineers who have studied Operations Research, the result may be concisely stated: [The Prisoner's Dilemma] demonstrates very elegantly that in a non-zero sum game a Nash Equilibrium need not be a Pareto optimum.

  As with the Tragedy of the Commons, the Prisoner's Dilemma creates concern because of the wide variety of situations in which it applies. We see nations locked in its grip in the standoff of the arms race, the strategic defense initiative, and reduction of nuclear weapons.

Sample heuristics:
The issue here is to discover heuristics to determine if fatal flaws exist in our species and what to do about them if they do exist.

[CASSANDRAS AND CASSANDRA WANT-A-BES] Cassandra was given the gift of prophecy by Apollo. When she accepted his gift but refused his advances, he deprived her prophecies of the power to persuade (Hunter). For example, she correctly prophesied the Trojan horse and, as we all know, she was not believed. Throughout history there have been many individuals who have predicted the end of the human species or at least serious problems for it. Some should have been heeded; others should not have been. You be the judge.
Sample vulnerabilities:

- **Rachel Carson** is the author of the classic book *The Silent Spring* and often credited with starting the environmental movement (Carson 1962).

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[12] The Prisoner's Dilemma was originally framed by Merrill Flood and Melvin Dresher working at RAND in 1950. Albert W. Tucker formalized the game with prison sentence payoffs and gave it the "Prisoner's Dilemma" name (Poundstone 1992) (Prisoner's dilemma 2008).

- **Donella Meadows et al.** are authors of the book *Limits to Growth* which predicts "overshoot and collapse" in approximately 2020 (Meadows et al. 1974). This book has been cited as starting the movement to limit growth and promote sustainability.
- **Paul Ehrlich** is the author of the book *The Population Bomb* which promoted concern over population growth leading to the Zero Population Growth (ZPG) movement (Ehrlich and Brower 1970).
- **Nostradamus** predicted many things such as "In July 1999" the world shall come to an end!
- **The Orion Prophecy** predicts that the world will end in 2012. "Its magnetic field will completely reverse. . . nearly the whole Earth's population will perish in the apocalyptic events"
- **Pat Robertson** feels that "Natural disasters affecting the globe 'might be' signs that the Biblical apocalypse is near."
- **Al Gore** is author of *An Inconvenient Truth* which predicts global diaster due to global warming (Gore 2006).

Sample heuristics:
The challenge is to develop heuristics to separate out the "prophets of doom" that should be listened to and the charlatans who should be ignored. Resources are limited and if they are squandered on the problems of the Cassandra want-a-bes, precious resources are unavailable for more urgent matters.

[CONFLICTING SOTAS] Some sotas in the overall sota contain heuristics that are antagonistic to each other. In that case the overlaping sotas in Fig. 27.10 might represent, for example, the following
Sample vulnerabilities:

- Different individuals
- Different ethnic backgrounds
- Different nations
- Different religions
- Different cultures
- Different races
- Different genders

Sample heuristics:
This class of problems in which two or more sotas conflict is important enough that the kind of heuristics it will take to control them merits a section of its own.

27.5.2 Sample Heuristics in Sota$|_{\text{heuristics for human survival, time}}$

The stated goals of this chapter were to provide a framework for human survival and to provide an example of an applied philosophy of engineering. A definitive taxonomy of heuristics in the sota$|_{\text{heuristics for human survival, time}}$ must await another forum, but some indication of the kinds of considerations is appropriate.

27.5.2.1 Definition of a Metaheuristic

All heuristics are equal as heuristics, but some are more equal than others in helping the human species to survive. One such is the metaheuristic, defined as follows:

> A metaheuristic is a contentless heuristic or one that only governs other heuristics.[13]

Earlier mention was made of a professor at the US Coast Guard Academy who used the price of hamburger meat to estimate the cost of a building. This is an example of a simple heuristic or rule of thumb that uses specific numbers to give direction in a specific situation. It is not content free and qualifies as a simple heuristic. It would not be applicable in another country or for a different kind of structure. Other examples of simple, specific heuristics are easy to recognize. For example (Koen 2003)

- One gram of uranium gives one mega-watt day of energy.
- A properly designed bolt should have at least one and one-half turns in the threads.
- Use a factor of safety of 1.5 for commercial airplanes.

Immediately after the professor from the Coast Guard Academy was cited, comparison in the number of prototypes in automobile design in Japan and America was given. This heuristic seems different. It is a metaheuristic because it is not limited to a very specific content, but is generally applicable in problem solving of large complex machines.

27.5.2.2 Example Metaheuristics

Examples of general metaheuristics that might prove helpful in human survival are easy to find.

- **All is heuristic** The central claim of this paper *All is heuristic* is the quintessential content free metaheuristic. It only operates on heuristics, indeed, it applies to all heuristics.
- **Seek metaheuristics** The range of applicability of a metaheuristic is broader than that of a simple heuristic and can be generalized across different domains.
- **Establish a metric** Here the issue is knowing if the changes you are promoting are helping or hurting.

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[13] Jon Schmidt has commented on a similar concept.

> The best and most successful engineers are the ones who have developed the most comprehensive and effective sets of heuristics—including "meta-heuristics" that help them quickly determine which specific heuristics to apply when a particular situation arises. (Schmidt 2006)

- **Look at the derivative to see change** Most of the time, we look at the absolute magnitude of a variable, but we should equally look at the rate at which it is changing.
- **Use engineering heuristics** For the most part they are metaheuristics and that is why the engineering method served as a model for Universal Method. Some examples have been given on page 3. Additional popular engineering metaheuristics include (Koen 2003):

    1. those that determine the correct attitude when confronted with a problem such as the admonition to *Solve problems by successive approximations*,
    2. others that control the amount of risk to be assumed such as the admonition to *Use feed-back to stabilize design*, and
    3. still others that indicate the appropriate attitude for an engineer to take when encountering a problem such as the admonition to *Work at the margin of soluble problems*.

- **Consider metaheuristics from all cultures** All metaheuristics are not engineering heuristics and all metaheuristics are not from the Western tradition. One specific comparison with the Chinese/Japanese tradition for solving problems will emphasize this point. Harmony is important in the Asian tradition. In confronting a situation of disagreement, the Asian looks first for the areas in which they can agree; the Western tradition is typically to look first for areas of disagreement and then aggressively debate these issues.

All of the heuristics above are metaheuristics. They are content free and only govern other heuristics.

27.6 Conclusions

In conclusion, this paper need only ask once again

***Quo Vadis*, Humans?**

and tender the invitation to each reader to join me in finding the best heuristics for the $\text{sota}|_{\textit{heuristics for human survival, time}}$ using *best* in the sense of the engineer.

The task will be hard; the time is possibly short; the mission is urgent and there is no guarantee of success, but the work is of paramount importance. This is the only theoretical way to proceed to make $\text{sota}|_{\textit{overall, time}}$ remain on the main trunk of evolution.

We have seen that an important engineering heuristic is *always allocate resources to the weak link* – that point where your efforts will cause the greatest effect. Our survival as a species based on our unique new weapon *intelligence* is that point. If we are unsuccessful, I doubt the sota we personalize as Nature, $\text{sota}|_{\textit{nature, time}}$, will give more than a magnificent shrug.

One final extremely important disclaimer remains: this analysis was based on your view and my view of the sota$|_{overall,\ NOW}$.

Quite possibly – perhaps even probably – in the future we will find that there is no elephant (See Fig. 27.12).

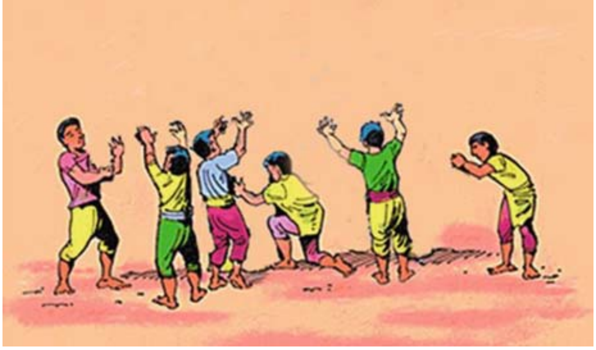

Fig. 27.12 The blind men

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Appendix: Multi-Attribute Decision Theory

A Very Brief Introduction to Multi-Attribute Decision Theory

k knob setting; k ranges from 0 to 8
$f_1(k)$ sharpness as a function of k; f_1 ranges from a_1 up to b_1
$f_2(k)$ fidelity as a function of k; f_2 ranges from a_2 up to b_2
$u_1(k)$ user's utility for sharpness; ranges from 0 to 1
$u_2(k)$ user's utility for fidelity; ranges from 0 to 1
v user's relative weight for sharpness versus fidelity; $v \in [0,1]$

In the television example (Fig. 27.2), k is a (physical) input and f_1 and f_2 are physically-measurable outputs of two performance measures. The utility functions, u_1 and u_2, and the relative weight, v, are instead based on the user's preferences. These are typically subjective and vary by user.

A simple utility function is linear in its performance measure:

$$u_1(k) = \frac{f_1(k) - a_1}{b_1 - a_1}$$
$$u_2(k) = \frac{f_2(k) - a_2}{b_2 - a_2}.$$

The weighted sum of the two utility functions is the following utility function:

$$\begin{aligned} u(k) &= v u_1(k) + (1 - v) u_2(k) \\ &= v \cdot \left(\frac{f_1(k) - a_1}{b_1 - a_1} \right) + (1 - v) \cdot \left(\frac{f_2(k) - a_2}{b_2 - a_2} \right). \end{aligned}$$

The user seeks the knob setting that maximizes the utility, i.e., the user should solve

$$\max_{0 \le k \le 8} \left[v \cdot \left(\frac{f_1(k) - a_1}{b_1 - a_1} \right) + (1 - v) \cdot \left(\frac{f_2(k) - a_2}{b_2 - a_2} \right) \right]. \tag{27.1}$$

Let k^* denote an optimal knob setting, i.e., a solution to model (27.1). Assuming k^* is strictly between 0 and 8 and f_1 and f_2 are differentiable, k^* satisfies

$$\frac{v}{b_1 - a_1} \cdot \frac{df_1}{dk}(k) + \frac{1 - v}{b_2 - a_2} \cdot \frac{df_2}{dk}(k) = 0. \tag{27.2}$$

If f_1 and f_2 are concave functions then any k^* satisfying (27.2) is a global maximizer of model (27.1). If f_1 and f_2 are strictly concave then k^* is unique. It is possible to re-write model (27.1) so that it is simply a weighted sum of f_1 and f_2, for a different value of the weight.

The above development generalizes to allow for $f_i(k)$, $i = 1, \ldots, m$ performance measures with linear utilities $u_i(k) = (f_i(k) - a_i)/(b_i - a_i)$, $i = 1, \ldots, m$ and weights v_i which satisfy $\sum_{i=1}^{m} v_i = 1$, $v_i > 0$, $i = 1, \ldots, m$. The optimization problem is then

$$\max_{0 \leq k \leq 8} \left[\sum_{i=1}^{m} v_i \cdot \left(\frac{f_i(k) - a_i}{b_i - a_i} \right) \right], \tag{27.3}$$

and the first-order optimality condition is

$$\sum_{i=1}^{m} \frac{v_i}{b_i - a_i} \cdot \frac{df_i}{dk}(k) = 0. \tag{27.4}$$

As above, if f_i, $i = 1, \ldots, m$, are concave functions then any k^* satisfying (27.4) is a global maximizer of model (27.3). If each f_i, $i = 1, \ldots, m$, is strictly concave then k^* is unique.

Note: Complex issues such as continuity, multiple stationary points, etc. are beyond the present scope. Some researchers would identify this example as Multiple Criteria Decision Making. Acknowledgement is given to Professors Paul Jensen, David Morton, and James Dyer from Operations Research and Business at The University of Texas at Austin. See Wallenius et al. (2007) for an authoritative technical review article and discussion of the explosive growth in this area. -Billy Vaughn Koen

Chapter 28
The Focal Engineering Experience

Gene Moriarty

Abstract I suggest that postmodern engineering move in the direction of what I am calling focal engineering. The notion of focal comes from the advocacy of Albert Borgmann for focal things and practices to engage our lives, as a counter to the disengaging tendencies of modern technology. I propose to look at what focal engineering might be, what the experience of it might entail, and how it could be assessed. The German language has two words, *Erlebnis* and *Erfahrung*, that both translate into the English word experience. *Erfahrung* is reflective, mediated, second-hand experience, our ordinary everyday experience. *Erlebnis* is our first-hand immediate experience, the *Augenblick* experience, the moment of vision, or the "a-ha" experience. These two notions of experience will play a role in the ethical assessment of the engineering project. Three types of ethics emerge, one relevant to the person (engineer), another to the process (engineering), and the third to the product (the engineered). Each type of ethics will initially seek an *Erlebnis* assessment, then an *Erfahrung* experience, then a circle back to the beginning for another *Erlebnis*, etc. Such a progression is a hermeneutic circle. A couple of circles around the *Erlebnis/Erfahrung* constellation should provide an authentic ethical assessment of the focal engineering experience.

28.1 Introduction

Ethical assessments of the engineering project require procedures of some sort. Typically engineers are urged to follow their codes of ethics and everything will be ok. But that does not say much about how to deal with ambiguous situations. Codes, for example, tell us to reject bribery in all its forms. But when exactly is a bribe a bribe, rather than say a gift which some cultures might require acceptance of in order to

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show good faith? Codes are good, but as Michael Davis maintains, interpretation is central to their effective employment (Davis 2001). I am interested in explicating what I call the focal engineering experience, the ethical assessment of that experience. Codes per se will not be my concern but rather I will propose an ethical assessment procedure, an interpretation, which distinguishes the elements of person/process/product in dynamic interrelation within the holistic engineering project. Pertinent to each of these elements is a different kind of ethics, each of which will require experiences of assessment and interpretations of those experiences.

In my investigations, I rely on a distinction between two kinds of experience: the immediate intuitive experience and the reflective thoughtful experience. The assessment activity initially requires an intuitive first-hand experience which should yield a preliminary orientation. Secondly, conversations invoking contextual issues should be brought into the deliberations and these first-hand experiences should be hashed out. After that we return to the immediate experience, then back to the conversations, etc. This is a hermeneutic circle of interpretation, where each time around we get a more clear idea of what constitutes an appropriate assessment.

In order to facilitate a quick take on the immediate assessment, I promote what I call “The Ethics Engine,” which is a quasi-mathematical procedure for procuring and registering immediate assessments in terms of a number from –3.0 to +3.0. The –3 indicates a very negative take, the +3 a very positive take, and a zero is neutral. Such a number should pin down the intuitive first-hand experience and allow an orientation toward some particular way of being. This way of being would then inform the reflective conversations which deliberate about the first hand experience of the assessment procedure. Returning to the beginning, another go around with the Ethics Engine yields another set of numbers. A couple of trips around the hermeneutic circle should yield a solid assessment, lending the engineering project and the focal engineering experience an authentic cast.

28.2 Engineering: Past and Present

Engineering is a practice and a project involving persons, processes, and products. The person (engineer) activates the process (engineering) to bring forth a product (the engineered). The engineering project was practiced differently in the pre-modern era than it is today in modern times. Ancient and medieval engineers designed and constructed wondrous things largely without the advantage of a clear and distinct methodology. They used heuristics and design experience instead. The incorporation of a method into the design process, in fact, characterizes the shift from pre-modern to modern engineering. Mathematics and the scientific method were increasingly applied to engineering practice after the time of René Descartes and Francis Bacon. Today roughly one-third of the modern engineering university curriculum is devoted to background math and natural and applied science studies. Engineering science is the name we give to this body of engineering knowledge.

The present day engineering project employs a wealth of methods and procedures, including engineering science, engineering design, and engineering professionalism. It is from within professionalism that the notion of an engineer's responsibility arises. Responsibility to whom? To each other, to clients, to members of one's profession, to society. Both the pre-modern and the modern engineering projects were and are guided by some sense of "the ought." While engineers engaged in the modern project are guided by responsibility to each other, clients, professionals, and society, engineers engaged in the pre-modern project were primarily guided by obedience to one's client, as well as responsibility to each other which entailed looking at character issues. Different types of ethics were and are appropriate to the modern and the pre-modern engineering projects.

28.3 Engineering the Future

And what about the future? Post-modern engineering practice is incorporating and will continue to incorporate much of the apparatus of modern engineering practice. But what else? Borgmann (1992) distinguishes between two possible directions for modernism as it moves into a postmodern modality. Applying his suggestions to the engineering project, modern engineering can be seen as moving either toward hypermodern engineering or toward a kind of engineering characterized by what Borgmann calls a postmodern realism.

Hypermodern engineering is an accelerated version of modern engineering. It is a faster, louder, brighter version. Although it stays on the surface of reality, in true postmodern fashion, it does tend to put one on edge. It is unquestionably adding excitement to the realms of design, production, and consumption. Hypermodern engineering could continue to be pursued under the banner of modern engineering values, especially moral values, like health and safety or social justice. Such values provide an ideality at which the process of the modern and the hypermodern engineering enterprises can aim. And pursuing such values is certainly a good thing except that there is a dark side, a seductive and absorbing power to hypermodernism. Hypermodernism can outrun the swiftest among us. It can be addictive. It will often leave only anomie and ennui in its wake. Once you are "on-board" there is often an *unheimlich* sense that befalls you, that is, you find yourself in a mood of not-being-at-home-ness, uncanniness, or anxiety. One has no place to call one's own.

The promise of the modern and hypermodern engineering projects is to rid ourselves of burdens. Certainly we are grateful for the engineered products that have lifted many onerous burdens. For instance, we no longer need to shovel coal to stoke the furnace to heat the house. And entertainment technologies lift the burden of ennui. Temporarily at least. But then, as is often the case, anxiety sets in and becomes a burden that sometimes seems even heavier than the burden of ennui the entertainment technology was originally lifting. And there seems to be so many more things everyday to be anxious about. Even if all the visible air pollution, for example, is eliminated, what about all the invisible electro-magnetic radiation smog that is encircling the globe?

Yet, as Borgmann maintains, there is an option, a movement away from hypermodernism and toward a postmodern realism. This would indicate a kind of engineering – I call it focal engineering – which aims to bring into the world only products that move us toward the Good. The notion of the Good, of course, is not without problems. We certainly do not employ a sense of absolute good along the lines of Plato. An understanding of the Good is only available by virtue of thoughtful conversation and questioning. Conversations imply a willingness to converse. Without that, hypermodernism prevails, postmodern realism falters, and humanity might just, as Heidegger despairingly claims, get caught up in "the giddy whirl of its products so that it may tear itself to pieces and annihilate itself in empty nothingness" (Heidegger 1973). Not happy prospects. Lest annihilation comes to pass – and Heidegger probably meant annihilation of spirit rather than any complete and total physical annihilation – focal engineering and postmodern realism suggest the need for a renewal of conversation, that we converse, for example, about what makes a product a good product, a focal product. Whether hypermodernism will lead to a *Brave New World* or a *Nineteen Eighty-Four* society is open to debate. To escape these dystopian conclusions, we need to engage in what Habermas calls non-coercive communicative discourse which can move us toward some kind of consensus concerning the Good. Although Habermas' notion of discourse represents an ideal which is never achieved with any kind of finality, it does provide conversations with a target to aim for. Focal products involve end-users, who are part of these conversations, and end-users are embedded in a world of circumstance, a human lifeworld. In arriving at a notion of the Good, a trinity of end-user, product, and lifeworld necessarily becomes pivotal.

28.4 Engineering Ethics

The ethics of focal engineering presupposes the involvement of persons (engineers) and processes (engineering) coming together to bring a product (the engineered) into being. Is that product a good product? This is the question of the ethics of the product which Borgmann calls Material Ethics. But there is also an ethics of the person (Virtue Ethics) and an ethics of the process (Process or Conceptual Ethics). Virtue ethics is concerned with the question of how good the engineer, the person, is. Good in the moral sense. I assume the engineer is already good in the technical sense, as evidenced, for instance, by a degree in engineering from an accredited university. The notion of moral good will take on three separate senses corresponding to the three types of engineering ethics. If the engineers, the actors, are morally good, they can be expected to enact good processes which are aimed at good values like environmental sustainability. If the person is good and the process does good, then we can expect the well-made product to be a good product. Being, doing, and making are all implicated in these considerations.

Three kinds of ethics, then, for three different dimensions of the engineering project. How should we assess these three types of ethics? Certain values arise as appropriate to each type of ethics. Virtue ethics can be assessed in terms of values which are virtues. Which set of virtues should engineers practice? A case can be made for many different virtue systems. But the three virtues I see as necessary to the character of the engineer engaged in engineering processes, which are aimed at engineered products, are the virtues of *fairness*, *honesty*, and *care*. To the second kind of ethics, process ethics, values of *health & safety*, *environmental sustainability*, and *social justice* emerge as fundamental. To material ethics, *engagement*, *enlivenment*, and *resonance* are central.

28.5 Experience

The focal engineering *experience* would include the experience of the virtue ethics assessment, the process ethics assessment, and the material ethics assessment. The notion of experience begins to be important. What is experience? The American Heritage Dictionary says it is the apprehension of an object, thought, or emotion through the senses or the mind. To experience something (object/thought/emotion) is to perceive it, to take up with it, to be affected by it. We must open ourselves to the world in which that something comes to be. However, the German language has two words *Erlebnis* and *Erfahrung* which both translate into the English word *experience*. Roughly, *Erlebnis* is first-hand experience, and *Erfahrung* is second-hand experience. The second-handed-ness of *Erfahrung* is not intended in a derogatory sense but in the sense of it being reflective, historical, mediated, and social. *Erlebnis* and *Erfahrung* and the ideas behind them have had a long and distinguished history within Western culture, as shown in the captivating treatise *Songs of Experience* (Jay 2004). Buber, Husserl, Dilthey, Heidegger, Bergson, Adorno, Benjamin, Gadamer, Agamben, among others, have expounded upon the *Erlebnis*/*Erfahrung* distinction, offering a wide array of interpretations.

Erlebnis is the German word for an eventful experience, an adventure, or "something memorable which happens to someone" (Arthos 2000). It is often associated with the artistic experience. *Erlebnis* indicates a direct and first-hand encounter with the particular in its uniqueness. It suggests a pre-reflective immediacy of the moment of experience, an intuitive holism, and an intensity of feeling. It relates the transience of undistinguished and everyday life to the achievement of permanence in certain experiences (Arthos 2000). As Hans-Georg Gadamer puts it: "Something becomes an 'experience' not only insofar as it is experienced, but insofar as its being experienced makes a special impression that gives it lasting importance" (Gadamer 1993, p. 61). *Erlebnis* is the *Augenblick* experience, the moment of vision, the "a-ha" experience. It indicates the thrill that life offers from time to time.

Erfahrung, on the other hand, is more mundane. It refers to ordinary everyday experience. It is what remains after the thrill is gone. Still, as mentioned earlier, *Erfahrung* can be enlightening by incorporating historical, social, and contextual perspectives. *Erfahrung* is mediated, reflective, and second-hand. It entails generalizations out of the original context of the experience, away from the particular in its particularity. *Erfahrung* is socially undergone, concerned with causes and effects, and has lasting consequences. It is an on-going process extended over time and space. There is in it a sense of being on a journey or a trip. Knowledge gained from *Erfahrung* is sedimented into the structures of our being. When one has *Erfahrung* type experiences, one becomes "an experienced" person.

28.6 Assessment

I suggest that each of the three ethical assessments involved in the focal engineering experience can be envisioned in terms of both the *Erlebnis* and *Erfahrung* modalities. Such experience is always to some degree *interpreted* experience, especially the reflective Erfahrung experience, but also immediate *Erlebnis* experience that can knock you over with its intensity. But even here, on your way down, you grasp some kind of meaning, or it grasps you. The movement of interpretation between *Erlebnis* and *Erfahrung* becomes a hermeneutic circle in that it can refer to a backwards and forwards relatedness involving *Erlebnis* experience – intrinsic to which is pre-conceptual understanding and meaning – then further *Erfahrung* experience, then deeper interpretation of the preliminary understanding, and so on. Just looking at the case of the focal engineering venture, we can consider a hermeneutic circle between the *Erlebnis* experience of the ethical assessment of the focally engineered product, involving an immediate impression of the values of engagement, enlivenment, and resonance, and the *Erfahrung* experience which entails practical conversations about how end-user, product, and lifeworld harmonize with each other and how they bring context to bear on the assessment broadly conceived. We can view the hermeneutic circle of interpretation as a full experience covering much of what is typically at issue in most engineering assessments. We could start with the affective *Erlebnis* experience, which contains an immediate interpretation of that experience, then undergo a cognitive and holistic experience of that interpretation (*Erfahrung*), then move to a sedimentation of that experience. It would be like adding layers on the onion. Finally, returning to the Erlebnis, back to square one, we begin again. This time, however, everything should be at a slightly higher level.

The *Erlebnis/Erfahrung* experience of the focal engineering venture entails an experience of all three of the ethical assessments relevant to the engineering project. An *Erlebnis* experience of say the virtue ethics assessment would entail a gathering of first impressions of the people involved, say a team of seven engineers overseen by a group leader. The group leader might say yes we all acted fairly, but we were not entirely honest, and we could have been more caring. Someone else in the group might have different views and arriving at a consensus for an assessment could get complicated. But we are at first blush looking for quick intuitive impressions. To help make the information gathering process more efficient I advocate what I am calling The Ethics Engine.

28.7 The Ethics Engine

What drives such an engine and what are its consequences? The desire to get a quick but systematic first impression (*Erlebnis*) is the driving force, the engine, of the Ethics Engine and the major consequence or outcome is simply a number which provides a preliminary orientation for the more extensive conversations of the *Erfahrung*. I associated three values with each of the kinds of ethics under consideration. As mentioned earlier, virtue ethics pursues the values of fairness, honesty, and care; process ethics the values of environmental sustainability, social justice, and health and safety; material ethics the values of engagement, enlivenment, and resonance. Then let each of these values be represented by a value function, J. Each J term is restricted to be between –3 and +3. This is best illustrated with an example.

Consider the engineering of Radio Frequency IDentification (RFID) devices. Assume the technical aspect of the engineering has been impeccably done, meeting all the standards of efficiency and productivity. How might we assess the moral dimension of the processes of engineering of RFID devices? We should certainly gauge it against the standards of health and safety, environmental sustainability, and social justice. But where and how is this assessment to be carried out? And by whom? I suggest we assess preliminarily at the professional level. Initially, we might involve individual engineers along with members of a professional ethics committee on an assessment team.

To initiate discussions with regard to assessment, and to register the *Erlebnis* experience of the committee members, we can proceed via a quasi-mathematical approach of the Ethics Engine. The procedure is simple but can help to provide a point of departure for deeper discussions at the *Erfahrung* experience level. If we assign a value function (J_{p1}, J_{p2}, J_{p3}) to each of the three moral standards we are aiming at, we can write an expression for the over-all process ethics value function:

$$J_p = \alpha_1 J_{p1} + \alpha_2 J_{p2} + \alpha_3 J_{p3}$$

with

$$\alpha_1 + \alpha_2 + \alpha_3 = 1.0$$

where the α_i terms are weighting factors whose values are to be determined by consensus. Initially assume all three value functions are equally weighted, so all α_i terms will be set to 1/3 and all value functions can range from –3 to +3. A minus number for one of the J values may indicate that social justice is not achieved. A positive number for another J value may indicate that health and safety are well provided for.

The professional level committee might decide that the health and safety associated with the RFID device is quite well accounted for. In the manufacturing process the usual precautions are taken. The chips to be produced will need a series of typical processing procedures. Usual safety measures are taken. No problems are foreseen in manufacturing. However, there is the problem of the electromagnetic energy to be beamed at the RFID device from the reader device. Although the power is very low, if there is a huge proliferation of such activity, it is not clear if this presents a danger to people close by. The same uncertainty with cell phones, however, does not seem to have deterred anyone from owning a cell phone. The committee – after gathering all the member's first impressions and averaging them – rates health and safety ok, but not excellent. They come up with a value of $J_{p1} = 1.5$ which is a fairly good assessment. No problems are seen with disturbing the environment with RFID devices. So, the committee comes up with $J_{p2} = 3.0$ which is an excellent assessment. But social justice issues present a problem. There is a worry that RFID devices can and will be used to spy on people. A person's buying profile can be generated, for example, and their privacy can be invaded. Another issue is that a loss of jobs is likely to occur as the efficiency and productivity in the distribution chain get augmented thanks to the increase in the number of RFID devices. Generally, the powerless masses might suffer because RFID devices will augment the power of those who already have it, those who control the flow of information by deciding what choices will be available to the masses. But from the point of view of several of the evaluators, the RFID device appears rather neutral. Gathering first impressions, the professional committee comes up with $J_{p3} = -1.0$ which is not such a good assessment. The total value function J_p is computed:

$$J_p = 1/3(1.5) + 1/3(3.0) + 1/3(-1.0) = 1.17$$

which is on the positive side and indicates a pretty good ethical assessment. There are more positives than negatives, but that there are negatives at all indicates that caution needs to be taken, and not taken lightly. This number of 1.17, again, is not the "answer" to the ethical question about whether or not the modern engineering process involved in RFID device design, development, and manufacturing is good. But the number can provide a point of departure for further discussion. It can help to orient the discussion as it moves beyond the *Erlebnis* experience and into the *Erfahrung* experience involving the reflective conversations of the lifeworld. After the *Erfahrung* we circle back to another *Erlebnis* and gather another intuitive take, then another reflection, and so on. The assessment process is over once a steady state is achieved with the value functions.

Then there is an analogous approach for virtue ethics. I consider all three virtues of fairness, honesty, and care in terms of the example of RFID devices. Again, assume the technical aspect of the engineering has been impeccably done. All standards are met. How might we assess the moral dimension of the engineers involved in the engineering of RFID devices? We should certainly gauge them against the virtues of fairness, honesty, and care. This assessment can be carried out at the company level, perhaps initially within the group, involving team members and the team leader.

If I assign a value function (J_{v1}, J_{v2}, J_{v3}) to each of the three virtues I am aiming at, I can write

$$J_v = ß_1\ J_{v1} + ß_2\ J_{v2} + ß_3\ J_{v3}$$

with

$$ß_1 + ß_2 + ß_3 = 1.0$$

where the $ß_i$ terms are weighting factors we will again assume are initially set to 1/3. Assume the group leader is assessing the ethics of the engineers while the engineers are simultaneously assessing themselves via virtue ethics stressing the virtues of fairness, honesty, and care. Again, our initial aim is to get a quick take, an *Erlebnis*, incorporating the assessments of all participants. But in the on-going lifeworld background of this group there are several issues brewing. There has been some concern about a few engineers not contributing 100%. The first impression regarding fairness averages out to be a bit negative ending with a $J_{v1} = -1.5$ value for their fairness to each other. The honesty, let us say, of certain group members was also somewhat suspect. The first impression regarding honesty also averages out to be a bit negative ending with a $J_{v2} = -1.5$ value for their honesty toward each other. Their caring attitude, let us also say, was rather weak calling for another negative assessment. They averaged a $J_{v3} = -1.5$ for their rather negative caring attitude. In retrospect, the team leader was surprised that the team did so well on the technical side, because their virtue ethics profile was not so good. The total value function J_v is computed:

$$J_v = 1/3(-1.5) + 1/3(-1.5) + 1/3(-1.5) = -1.5$$

indicating that some work needs to be done. This *Erlebnis* experience of ethical assessment gives the subsequent *Erfahrung* experience something to reflect on.

Again, this number is not the "answer" to the ethical question about whether these engineers involved in RFID device design, development, and manufacturing are morally good. But the number can provide a point of departure for further discussion within the *Erfahrung*. The team can get together and decide that even though they were able to do good technical work with a not very good ethical assessment, they can in fact do even better technical work, and it will be more enjoyable for all concerned, if all team members strove for excellence in fairness, honesty, and care in their everyday human interactions.

For material ethics, I consider the engineered, the actual product, the RFID device. Again, assume the technical aspect of the engineering has been impeccably done, meeting all the standards of efficiency and productivity. How might we assess the moral dimension of the engineered, the actual RFID device? I suggest we gauge it against the values of engagement, enlivenment, and resonance. This assessment can be carried out within the conversation of the lifeworld involving all interested parties. Initially a quick take using the Ethics Engine provides an *Erlebnis* experience which then gives way to the conversations of the *Erfahrung* experience.

If I assign a value function (J_{m1}, J_{m2}, J_{m3}) to each of the three values I am aiming at, I can write

$$J_m = \gamma_1 J_{m1} + \gamma_2 J_{m2} + \gamma_3 J_{m3}$$

with

$$\gamma_1 + \gamma_2 + \gamma_3 = 1.0$$

where the γ_i terms are weighting factors whose values are to be determined by consensus. Initially assume all three value functions are equally weighted, so as before all γ_i terms will initially be set to 1/3. That means the three values I am considering here are all of more or less the same importance. Again, assume all three value functions can range from –3 to +3, where a minus number indicates that, say, engagement is weak, and a positive number indicates that, say, enlivenment is strong.

Assume that as a result of tabulating first impression *Erlebnis* experiences from all involved parties, we can gather a material ethics assessment of the RFID device. The participants decided that the engagement of the end-user with the RFID device will be rather minimal. A value of $J_{m1} = -2.0$ was recorded. The enlivenment of the end-user in his world also turned out to be minimal resulting in a value of $J_{m2} = -2.0$. The resonance of the RFID product and the human lifeworld was more initially felt to be rather positive resulting in a value of $J_{m3} = 1.0$. The total value function J_m is computed:

$$J_m = 1/3(-2) + 1/3(-2) + 1/3(+1) = -1.0$$

indicating a not very positive material ethics *Erlebnis* assessment. Again, this number is not the "answer" to the ethical question about whether or not the RFID device contributes to harmonious reality. But the number can provide a point of departure for further discussion taking place in the *Erfahrung* experience, after which another hermeneutic circle back through *Erlebnis* and *Erfahrung* would probably suffice for a material ethics assessment.

28.8 So What?

A run through all three hermeneutic circles will yield a virtue ethics assessment, a process ethics assessment, and a material ethics assessment. Focal engineering is most interested in the material ethics assessment. But the product requires the process and the process requires the people, the engineers. If the engineers get high ethical marks via virtue ethics and the process does too via process ethics, then it stands to reason that the product might very well also be a good product. Not necessarily, but it does seem more likely than if the virtue and process ethics assessments turned out to be negative. Now, in most cases the product will *not* undergo material ethics assessment simply because technological innovation and development result in products that emerge from the engineering process at such a fast and furious rate. The efficacy of the great mass of these products will be determined by market forces. They will sink or swim on their own. Nevertheless, the additional step of a material ethics assessment should certainly be undertaken for products that indicate a significant potential impact on the human lifeworld.

One more point, about where these assessments are to be carried out. I mentioned that the virtue ethics assessments could be enacted at the company level, being largely self-assessments. The process ethics assessments could be carried out at the professional level, ideally in a professional ethics committee. But the material ethics assessments were to be done within the conversation of the lifeworld. That would involve, as I mentioned, all interested parties. In order to formalize such a gathering, I would recommend a *Danish Consensus Conference Model*.

A consensus conference can be defined as a method of technology assessment organized as a meeting between an expert panel and a lay panel consisting of concerned citizens (Grundahl 1995). The lay panel of citizens actually does the assessment after being informed by the experts. My suggestion is that the lay panel has some focal engineers on it and the expert panel does too. Focal engineers on the expert panel would, of course, be experts in the area of engineering from which the product springs. Focal engineers on the lay panel would be non-experts but would be functioning in their role as citizens. A consensus conference is analogous to a jury process used in the courts. Sometimes they are called citizens' panels. Each panel consists of a representative cross-section of 9–15 citizens. These are people to be affected by the public policy under consideration. The citizens' panel is chosen by a steering committee whose membership includes only those who have no direct stake in the outcome of the policy recommendations (Hudspith and Kim 2002). Of course, everyone's interests can never be totally served. Decisions must be made in the face of uncertainty. The Danish Consensus Conference Model is merely an aid to these difficult decisions which has become known as a dependable method for generating highly unbiased choices. Further details are available in the literature.

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