PRACTICAL AND PROFESSIONAL ETHICS

THINKING LIKE AN ENGINEER

Studies in the Ethics of a Profession

MICHAEL DAVIS

Thinking Like an Engineer

Practical Ethics
A Collection of Addresses and Essays
Henry Sidgwick
With an Introduction by Sissela Bok

Thinking Like an Engineer
Studies in the Ethics of a Profession
Michael Davis

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For Jeffrey, who was an engineer, sort of;
for all my former students who are now;
and for Alexander, who may be, some day.

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Preface

This book is a contribution both to engineering ethics and to the philosophy of a profession, engineering. Teachers of courses in engineering ethics, the philosophy of any profession, or even philosophy of technology should find much in the book useful, but its proper audience is anyone, engineer or not, scholar or not, who has ever wondered, "What is an engineer?"

What is engineering ethics? The word "ethics" can be used in at least three senses. In one sense, it is a mere synonym for ordinary morality. In another, it names a field of philosophy (moral theory, the attempt to understand morality as a rational undertaking). In a third, it refers to those special standards of conduct that apply to members of a group just because of that membership. When I describe this book as a contribution to engineering *ethics*, "ethics" has both the second and third sense. The ethics in this book is ethics in the second sense, philosophy; but insofar as understanding standards makes both following them and improving them easier, what I do should contribute to engineering ethics in the third sense of ethics as well—that is, to the interpretation, application, and revision of engineering's special standards of conduct.

As a work in ethics, this book resembles such philosophical textbooks as Harris, Pritchard, and Rabins, *Engineering Ethics: Cases and Concepts.*[1] It nonetheless differs from them in at least two ways. First, it is not a survey but a series of essays, a supplement to textbooks rather than their competitor. The book concentrates on a few particularly important points, corresponding to the book's four parts. Part I, the first three chapters, puts engineering in historical perspective, making clear both how new engineering is and in what that newness consists. Part II is an extended meditation on the Challenger disaster. Each of its three chapters considers one aspect of the complex relationship between engineering ideals and engineering practice today. Here we see in detail how social organization and technical requirements combine to define how engineers should (and presumably do) think. Part III's two chapters clarify the importance of protecting engineering judgment and identify the chief means of doing it. These three parts together give considerable content to the notion of "thinking like an engineer." Part IV, the last three chapters, is concerned with testing this philosophical construction empirically. Chapter 9 reports results of a study of how engineers and managers work together in ten different companies. Chapter 10 attempts to clarify the concept of professional autonomy in such a way that social scientists should be able to tell us how much professional autonomy engineers have. The epilogue draws from the book's argument four questions concerning engineering that the social sciences, including history, could answer in a way helpful to engineering ethics. The epilogue is an invitation to those working in the social sciences to contribute to engineering ethics.

That is one difference between this book and textbooks in engineering ethics, a difference in intensity. The other difference is one of extension. This book is as concerned with the "engineering" in "engineering ethics" as with the "ethics." It is a contribution to the *philosophy* of engineering.

What is the philosophy of engineering? Like the philosophy of science, of law, or of art, the philosophy of engineering tries to understand its subject as a rational undertaking. It does not offer *a* philosophy of engineering—that is, a (controversial) conception of how engineering *should* be done. It attempts to say what engineering *is*—without becoming a mere subtopic in the philosophy (or sociology) of technology. Although the philosophy of technology focuses on what engineers (and others) help make, the philosophy of engineering focuses on engineers themselves—on what they try to do and why.

I have learned from Walter Vincenti's *What Engineers Know and How They Know It*,[2] but that book and this one differ substantially. First, Vincenti is both an engineer and a historian. I am neither. He has a grasp of technical principle and historical documents that I never will. Second, although Vincenti's work contributed to mine, his has a narrower focus. He tries to understand engineering as a developing body of technical knowledge, a discipline; I, on the other hand, try to understand engineering as a profession. Knowledge, though of course a part of what makes an engineer, is only a part. At least as important is the way the knower moves (or, at least, is supposed to move) from knowledge to action. That movement from knowledge to action is the "thinking" of my title. The thesis of this book, if it has only one, is that this thinking is fundamentally ethical (in both my first and third senses).

The philosophy of engineering may seem too technical a field for philosophers: Who could know better than engineers how engineers think? The question answers itself. Of course, engineers know better than anyone else how they think. That, however, does not decide who should do philosophy of engineering. Generally, scientists know science better than philosophers of science, lawyers know the law better than philosophers of law, and artists know art better than most philosophers of art. Philosophers still do philosophy of science, law, and art, doing something that scientists, lawyers, and artists cannot do for themselves. Although some of these philosophers are amphibians, philosopher–scientists, philosopher–lawyers, or philosopher–artists, even some of the best are not. That is a fact, but it raises the question: How is it possible for those who know less to teach those who know more? Answering that question requires a little "philosophy of philosophy."

Philosophy (at its best) puts our tacit knowledge into words. It makes the obvious obvious. The first philosopher, Socrates, distinguished himself from the "wise men" of ancient Greece by asking rather than telling. He asked the pious what piety is, politicians what politics is, and so on. Those he asked had great trouble putting what they knew into words; indeed, much they said turned out, on Socrates' examination, to be false.

How have engineers done compared to the experts Socrates questioned? Certainly, many engineers feel that nonengineers generally do not understand what engineers do, that the achievements of engineers are appreciated less than they should be, and that engineering does not do as well as it should in recruiting the next generation. Scientists, architects, lawyers, and even MBAs generally seem to carry off the prizes. Yet, when engineers try to make their own case, what happens? Even Samuel Florman, as literate a polemicist as any profession can claim, is surprisingly unhelpful. His *The Existential Pleasures of Engineering*[3] is a powerful defense of technology, but one from which engineers are largely absent. Change a few words and the book could be a defense of scientists, industrialists, or even mere inventors rather than engineers. His *The Civilized Engineer*[4] fails in another way, pleasing engineers rather than informing nonengineers.

The power of philosophers is not in their initial knowledge of a field but—as Socrates stressed—in their initial ignorance of it. That ignorance is not ordinary ignorance, the unassuming or presuming of the benighted; it is, instead, experienced, open, systematic, cooperative, and dogged. Such ignorance can help those who know a field to put their knowledge into words even those who do not know the field can understand. The result is paradoxical. Even the expert seems to learn from having what she said put into a philosopher's words—as one learns something when seeing for the first time the pattern in a mosaic known by heart. The expert may then conclude that the philosopher "really" knows more about the expert's field than the expert herself, forgetting that the philosopher could only reveal what he revealed by drawing it out of her. While philosophers often seem generators of knowledge, they are, as Socrates put it, merely its midwives.

This book is the product of more than a decade working with engineers, trying to understand what so absorbed them and about which they could say so little. I began by thinking that engineering was primarily about things, a complex but fundamentally unimaginative application of science, mere "problem solving" (as even engineers will describe it, if you let them). I have come to understand engineering quite differently: as the practical study of how to make people and things work together better—an undertaking as creative as art, as political as law, and no more a mere application of science than art or law is. That is the understanding I have tried to put into words here. I will consider myself successful if engineers reading this book say, "Yes, of course, exactly" and nonengineers add, "So, that's what they do: I had no idea!"

I publish this book without apology for the mistakes it must contain. The only way to write without mistakes is to write nothing—or, at least, nothing interesting. I have done my best to be interesting, taking controversial positions if I believed them right and defending them as best I could, hoping thereby to incite others to add their views, explained and justified, whether or not they agree with mine. Only through critical discussion that is rational and informed can either engineering ethics or the philosophy of engineering grow as a field of study. If, in the process, I am shown to have erred, I will not complain.

Though I publish this book without apology, I do not publish it without trembling. For his efforts, Socrates was put to death. Apparently, some experts do not take well to philosophical ignorance. If I fare better than that master of philosophy, it will be because of those engineers (practitioners, academics, and students) who pulled me aside, explained what I got wrong, and then patiently answered one question after another until I got it right. My notes thank those I remembered, but my memory for names is not good. I hope those I forgot will forgive the forgetting.

I owe special thanks to two colleagues: to Vivian Weil, for helping me, more than a decade ago, to see that engineers might be at least as philosophically interesting as lawyers, and to Robert Ladenson, for convincing me to join a small band of philosophers following their calling among the engineers at the Illinois Institute of Technology (IIT). Though I accepted the invitation more because I trusted him than because I believed what he said, I now doubt that any other course of action could have had as good an outcome. I had taught at three other universities with engineering schools; IIT was the first where the philosophers and engineers had much to say to each other.

Chapters 1, 3, and 5 through 10 have appeared in print before much as they do here. Chapter 4 is a much enlarged version of an essay previously published. Chapter 2 and the epilogue see print for the first time. Though acknowledgement of prior publication is made at the appropriate place, I should like to thank the editors of the journals in which those chapters initially appeared, as well as Alan Wertheimer, the editor of this Oxford series, and two of his reviewers, Deborah Johnson and Michael Pritchard, for suggesting many of those improvements now incorporated in the text.

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M. D.

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PART I

INTRODUCTION TO ENGINEERING

This work of philosophy begins with a long foray into the history of engineering. Foraging in another's field is always risky. One can easily get lost, fall into traps the owners long ago learned to skirt, or find oneself suddenly outnumbered and outgunned. I am taking the risk for four reasons. First, I believe that reading history can lead to philosophical insights. The past gives the present context. Second, I believe that some historians, those I have been reading, sometimes miss the obvious—or, at least, get the emphasis wrong—and therefore tend to mislead those trying to understand engineering. I believe I can do better. Third, although I am trespassing, I have precedent on my side. Philosophers have long made themselves useful by pointing out the obvious in fields not their own—which is all I intend to do. Fourth, and most important, I believe that my trespass will pay off. Understanding the history of engineering better, we shall understand engineering better.

This foray has two important outcomes. First, it works out a definition of engineering as an occupation, a way to distinguish engineers from nonengineers. In other words, it defines the field this book is to study. Second, it makes a case for distinguishing between engineering as an occupation and engineering as a profession. It makes clear the importance of understanding engineering as a profession rather than as a mere intellectual discipline or occupation of "knowledge workers." To understand engineering as a profession is, I argue, to make ethics central to what engineers do.

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Science, Technology, and Values

Is engineering just applied science, a field as free of values as science itself? Or is engineering just technology, a field already well studied by those who study technology? Are the values of engineering, if there are any, just the values of technology, whatever those are? Or does engineering contribute something more? What? Why?

We must answer these important questions as soon as possible. But before we can, we must clarify the terms. "Science," "technology," and "values," like "engineering" and "ethics," are used in enough different ways to be dangerous. Clarifying these five terms and others related to them requires a foray into history. History explains some of the confusion about these terms and helps us choose meanings useful to the work ahead.

Techne and *Sophia*: Twins Ancient but Unequal

I begin with etymology. "Technology" is a compound of two words from ancient Greek, *techne* and *logos*. *Techne* means manual art. So, for example, a *tekton* was a carpenter or builder; an "archi*tect*" was a master builder. The suffix form of *logos*, "ology," means a putting into words, an explanation or study. So, when our word "technology" still meant what Greek tells us it means, technology was the explanation or study of manual art, just as biology is the explanation or study of *bios*, "life". It was a field in which gentlemen entered the workshop to record the artisan's secrets for later publication.[1]

That, of course, is not what technology means now. Despite its Greek root, "technology" is really a new word, recoined in the middle of the last century for a new idea.[2] What idea?

Ancient Greece was a slave-owning society and, like other slave owners, Greeks tended to associate manual labor with slaves. Because no free man would want to be mistaken for a slave, the ancient Greeks generally avoided doing what slaves do. For example, because slaves tended to rush about on their master's business, free men were supposed to walk slowly.[3] Greeks had such a low opinion of manual labor that they even rated sculpture less noble than painting because the sculptor, unlike the painter, had to sweat over his work like a slave.[4]

There were a few exceptions to this low opinion of manual labor. One was athletics. Athletics, however sweaty, was not something slaves did. War was another exception. Hacking one another with swords, though hard and dirty work, was a job for free men.

The Greeks contrasted *teche* with *sophia*. Although often translated as "intellectual knowledge" or even "science," *sophia* is probably better translated as "wisdom." From *sophia* comes our word "philosophy" (the love, that is, the pursuit, of wisdom). For the Greeks, philosophy included mathematics, physics, economics, and similar sciences. Because philosophy was primarily a matter of thought, not manual art, philosophy was appropriate to free men.

The Greeks of Greece's Golden Age loved *sophia*, and she rewarded them accordingly. The Greeks of that period can claim credit for beginning the tradition of philosophy now dominant over most of the world, the one to which I belong. They can also claim credit for beginning a number of the sciences, including geometry, biology, and political science.

Their achievements in poetry, architecture, and history are no less impressive. Not so their contributions to *techne*. Of course, there were some contributions—for example, improved design of war galleys. But you must hunt for them. Europe's Dark Ages seem to have given us many more useful devices than did Greece's Golden Age.[5]

By now, perhaps, you can see two reasons to distrust that ugly word "technology."[5] First, there is the implicit opposition between *sophia* and *techne*. Today we think of science and technology as related, not opposed. So, for example, one reason politicians give for funding scientific research is that it will pay off in new technologies.[6] Second, there is the word's meaning in Greek. For us, technology is not—as its Greek parts suggest—a study of manual art but, primarily, our way of referring to all those inventions that make manual labor easier, more productive, or unnecessary. In this sense, technology began with the first tool someone made; the new technologies we hear about are new technologies in this sense—new tools someone has made.

Of course, there is yet another sense of technology, one derived from this second but referring to a study—as in, for example, the title "institute of technology" (or "technological university"). An institute of technology is not, as the Greek suggests, a place to study manual arts (carpentry, machining, and so on)—a mere technical school. An institute of technology is, instead, a place to study practical inventions: how to make them and how to organize them (and those who use them) to make other useful things. The Greeks, who had a word for almost everything, seem not to have had a word for that.

What does this history have to do with us? Consider, for example, how we dress for work: Some of us dress in "white collars"—that is, fine shirts, ties, good slacks, dresses, sport coats, or the like. Others wear "blue collars"—that is, coarse shirts, denim pants, coveralls. Generally, those in white collars have higher status than those in blue. Salary is secondary, as is social usefulness. A carpenter has less status than an accountant earning half as much. Why? Though carpentry requires a trained mind, it requires as well, like other blue-collar work, much sweaty labor surrounded by dust and debris. Because such labor would quickly ruin good clothing, the white collar guarantees some distance between its wearer and such "slavish labor." And, because it does that, the white collar confers status.

No matter the origin of our parents, we are, in this respect at least, all more or less descendants of the ancient Greeks. Even if we ourselves like manual labor, we do not respect it as much as we do mental labor.[7] I doubt that this is good, especially for engineers. But it does seem to be a stubborn fact about us. We are prejudiced against blue collars, not only those who work in them but even those who associate with those who work in them.[8]

That prejudice shows up even in a phrase seemingly having nothing to do with it—"science and technology." Why does technology always come second? The explanation cannot be historical. If technology refers to inventions making manual labor easier, technology is older than science by thousands of years. And, even if the "technology" in "science and technology" refers instead to the systematic study of practical invention, technology would be no younger than science in the corresponding sense—the systematic study of nature. Until quite recently, "science" included all systematic knowledge, whether of nature or invention, including even jurisprudence and theology.

Nor can the explanation of the inevitable priority of science be alphabetical order. Substitute "engineering" for "technology" and the order remains the same: science and engineering (as in the journal *Science and Engineering Ethics*), not engineering and science. Nor can the explanation be practical importance. Technology bakes our bread; science only helps us to understand how. Nor can the explanation be mere accident. Accident would produce more variation. The order seems fixed: science and technology. Why?

The answer, I think, is that the order indicates relative status. Science has higher status than technology; hence, it gets first mention.

Well, shouldn't science have higher status? After all, isn't technology just applied science? Doesn't science come first in the order of development? Doesn't science lay down the law, like a master whereas technology merely applies it, like a slave? Even engineers may be tempted to answer yes to these questions. But the answer is: No, technology is not merely applied science.

Science, Technology, and Engineering

One can understand the words "science" and "technology" to refer to comparable concepts. Science is explicit, systematic knowledge of how "nature" works; technology is explicit, systematic knowledge of how to make useful things. Unfortunately, usage today is not so neat. Although the term "science" did once refer primarily to explicit, systematic knowledge of nature, its meaning has now shifted somewhat so that today it refers as much, or instead, to a social undertaking: "a voyage of discovery" (as scientists like to say) rather than merely to what they discover. In this sense, science consists of certain communities engaged in trying to understand how nature works.[9]

Because "technology" refers only to our practical inventions, or to the study of how to make more, we lack a term comparable to this new sense of science. What do we call communities that invent useful things or, at least, add to our knowledge of how to do it? "Technician" is wrong: A technician is an assistant, one who carries out routine work under direction of a scientist, engineer, architect, physician, or the like. "Technologist," though a natural choice, has not caught on; "applied scientist," though once popular with sociologists, natural scientists, and even engineers, is now fading.

Why? I think the reason is that the great majority of people who would have to be called technologist or applied scientist already have a satisfactory name: "engineer."

I said "great majority." I meant it. The United States today has well over two million engineers. That is more than all other technologists together. Most other technologists are either architects, chemists, physicists, biologists, physicians, computer scientists, or mere inventors. The United States has only about 135,000 architects, 388,000 natural scientists (including chemists, physicists, and biologists), 450,000 computer scientists, and 600,000 physicians.[10] I have no figure for "mere inventors," but, since most inventors seem to be engineers, there can't be many "mere inventors." The number of physicians contributing to technology also cannot be large. Most physicians are not in research or development but simply provide health care. So, even assuming that most scientists are in technology, not pure research, engineers must outnumber all other technologists combined by at least two to one.

These numbers suggest an obvious solution to the problem of what to call all those who make technology: Call them engineers. But that would, I think, be a terrible mistake. Chemists, architects, physicians, biologists, and the like are not engineers. Understanding why they are not will help us understand both the values inherent in most technology, the technology engineers develop, and the place of ethics in any technology. It also brings us to the heart of our subject. But it requires more history, though mostly history less ancient than before.

The Beginnings of Engineering

Professions, aping aristocracy, like to trace their origins back to ancient times. So, for example, the American Medical Association's *Principles of Medical Ethics* cites certain provisions of Hammurabi's Code (about 2000 BC) as the earliest known code of medical ethics.[11] There is, of course, some truth in such going back. The healers of ancient Babylonia resemble today's physicians in many ways. For example, like modern physicians, they tried to cure the sick. However, there are many differences as well, and, for our purposes, the differences are more important. For example, Babylon's healers do not seem to have been organized as a profession or even as a guild. We will understand professions better if we start their history with the rise of modern markets about two centuries ago, the accompanying dissolution of the old distinction between trades and "liberal professions," and the slow emergence of something new. Even an old occupation can be a new profession.

By 1850, especially in England, we begin to see the modern pattern. The professions are connected with both a formal curriculum, ending with an examination and a certification of some sort, and explicit standards of practice, a code of ethics.[12] Admittedly, those creating this new pattern seem unaware of doing something new. But there can be little doubt that they misunderstood their own actions. Even some of the terms they used were new. For example, the term "medical ethics" was coined in 1803 by a physician, Thomas Percival, for a book he thought was on an old topic.[13]

What is true of most professions is true of engineering. False pedigrees abound. Some histories of engineering begin with the Stone Age, with the first tools. They confuse engineering with mere technology.[14] Other histories begin more sensibly, recognizing that engineers generally do not do manual labor but prepare instructions for others to carry out. As the first tool almost certainly predates such a division of tasks, these histories begin much later, with the first projects large enough to have some people laying out a plan and others implementing it. They begin with the building of Stonehenge, the Pyramids, or some other wonder of ancient civilization.[15]

Though better than the first, this second way of beginning the history of engineering still has at least two embarrassing consequences. One embarrassment is that it makes architects (or "master builders") the first engineers. This is embarrassing because engineers generally agree that architects today are definitely not engineers. Another embarrassment is that this way of telling the story makes a mystery of why our word for engineer comes from French, rather than Greek, like "architect," and why the French have had the word for barely four hundred years. Generally, we have a word for anything important to us almost as soon as we have the thing. There are no significant "whatchamacallits."

So, when I tell the story of engineering, I start four hundred years ago in France. Back then there were things called "engines"—but engine then simply meant a complex device for some useful purpose, a contraption showing intelligence in design—in short, a machine. The first people to be called engineers were soldiers associated with catapults, siege towers, artillery, and other "engines of war." They were not yet engineers in the sense that conerns us. They were, rather, engineers in the sense that, even today, the driver of a locomotive is an engineer. They were engineers only in the sense that they operated (or otherwise worked with) engines.

Some soldiers are still engineers in something like this sense: They belong to an engineering corps. Though they do not know what engineers know, they are directly involved in works of engineering, though not precisely with engines of war, a term no longer in common use.

Four hundred years ago the armies of France were led by nobles, men on horseback who learned war from their fathers or on the battlefield or died in the attempt. The foot soldiers came with the nobles. Most were peasants or artisans who knew little of war until trained in camp. When the war ended, the army dissolved, each noble leading his own people home. In such an army, an engineer was usually a carpenter, stone mason, or other artisan bringing civilian skills to war.

When Louis XIV ended the regency in 1661, France still made war in this way. But, within two decades, France had a standing army of 300,000, the largest, best trained, and best equipped European fighting force since the Roman legions. This achievement was widely copied. To this day, most of our military words—from "army" itself to "reveille," from "bayonet" to "maneuver," from "private" to "general"—are French. "Engineer" is just one of these military terms.

Until 1676 French engineers were part of the infantry. But in that year the engineers were organized into special units, the *corps du génie.*[16] This reorganization had important consequences. A permanent corps can keep much better records than isolated individuals; can accumulate knowledge, skills, and routines more efficiently; and can pass them on. A corps can become a distinct institution with its own style and reputation. More than a group of protoengineers, the *corps du génie* were, potentially, both a center of research in engineering and a training ground for engineers (in something like our sense)—*officieurs du génie.*

The *corps du génie* did not take long to realize this potential. Within two decades, it was known all over Europe for unusual achievements in military construction. When another country borrowed the French word "engineering" for use in its own army, it was for the sort of activity the *corps du génie* engaged in.[17] That was something for which other European languages lacked a word.

The *corps du génie* was not, as of 1700, a school of engineering in our sense; it was more like an organization of masters and apprentices. Indeed, strange as this may seem now, at that time neither France nor any other European state had a permanent military academy (in anything like our sense), much less a school of engineering. There was no settled curriculum for training officers generally or engineers in particular, or even a very clear idea that a curriculum was necessary. Only during the 1700s did the French slowly come to understand what they wanted from an engineering education and how to get it. But, by the end of the 1700s, they had a curriculum from which today's engineering curriculum differs only in detail; they had also invented engineering.[18]

An army needs fortifications for protection, mines under enemy fortifications, roads to march on, and bridges to cross. Civilians either need the same things or need other things that require similar skills to build. So, in 1716, the French established another corps of engineers, the *corps des ponts et chaussés,* to build and maintain the nation's bridges, roads, and canals (as important to the army as to commerce). This corps set up a school for training its officers, the first engineering school to survive long enough to matter. Like the military engineers, these civil engineers were admired all over Europe. Those who copied their method copied their name as well.[19]

What was their method? Engineers, military as well as civil, resembled architects in being able to make drawings for construction projects, develop detailed instructions from those drawings, and oversee the execution of those instructions. They nonetheless seem to have differed from architects in at least three ways.

First, engineers were much better trained in what was then the new mathematics and physics than the architects were. They had the ability to consider systematically questions most architects could only deal with intuitively or ignore.[20]

Second, because the strategies of engineering had their roots in the necessities of war, engineers paid more attention to reliability, speed, and other practicalities. So, for example, the systematic testing of materials and procedures in advance of construction was early recognized as a characteristic of engineers.[21] At least in comparison, the architect seemed an artist, one for whom beauty claimed much of the attention an engineer would devote to making things work.

Third, to be an engineer was to be trained as an army officer, to be disciplined to bear significant responsibility within one of world's largest organizations. Engineers were therefore likely to be better at directing large civilian projects than were architects, most of whom would have had experience only of much smaller undertakings.

These three advantages tend to reinforce one another. For example, not only do large projects require more planning in advance and more discipline in execution, but they are also more likely to require better mathematical analysis and to justify extensive testing of materials and procedures. For this, and perhaps other reasons, civil engineers slowly took over much of the work that once would have been the domain of architects. They were a new power in the world.

Early experiments in engineering education culminated in the École Polytechnique. Begun in 1794 as the École des Travaux Publics (the school of public works), it changed its name the following year, for the first time connecting engineering and *techne*. I don't know why the French changed the school's name. The school never trained architects, much less artisans or mechanics. It was a school of engineering, deserving the "poly" only for offering preparation for many fields of engineering, military and naval engineering, as well as civil.[22]

The École Polytechnique's curriculum had a common core of three years. The first year's courses were geometry, trigonometry, physics, and the fundamentals of chemistry with practical applications in structural and mechanical engineering. There was a good deal of drawing, some laboratory and workshop, and recitations after each lecture. The second and third year continued the same subjects, with increasingly more application to the building of roads, canals, and fortifications and the making of munitions. For their last year, students were sent to one of the special schools: the school of artillery, the school of military engineering, the school of mines, the school of bridges and roads, the school of geographical engineers (cartographers), or the school of ships.[23]

Engineers will immediately recognize this curriculum, especially the four years, the progression from theory (or analysis) to application (or design), and the heavy emphasis on mathematics, physics, and chemistry.

The École Polytechnique was the model for engineering education for much of the nineteenth century.[24] The United States began using it very early. Our first engineering school was the military academy at West Point. By 1817, it had adopted much of the École's curriculum, its methods of instruction, and even some textbooks.[25] I say more about West Point in the next chapter.

Values in Engineering

What values does engineering incorporate? A decade ago, Eugene Ferguson, an engineer turned historian, drew up a list of "imperatives of engineering."[26] The list is neither complete nor fundamental—nor, indeed, even entirely fair. It will nevertheless help us understand engineering.

Engineers, Ferguson claimed, (1) strive for efficiency, (2) design labor-saving systems, (3) design control into the system, (4) favor the very large, the very powerful, or—in electronics—the very small, and (5) tend to treat engineering as an end in itself rather than as a means to satisfying human need. These imperatives are, according to Ferguson, instincts engineers bring to their work. Although engineers can resist them, just as I can resist drinking water even if I am thirsty, they are, in effect, the engineer's default setting, what engineers will do unless they consciously try to do something else.

Ferguson intended this list to be a criticism of the way engineers work. It is, I think, both less and more than that. The list is less than a criticism because the first four imperatives seem, on reflection, at least as much virtues as vices. The list is also more than a criticism because it highlights certain enduring features of engineering, permitting us to connect engineering's history with today's practice. Let's take a closer look at Ferguson's list.

"Efficiency" is the first imperative Ferguson identifies. Ferguson points out, rightly, that "efficiency" is a slippery term, meaning "most powerful" here, "lowest cost" there, and something else elsewhere. What he overlooks is the concept's utility.

Engineers generally define efficiency so that they can measure it (or its components), assign numbers, and thereafter seek to control it. That is not surprising. Like other professions, engineering tends to analyze a situation so that its distinctive skills can be applied. One distinctive skill of engineers is giving mathematical structure to practical problems. The concept of efficiency allows them to exercise that skill.

Engineers have, no doubt, sometimes paid too much attention to efficiency, especially forms of efficiency that turned out not to matter. Indeed, the history of engineering is in part the history of measurable properties used for a time as proxy for something that could not be measured and then discarded when the proxy proved not to have enough of a relation to what the engineers actually cared about.[27] Because engineering is a practical undertaking, it must learn from practice. It cannot learn from practice without making mistakes. Some of engineering's mistakes concern efficiency.

Engineers can be quite slow about giving up one of these proxy measures. But, even this slowness is understandable. Engineers are used to working in large organizations, organizations in which change is difficult and the consequences are often hard to predict. They therefore have a tendency to follow practices they would no longer adopt. (Consider, for example, how American engineers still specify nonmetric bolts or screws.) The world is a tough laboratory. Many things better in theory are worse in practice. How daring do we want engineers to be with our lives?

The second imperative on Ferguson's list is a preference for labor-saving devices. Engineers will, Ferguson thinks, design to save labor even when labor is cheap and the end result will be higher production costs and more unemployment.

The engineer's preference for labor saving is understandable as a product of engineering's military origin. Since engineering began, the primary labor pool of most armies has been their own soldiers. Because no general wants his soldiers doing construction when they could be fighting, military engineers have always had an incentive to look for means of saving labor even though the labor saved was, in one sense, cheap (indeed, free).

As military engineering became civil engineering, this tendency might have put engineers at a disadvantage in their competition with other technologists. Their designs might have proved too costly. Those who hired engineers would, however, soon have learned this. They would then have compensated, either by calling in an engineer less often or by making sure that the engineer called in defined the desired outcome taking cost into account.

If, as Ferguson's criticism suggests, such compensation seldom occurs, the most likely reason is that the engineer's preference for labor-saving devices generally serves those who employ engineers. The reason that preference might serve their employers is not hard to see. Labor has a tendency to become scarce, and so costly, when it is not routinely saved.

Of course, that is only a tendency. Many of those thrown out of work by a particular innovation may live out their lives on the dole. Many engineers would, no doubt, like to take such effects into account, and perhaps many of their employers would let them. But, if engineers are to take such considerations into account, they will need both the relevant information and a routine for using it.

Gathering such information belongs to the social sciences, not to engineering as it is or as it is likely to become. Any curriculum that could give engineers the skills to develop significant social statistics would probably be too long to attract many students. Engineers should not be blamed for failing to take into account social consequences about which they can only guess.

However, when such information exists, developing ways to incorporate it into engineering work is certainly something engineers can, and should, do. Indeed, they have long done this with the employer's share of the cost of production. And, over the last two decades, thanks to the Environmental Protection Agency (EPA), engineers have become adept at incorporating environmental costs into their designs (e.g., by designing for disposal as well as for manufacture and use). They could do the same for social impact if they had numerical standards for assessing impact and sources of information from which the relevant numbers could be taken.

Engineers can help to develop such standards, just as they helped to write EPA standards. But, just as with environmental standards, standards for permissible social impact are probably not what most people would want engineers alone to decide—or even engineers with the help of lawyers, accountants, corporate executives, and other specialists. Social impact raises political issues—that is, issues everyone wants a part in deciding. If engineers decline to develop such standards unilaterally, should we blame them?[28]

Ferguson's third imperative is designing controls into the system. Engineers generally try to separate planning and execution. Intelligence is designed into the system, requiring as little intelligence as possible of the system's operators. The assembly line is the typical example of this imperative. Engineers generally try to design an