PRACTICAL AND PROFESSIONAL ETHICS SERIES

Published in conjunction with the
Association for Practical
and Professional Ethics

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

ASSOCIATION FOR PRACTICAL AND PROFESSIONAL ETHICS

Thinking Like an Engineer

Studies in the Ethics of a Profession

MICHAEL DAVIS

New York Oxford
OXFORD UNIVERSITY PRESS
1998

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.

1

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 assembly line so that the work is so simple that only a few minutes training is necessary to learn the job. The job is therefore likely to be repetitive and boring; those doing the job are reduced to little more than organic robots.

Engineering's military past certainly explains the origin of this imperative. Soldiers sent over to help on an engineering project, whether digging trenches or putting a bridge over a river, don't have much time to learn the job. The military engineer must design the work so that anybody can do it. (Architects, in contrast, seem, if anything, to have a bias in favor of designs requiring craftsmen.)

But its military past alone does not explain why this imperative persists in civilian engineering (or, at least, why engineers who do such things should be so much in demand). The explanation of that, like the persistence of engineering's second imperative, must be that this tendency is useful in civilian engineering as well. One recent example suggests why that might be.

McDonald's restaurants now have cash-register buttons with pictures of the various items on the menu. The cashier need not know the price of anything or even be able to read; the cashier only has to recognize the pictures and push buttons accordingly. In a business where employee turnover is high and education is low, where prices change frequently and training is expensive, this dumbing down of the cashier's job both saves money for McDonald's and opens employment to many who might not otherwise qualify. Whoever thought of that device, engineer or not, was undoubtedly a hero to McDonald's.[29]

The fourth imperative of engineering that Ferguson lists is a tendency to disregard human scale, preferring the very large or the very small. The reason for this imperative is that engineering was, and remains, a creature of large organizations. Louis XIV's army, one of the largest organizations of its day, created engineering to do what civilian artisans could not do (or could not do well enough). Even today, most engineers work in large organizations. You do not need an engineer to construct a single-family house. A carpenter or architect will do, as they always have. If, however, you want to construct a thirty-story building, you need engineers.

The problem, I think, is not so much that engineers disregard human scale as that they are seldom needed for things on a human scale. Generally, asking engineers to work on a human scale is like asking lawyers to prepare a partnership agreement for two children opening a lemonade stand. They can do it, but either they will do what anyone else could do or they will do something out of all proportion to the job.

In this respect, the very small can be like the very large. For example, to make today's tiny electronic circuits requires productive forces and controls of which a single human being is incapable. Hence, there is work for engineers.

Ferguson's last imperative, putting technical brilliance ahead of human need, is unlike the others. It is a failing common to all professions. (We all know the joke about the surgeon who says, "The operation was a success, though the patient died.") But this last "imperative of engineering" is worse than a failing common to all professions; it is a failing inconsistent with one of engineering's fundamental values.

I have stressed the military origins of engineering.[30] I have not pointed out that most of the period we have been talking about, roughly the 1700s, is known as the Age of Enlightenment. This was the time when many Europeans first came to believe that enlightenment, that is, scientific learning, would bring peace, prosperity, and continuous improvement. For countless ages, the best hope of the wise was that the world would not get much worse. With the Age of Enlightenment, people began to act on the belief that the world could be made much better. Engineering has this belief built into it. So, for example, early graduates of the École Polytechnique were noted for "scientific and democratic idealism and a desire to work for human progress."[31] The same attitude was evident in England at about the same time. When, in 1828, the British Institution of Civil Engineers, then nine years old, asked one of its members, Thomas Tredgold, to define the term "civil engineering," he gave an answer engineers still quote: "Civil Engineering is the art of directing the great sources of power in Nature for the use and convenience of man. . . . The most important object of Civil Engineering is to improve the means of production and of traffic in states, both for external and internal trade."[32]

For Tredgold, engineering was committed to making things "for the use and convenience of man." But, for Tredgold, this was not simply a matter of *maintaining* things as they are. Engineering was supposed to "*improve* means of production and traffic." Engineering was, by definition, an instrument of material progress.

But what about engineering today? Most engineers would, no doubt, want to tinker with Tredgold's definition, for example, by substituting "people" for "man." But few, if any, would want to change its core. Engineering remains an undertaking committed to human progress. So, for example, the most widely adopted code of engineering ethics in the United States begins: "[Engineers uphold and advance the integrity, honor, and dignity of the engineering profession by] using their knowledge and skill for the *enhancement* of human welfare."[33]

Why Engineers Are Not Scientists

That is enough about engineering. We are ready to see how engineers differ from other technologists. I have already pointed out some of the ways engineers differ from architects. I shall now explain how they differ from applied *scientists*.

I once did a workshop at the research lab of a large petroleum company. The audience was about half chemists and half chemical engineers. I first asked the chemists, "If you had a choice between inventing something useful and discovering new knowledge, which would you prefer?" The chemists thought this a hard question: "After all," they reasoned, "it's hard to imagine an interesting discovery in chemistry that would not have a practical payoff." Eventually, I asked for a show of hands. About half the chemists voted for "something useful" and about half for "new knowledge." The engineers, on the other hand, *all* voted for usefulness. For them, new knowledge was just a means to improving human life.[34]

Unlike the chemists, the engineers had no commitment to science as such. They *used* science, much as they used other sources of insight. They also contributed to science much as they contributed to lawyering and other social practices, for example, by helping to reduce the cost of chemicals used in the manufacture of computers. But they did this as nonscientists, as participants in a voyage of invention rather than discovery.

This difference between engineers and chemists came as a surprise to these researchers. Many had worked side by side for decades. They thought that they shared the same values. But we do not wear our values on our clothing like an identity badge—except, of course, by declaring ourselves to be of this profession rather than of that. These researchers had not taken the difference in profession seriously. That is why they were surprised.

This difference between scientists and engineers is not a mere idiosycracy of one industrial laboratory. I have asked the same question at other industrial laboratories since, with much the same result. Nor is this difference between scientists and engineers restricted to industrial laboratories. I have asked my question at university workshops attended by both engineering and science faculty. The results were even sharper. The only thing rarer than a university scientist who voted for something useful was an engineer who voted for new knowledge.[35] In this respect at least, engineers are not scientists, not even applied scientists. The primary commitment of engineers is not to knowledge, theoretical or applied, as one would expect of scientists, but to human welfare.[36]

Ethics and Engineering

Earlier, I described engineering as a "new power in the world." Power, though neither good nor bad in itself, is always dangerous. Because of the scale on which engineers generally work, engineering is particularly dangerous. Engineers long ago realized this and set about to ensure, as much as possible, that engineering would be used for good rather than evil. They organized as a profession, adopted codes of ethics, and tried to put the codes into practice.

"Ethics" (as noted in the Preface) has at least three common uses. It can refer not only to ordinary morality or the systematic study of ordinary morality but also to those special morally permissible standards of conduct every member of a group wants every other member to follow even if that would mean having to follow the standards too. It is in this third special-standard sense, I think, that members of a profession talk of their "profession's ethics."[37] In this sense, engineers did not have a code of ethics until they adopted one. In the United States, that was not until early in this century.[38]

In this sense, too, their code of ethics is what they make it—as long as the standards they lay down are consistent with ordinary morality.[39] That means that engineering ethics can change over time and even differ from country to country or field to field.

There is, then, an important difference between moral values, such as the engineer's commitment to improving human life, and ethics (special standards of conduct). While engineers generally seem to have valued human welfare since early in the history of engineering, failing to treat the public welfare as paramount in their work could not be unethical (in my third sense of "ethical") until engineers adopted a standard of conduct requiring them to treat the public welfare as paramount. Nor could failing to treat the public welfare as paramount as such be immoral until then. Morality imposes no such duty, though it does require us to avoid doing certain kinds of harm and perhaps to render certain kinds of aid.[40] The history of engineering ethics reminds us that ethical standards, like other engineering standards, are not discoveries but useful inventions.

Values such as honesty, safety, or efficiency are reasons for acting, and so reasons for adopting standards of conduct, but values as such, even moral or professional values, do not tell us how we should act. A value as such can only demand consideration, that is, a certain weight in our deliberations. Values such as efficiency, safety, and even honesty are considerations to be taken into account in deciding what to do. They cannot, as such, be obeyed or disobeyed. In contrast, standards of practice, including a code of ethics, do tell us how we should act. They do not lend themselves to weighing. They are imperatives we can only obey or disobey. And, as we see later, they deserve special attention in any discussion of engineering ethics.

2

A History of Engineering in the United States

This chapter continues our foray into the history of engineering, showing (1) that engineering (in the United States at least) is, in part, a fusion of several older activities (managing, craft work, science, and invention); (2) that conceptions of engineering changed substantially over the last two hundred years and also varied somewhat from industry to industry (with one activity, then another, seemingly central); and (3) that there are nonetheless real limits to what can be engineering, limits demonstrated especially by attempts to train engineers that apparently failed because they overemphasized one or another activity. Though engineering is undoubtedly a "social construct" in some sense or other, an engineer is not an engineer simply because society confers the title. The work engineers do has a discipline of its own. Any adequate understanding of engineering must acknowledge that discipline. Central to that discipline is a certain way of educating engineers (a certain curriculum) and a certain way of using what engineers know (a code of ethics).

In the Beginning

The first engineers in the United States, or at least the first to bear the title, were officers in the Revolutionary War; the first school of engineering here was a military academy, West Point.[1] This connection between engineering and the military was no accident. As explained in chapter 1, engineering began with the great army built by Louis XIV after 1661. Though engineers were soon called on for civilian projects—to build roads, bridges, and canals; to construct mines and oversee their operation; or to construct ships—most of the training of these "civil engineers" was identical to that of military engineers. So, for example, when the French reorganized engineering education in 1794, creating the École Polytechnique, they put students

of military and civilian engineering side by side for three years, separating them only in their fourth (and final) year of training, when they were sent to one or another school of "application" (the school of military engineering, the school of bridges and roads, and so on). After 1797, all students at the École Polytechnique wore uniforms and lived under military discipline.[2]

Establishing an engineering school in the United States in the first years of the republic was not easy. The first attempt occurred when George Washington was still only a general. Other attempts followed. Even with an Act of Congress in 1802, more than a decade passed before West Point had examinations, grades, or even a settled curriculum. The curriculum settled on, four years in length, was derived from the École Polytechnique. Along with the curriculum came a small library, recitations, examinations, one French officer, several textbooks, and even the use of blackboards.[3]

Though another two decades would pass before anyone successfully copied West Point, the first attempt came soon. Alden Partridge graduated from West Point in 1805, taught mathematics there for the next fourteen years, and briefly served as superintendent, leaving under a cloud. In 1820, he opened his own school—the American Literary, Scientific, and Military Academy—in his home town, Norwich, Vermont (just across the Connecticut River from Dartmouth College), to train officers for the army and engineers for public works.[4] In 1824 he moved the academy to Connecticut; in 1829 he moved it back to Norwich. In 1834 the academy became Norwich University, apparently without any change of purpose, and so remains to this day, an experiment complete and forgotten (though it moved once more, in 1865, to Northfield, Vermont).

Though Captain Partridge's school enrolled almost as many students as West Point between 1820 and 1840, it did not do nearly as well as an engineering school. Of West Point graduates through 1837, 231 became civil engineers; of Norwich graduates during the same period, only about 30 did (and they generally held less responsible positions).[5]

The 1830s were more hospitable to copies of West Point than the 1820s; the next decade, even more so. The Virginia Military Institute was founded in 1839; the Citadel, South Carolina's military college, in 1842; and the Naval Academy at Annapolis in 1845.[6] What was true of engineering education in general was certainly true of civil engineering. The late 1830s mark the real beginning of civil engineering education in the United States.

The age of Rensselaer Polytechnic Institute, our oldest school of civil engineering, may seem to refute this claim. But Rensselaer, founded in 1823, is in fact evidence *for* the claim, not against it.

Rensselaer was founded without either "polytechnic" or "institute" in its name. Like Norwich, it went through several changes, though it never moved. Stephen Van Rensselaer, a gentleman farmer with a Harvard degree, gave the school both his name and money to train *teachers* of agriculture and mechanical arts for the grammar schools of his locale. The original curriculum was a single year (as one would expect of a normal school of the day).

But by the 1830s, Rensselaer had become a kind of scientific finishing school for graduates of colleges of liberal arts like Harvard or Dartmouth. It may, in fact, rightfully claim to be the first American graduate school. Many of the graduates of this period became important in American geology, botany, and geography.[7]

But Rensselaer was not yet an engineering school. It did not award a degree in civil engineering until 1835 and did not have a distinct engineering curriculum until the late 1840s.[8] That curriculum, three years in length, along with the school's present name, seems to owe much to an 1847 trip to Europe by the school's director, young Benjamin Franklin Greene (who himself graduated from Rensselaer in 1842 with one of its first degrees in engineering).[9] Yet, the addition of "polytechnic" to Rensselear's name may not signal any direct connection with the École Polytechnique. By then, Europe had other polytechnics (all modeled, more or less, on the French original).[10] What the new name certainly did signal was that thereafter Rensselaer would focus on training engineers rather than scientists and that French schools, rather than American or English, directly or indirectly, provided the model.[11]

Why did the first engineering schools in the United States use French models? The answer is simple: The French then provided the only practical models. The English, although already leading Europe in manufacture in 1800, would not have a respected school of engineering until well after midcentury,[12] and whether we even say the English had civilian engineers in 1800 depends on how close we judge the analogy between the skills of the mostly self-taught mechanics, industrialists, and builders of England and the French engineers whom they admired and studied.[13] The English did well with what was, in effect, training through apprenticeship in a craft. In 1800, the United States was almost without engineers (or protoengineers) to whom apprentices could be sent.[14] So, like most of Europe, the United States copied France.

All our early engineering schools focused on mathematics, physics, chemistry, and drawing. There was also a good deal of bookkeeping, surveying, measurement, and other practical subjects. There was little of the Latin, Greek, or Hebrew; classical literature; or rhetoric characteristic of the liberal arts college of the day, though there might be enough French (or German) to read untranslated texts.

The difference between these early engineering schools and the liberal arts colleges of the day was not, however, that the engineering schools taught science while the liberal arts colleges did not. By 1800 Harvard, Brown, William and Mary, North Carolina, and the other important colleges already had professors of mathematics and natural science.[15] The early engineering schools differed from the liberal arts colleges primarily in offering an education that was explicitly practical in a way that the college education of the day was not. But practical for what? The historian Charles O'Connell tells a story that suggests an answer.

In 1825, James Shiver led a team of civilians to survey the route for an extension of the National Road in Ohio. Because the road was a project of the Army Corps of Engineers, Shiver reported to Colonel Macomb, the Army's chief engineer, in Washington. Shiver was soon reporting that his team found it impossible to use the Army's standard forms. Macomb wrote back that the forms "were conceived to be more full and distinct, and consequently better adapted to the fulfillment of the purposes for which they were intended," than what Shiver proposed instead. But, because Macomb had dealt with civilians before, he made allowances. The "civilian brigade" could use Shiver's simpler forms for now but should switch to the Army's forms "as soon as they shall be understood."[16]

Shiver was a competent civilian used to working the way civilians then did. Macomb spoke for an organization more complex than any other in the United States. In truth, the Army's ways made sense only in the Army. The United States was then largely rural, with most citizens living in towns with populations under 2,500. Its industry, although already inventive, still consisted almost entirely of small companies. Such companies did not need, or even understand, the standardization the Army took for granted.[17]

Even a major project like a canal could still be undertaken without engineers. Indeed, the greatest of them all, the Erie Canal, was begun about the time West Point settled on a curriculum (1817) and completed about the time Rensselaer was founded (1825). Though often called "America's first engineering school," the Erie was mostly a school of hard knocks. Those in responsible charge were surveyors, lawyers, or gentleman farmers. They learned as they went, sometimes from visits to other canals or from books and sometimes from experience.[18] Whether these "canal engineers" are properly engineers at all is, like the analogous question about the British "engineers" of the same period, one that can be answered either way, depending on whether one chooses to emphasize the analogies with today's engineers (what they built) or the disanalogies (their training and methods). They are marginal cases. Treating them as clear cases of engineers brings into engineering many who clearly do not belong.

What was true of the early canals was not true of the early railroads. Even the Baltimore & Ohio Railroad (B & O), often compared to the Erie Canal and called "America's first school of railroad engineering," employed school-trained, especially West Point–trained, engineers from the time work began in 1824.[19]

What explains this difference between the canals and the railroads? At least four factors seem relevant:

1. While canals were an old technology, railroads were not. Insofar as railroads were a new technology, experience counted for less and a knowledge of fundamental principles for more.
2. Second, railroads required more centralized planning than did canals. The chief economic advantage railroads had over canals was speed. Speed was possible only if lines were clear, water and wood were available at set distances, repair crews could be sent out quickly, and so on.
3. By 1824 West Point had been in existence long enough for its graduates to prove themselves likely to be useful to railroads.
4. West Point graduates brought with them styles of organization that suited engineers. So, for example, in 1829 Lieutenant Colonel Long, having worked on the B&O for five years, published the first *Rail Road Manual*, a book on which later railroad engineers, schooled or not, would rely.[20] There are many striking similarities between this manual and the Army's.[21]

Even so, the railroads of the 1820s or 1830s were not the domain of engineers they would become. The true achievements of American engineers of this period are of a different order. For example, between 1825 and 1840, the Army's arsenal in Springfield, Massachusetts, developed procedures eventually much admired in

Europe as "the American System." This system made weapons parts interchangeable to a degree never before achieved; it also subjected skilled workers to a new discipline, including the substitution of an hourly wage for the traditional piece rate. The arsenal was a model for later mass production.[22]

In 1850, the first year the census counted engineers, only about two thousand Americans identified themselves as nonmilitary engineers, two thousand in a population of about twenty-three million (that is, about one in ten thousand).[23] Today, in a population barely ten times larger, we have a thousand times that number of engineers (that is, about one in one hundred).

Engineering is sometimes described as a "captive profession" because most engineers work in large organizations (General Motors, Westinghouse, Dow Chemical, IBM, and so on).[24] Engineering is contrasted with such "free professions" as law and medicine, where most members practice as individuals or in small groups (or, at least, did so until recently). Unfortunately, the term "captive" gives the wrong emphasis to an important insight. Although we do need engineers for the vast undertakings typical of large organizations, engineering is no more a captive of those organizations than the heart is a captive of the body. The relationship between engineering and certain large organizations, like that between the heart and the body, is symbiotic. Work in large organizations is not a nightmare from which engineers will someday wake; it is their natural habitat. We don't need the skills of engineers to do what machinists, draftsmen, architects, carpenters, millwrights, and the like can do alone or in small groups. Engineers are numerous only when there are large organizations to employ them in large undertakings. In 1850 the United States still had few such organizations.

Middle Period: The "Fragmenting" of Engineering

In the United States of 1850, civil engineers still thought of engineering as a single occupation. In 1867, when a few hundred of them established the first national engineering society, the American Society of Civil Engineers, any civilian engineer could join.[25] But, even then, engineering had begun the branching into specialties that would, by 1920, produce five major societies (for civil, mining, mechanical, electrical, and chemical engineering) and many smaller organizations, each with membership requirements excluding most other engineers.[26]

The history of the half century from 1870 to 1920 can be read as tragedy: the loss of the primal unity of engineering under the impact of industrialization. One history of mechanical engineering even titles its chapter on this period "Engineering: The Fragmented Profession."[27] There are at least four reasons not to read history this way:

> First, much of the history of engineering, not just of this period, is a history of such branching. The first branching separated French civil from French military engineering in the middle of the 1700s.[28]
>
> Second, the primal unity of engineering is itself dubious. The period could equally well be portrayed as the one in which engineering became a single identifiable occupation of which civil engineering was but a part. In the United States of 1870, it was, I think, still not clear what relation civil engineering had to the "mechanic arts," bridge building, mining, or metallurgy. Were they all engineering? Even in 1896, when Columbia finally admitted that its school of mining, founded in 1863, had long since become what *we* would call a school of engineering, the name became "the School of Mining, Engineering, and Chemistry." Apparently, even in the 1890s, "engineering" still did not include everything we now mean by that term.[29]
>
> Third, the half century from 1870 to 1920 was a period of great success for engineering. In 1880, the United States, with a population of forty million, counted seven thousand civil engineers—more than triple the number in 1850 (while the general population barely doubled). Yet this impressive increase gave no indication of what would happen during the next four decades. The 1920 census reported 136,000 engineers, twenty times the number in 1880 (in a population that had again barely doubled).[30]
>
> Fourth, the enormous branching of engineering is inevitable given the enormous growth of industries that rely on engineers.

Engineering has an important connection with mathematics and natural science, as the similarity between early engineering curricula and today's suggests. But engineering is more than mathematics and natural science: Engineers know how to organize work, give instructions, and check outcomes. This knowledge varies from industry to industry. So, for example, a civil engineer designing pipes that ordinary plumbers are to install should *not* use tolerances an aerospace engineer could use without a second's thought.[31]

This field-specific knowledge is largely the result of experience, originally the experience of individual engineers, "field experience" as well as the results of tests in a laboratory or pilot plant. Because engineers routinely record and report their experience in the same way, this individual knowledge gets passed on to other engineers with whom they work. Eventually, much of it ends up in the tables and formulas that fill the manuals written for those in the field. From there, it works its way into customer specifications, government regulations, and courses taught those entering the field. Though this knowledge generally takes the form of graphs, equations, mathematical formulas, and drawings of things, it has little to do with natural science. It is congealed experience of how humans and things work together.[32]

Engineers often complain that when new technology works—think, for example, of the space shuttle—scientists get the credit, but, when it fails, engineers get the blame.[33] Although engineers are, I think, right about how praise and blame are often distributed, I don't think they should complain. That distribution is a compliment to engineers—though one given with the back of the hand. It implies that scientists only *experiment* and experiments generally fail, whereas engineers *engineer* and engineering generally succeeds. An engineer's failure is noteworthy for the same reason a scientist's success is—it is unexpected.[34]

What makes engineers so likely to succeed is not their knowledge of mathematics and natural science. That they share with scientists. What makes them so likely to succeed is their knowledge of particular industries, what works and what does not work *there*, what engineers call "engineering science." Consider, for example, the safety factor for steel struts supporting a bridge. Setting a reasonable margin of safety for such a structural component requires taking into account, among other things, past failures to catch flaws in materials, likely errors in maintenance, and unpredicted changes in use of a structure that, properly maintained, can last for centuries. Such knowledge is not the domain of any natural science. It is sociological knowledge, a knowledge of how people and tools work together, but it is nonetheless engineering knowledge. Only engineers know much about such things.

Here we reach another insight into engineering. Though engineers often describe themselves as applying natural science to practical problems, they could just as easily, and more accurately, describe themselves as applying knowledge of how people work in a certain industry. Engineering is at least as much management as it is natural science. All engineers share the ability to give mathematical structure to the problems they encounter, the ability to draw on the natural sciences for help in developing solutions, and the ability to state each solution as "a design" or set of useful specifications or directions. But these designs, specifications, or directions are, in effect, rules governing someone's work.[35] Engineering is, and always has been, technical management.[36]

Technical management requires detailed knowledge of particular techniques. When such knowledge becomes so great that no one can learn it all, knowledge of techniques in one industry will exclude similar knowledge of techniques in other industries. Engineers will have to specialize and that specialization will tend to break along industry lines.

But other occupations—law and medicine, for example—specialized without fragmenting in the way engineering has. Lawyers have the American Bar Association; physicians, the American Medical Association. Why then should engineers not have an American Engineering Association rather than so many interlinking societies, boards, councils, joint committees, and institutes that no engineer knows more than a part? The branching of engineering probably was inevitable; not so this fragmentation. Although I agree that the fragmentation of engineering was not inevitable, I think comparison with law and medicine will help explain why it was nonetheless likely.

Until recently, a majority of lawyers and physicians worked alone. Their employers, the client or patient, might come in with any sort of problem. An unspecialized practice maintained a common body of experience in law and medicine for which engineering had no counterpart since well before 1900.

Today, of course, *that* common experience has largely disappeared. Both lawyers and physicians now frequently specialize and their professional societies, once relatively homogeneous and unified, are now divided into hundreds of "sections" as diverse and almost as independent as engineering's separate societies. Still, few lawyers or physicians work the way engineers long have. Though both lawyers and physicians now commonly work in groups just as engineers do, they seldom work in the same kind of group. Few lawyers, and even fewer physicians, work on projects requiring coordination among even a hundred other lawyers or physicians. Few work on projects in which everyone else has the same specialty. Engineers, in contrast, generally work with engineers in their own field: civils, with civils; mechanicals, with mechanicals; and so on.[37] Often engineers must work with hundreds or thousands of other engineers. (For example, a single nuclear power plant needs several hundred engineers on site just to operate.) The names of specialties in law and medicine derive from problems any client or patient can have. The client or patient still provides a common experience for lawyers or physicians. That is not true of engineering. In engineering, the specialties generally take their name from a kind of employer or client, the industry in which engineers of that kind predominate. Engineering could remain a single occupation only when engineers had so little to do that they had little reason to specialize.

Who Is an Engineer?

Almost from the beginning of engineering, engineers have disagreed about the relative importance of the scientific (especially, mathematical) knowledge engineers share and the specific practical knowledge that tends to divide them. Those emphasizing practice tended to take an interest in professional ethics; those emphasizing science did not.[38] We can learn a good deal about what engineering is—or at least what it has become—by taking a look at how this disagreement affected the education of engineers.

The practical emphasis in engineering education has long appealed to practitioners, especially those who began as apprentices rather than students: Teach engineers what they need to know to do the job they are going to do, the extremist would say. Forget theory. Get the engineer into the shop as soon as possible.[39]

At this extreme, the practical approach would exclude not only courses in the humanities, social sciences, and other typical elements of a liberal education but also much engineering science. It would, in effect, substitute vocational training for the university education that has long been the norm for training engineers.[40]

The early history of engineering in the United States includes many experiments with practical education in a college or other academic institution, all more or less short-lived. For example, Amos Eaton, who taught civil engineering at Rensselaer in the 1830s, described its program in this way: "The *cloister* begins to give way to the field, where things, not words, are studied." Eaton claimed that no mathematics more advanced than arithmetic was necessary to teach engineering, that the most important part of engineering could not be learned from any book, and that the civil engineering text used at West Point was good only for "closet reading."[41] Yet, during Amos's tenure, Rennselaer was no more successful at training engineers than was Norwich.[42] And, when Greene replaced Amos, Rensselaer moved much closer to the scientific extreme which, by the standard of the times, West Point represented.[43]

Beginning with the Erie Canal, many large undertakings in the United States tried the practical approach as a way of supplying technical skill not obtainable in any other way. Whether these count as attempts to train engineers in the shop is an open question. I will give just one example.

During the 1890s, General Electric offered a course in "practical engineering" for $100. To be eligible, one had to be a "young man" at least twenty-one years old and have *either* a degree in civil, mechanical, or electrical engineering *or* two years' experience in practical electrical work or two years in a machine shop. The course of study, a year long, consisted of rotating through various departments of GE's Lynn Works: four weeks in the shop plant doing wiring, two weeks in the arc department assembling arc lamps, and so on. There was no formal instruction.[44]

What are we to make of this shop training? Notice that for this course in practical engineering, two years of work experience were considered equal to a college degree in engineering. By the 1890s, a first degree in engineering required four years, just as it does today. So, at GE, practice was not only a substitute for formal education, it was, it seems, considered, year for year, twice as good. This is a striking attitude, especially in a company that, like GE, was then among the technologically most advanced. What explains GE's attitude?

We must, I think, recognize that the meaning of engineer (and engineering) has changed over time. The term "engineer" was vague in 1890 and, though less vague than it used to be, is still vague today. But it is not confused.

A term is confused when any case to which it is thought to apply is disputable. A confused term, such as "round square," has inconsistent criteria of application. "Engineer" is not like that. There are clear cases. On the one hand, someone with a degree in civil or mechanical engineering and several years of successful practice is certainly an engineer. On the other hand, train operators and boiler tenders, though usage allows them to be called engineers, clearly are not engineers in the sense relevant here. Such "technicians" are engineers only in a sense belonging to an earlier age.

Though not confused, "engineer," like other terms, is still vague. In addition to the clear cases, there are disputed cases. One contemporary dispute concerns whether an individual can, by getting the right experience, become an engineer without a degree in engineering (for example, with only a degree in physics or chemistry). Complicating this dispute is a subsidiary dispute concerning which experiences are of the right kind. Is supervising engineering work for a decade or so the right kind? Or must an individual actually do some engineering himself? And what constitutes "doing engineering"? Why isn't supervising engineers doing engineering?

Back in the 1890s, the boundaries were vaguer. Then mechanical engineers were still at pains to distinguish themselves from "mere mechanics" who were, in turn, something more than today's mechanics. Mechanics then were still expected not only to repair machines but to make improvements as necessary. They were still regularly allowed to invent.[45] Electrical engineers had a similar problem distinguishing themselves from "mere electricians" who were, in turn, something more than today's electricians.[46] And so on. Perhaps what GE then meant by practical engineering might today be identified by a two- or four-year degree in technology rather than engineering (or even by an advanced degree in technological management). But, back in the 1890s, such distinguishing degrees were not an option. Engineers had to find other ways to explain how they differed from mechanics, electricians, and other craftsmen with whom they shared some tasks and much technical knowledge. Engineers found only two ways to explain the difference.

One way was to understand engineering as a kind of management.[47] Engineers issue orders; those with technical skills merely carry them out. Engineers are officers in the army of production. Though it has strong roots in the history of engineering, this way of distinguishing engineers from craftsmen is plainly inadequate. It fails to explain why engineers *should* be in charge. The explanation cannot simply be that the employer so ordains. If being put in charge of engineering work is all that distinguishes engineers from other employees, anyone put in charge of engineering work would be an engineer. Engineers have generally supposed that engineering requires more than that (as, indeed, their employers have as well).[48] The other way, then, is to see that engineering requires knowledge craftsmen do not have: Engineers can give orders to craftsmen because engineers know things that mere craftsmen do not. This claim, though plausible, is plausible only if the knowledge in question depends, at least in part, on training outside the shop. Knowledge of natural science and advanced mathematics certainly is such knowledge. Hardly anyone would suppose much of those subjects could be learned in the shop.

That is one advantage of understanding engineering as fundamentally "scientific" rather than "practical". There are at least three others. First, if engineering was to be a profession, like law or medicine, not just a job title such as "manager," engineers could not let being an engineer depend on how an employer happened to define the engineer's job. Credentials, not employment, had to define the engineer. Second, a common academic training is generally considered one crucial mark of a profession. Insofar as engineers considered engineering a profession, or wanted engineering to be one, they tended to emphasize academic training. Third, engineering's unity, insofar as it exists, depends heavily on all engineers having an education that they share with each other (a basis for the "engineering method" engineers believe all engineers share). Emphasis on what goes on in the shop stresses just those features of engineering that threaten to divide engineering into many mutually incomprehensible occupations. In contrast, emphasis on "engineering as science" seems to confirm the sense most engineers have that, for all the immense differences between fields, virtually all engineers share something that distinguishes them both from ordinary workers and from ordinary managers.[49]

The question, "Who is an engineer?," sounds like a philosopher's question—and it is. But it is also a practical question: Every engineering society that decides, as most do, to limit membership (or a certain category of membership) to engineers has to define engineer with more or less precision. The historian Edwin Layton taught us much about the consequences of adopting various definitions. Definitions close to the practical pole tend to turn engineering societies into trade associations; definitions close to the scientific, to exclude many who shape the projects engineers carry out and do much to maintain discipline among engineers.[50]

Layton, however, taught us that while failing to make clear how hard it is to say what an engineer is. In particular, he failed to notice that, at its extreme, engineering as science can be as disastrous for engineering as "engineering as practice." Training engineers as scientists, if only as "applied scientists," tends to turn out scientists rather than engineers.[51] Consider, for example, the Lawrence Scientific School, founded in 1847 as part of Harvard, to teach: "1st, Engineering; 2d, Mining, in its extended sense, including metallurgy; 3d, the invention and manufacture of machinery."[52] Plainly, Lawrence was supposed to be an engineering school. By 1866, Lawrence had graduated 147 students: 94 of these became professors or teachers; 5 became college presidents; but only 41 actually became engineers (as against 126 from Rensselaer during the same twenty years).[53] The Massachusetts Institute of Technology opened in Boston in 1865 in large part because Lawrence had failed as a school of engineering.[54]

Nonetheless, during much of this century, especially after World War II, engineering education moved ever closer to the scientific extreme. Programs in specialized fields of engineering—everything from agricultural engineering to telephone engineering—disappeared from the undergraduate curriculum, leaving only the larger divisions: civil, chemical, electrical, and the like. And even courses in these fields tended more and more to emphasize general principles, calculations, and laboratory work. Students were left to learn the art of engineering after graduation, if at all.[55]

Only recently did engineering schools begin to move back toward practice. They did so largely under pressure from industry and the board that accredits engineering schools. But, this countermovement did *not* mean a return to the shop. Engineering schools, instead, began to think of engineering in a new way—as fundamentally concerned with design.[56] Some results of this new thinking are already in place—for example, senior courses in engineering design. Other results are only now showing up—for example, as design elements in junior or even sophomore courses in engineering science. And some results are only at the stage of talk or experiment—for example, as attempts to include in design courses everything from the ethical issues a design might raise to the practical problems of getting colleagues and superiors to adopt one's design.[57]

In retrospect, these recent developments seem both sound and overdue. The stereotype of engineering as the logical or, rather, mechanical, solution of practical problems by deduction from scientific principles misses the creative side of much engineering, something that should have been obvious from the striking newness of so many works of engineering, whether the bridges of the early railroad engineers or the bewildering variety of today's computers.

Of course, engineering is not only inventiveness, just as it is not only science or only management. We want engineering rather than mere invention in many departments of life in part because engineers work within constraints other inventors—whether architects, applied scientists, industrial designers, or mere handymen—do not. Engineers have distinctive routines for ensuring safety, economy, reliability, durability, manufacturability, and so on. These routines, and the engineering science behind them, are subordinate to engineering design. But, though subordinate, they are fundamental to engineering, much as a certain pattern of rhyme and meter is to making a sonnet.

Who then is an engineer? Today we must answer: anyone who can design as engineers do.[58] Unfortunately, we have only the roughest idea of what engineering design is. Today, the philosophy of engineering is where the philosophy of science was a hundred years ago. We have barely begun to understand that there is a question.[59]

Ethics and the Profession of Engineering

So far in this chapter, I have discussed engineering primarily as an "occupation," not a "profession." I had a reason. While the old expression "liberal profession" referred to any occupation suitable for gentlemen, the modern use of "profession" requires more—organization, with standards of admission, including both training and character, and standards of conduct beyond the merely technical.[60] In 1850 engineering was still not a profession in this sense; nor was it so in the United States even in 1900. Today it is. What explains the change?

Until this century, engineering societies in the United States were primarily scientific or technical associations. So, for example, the American Society of Civil Engineers (ASCE) was established with the purpose of "advancing knowledge, science and practical experience among its members, by an exchange of thoughts, studies, and experience."[61] There was no suggestion either of improving the formal education of engineers or of setting standards of conduct.

Indeed, the first efforts to set minimum standards for engineering education came from the engineering *schools*, not from practicing engineers. In 1893, at the Columbian Exposition in Chicago, seventy engineering teachers organized the Society for the Promotion of Engineering Education (SPEE), later to become the American Society of Engineering Education (ASEE).[62] While SPEE undertook a number of valuable studies of engineering education, making many influential recommendations, not until 1932 did the major engineering societies establish the Engineers' Council for Professional Development (ECPD) to accredit engineering curricula.[63]

The adoption of standards of conduct began earlier. Indeed, in one sense, it began when engineers first distinguished themselves from those unable to work the way engineers do. Engineering can be defined, in part, by standards of competence—and standards of competence are, in a sense, standards of conduct. But every skilled occupation has standards of conduct in this sense, and some, like trade associations or scientific societies, may be organized to maintain them. Ethical standards, not standards of competence or organizations, seem to distinguish professions from other skilled occupations.[64]

Engineers in the United States lacked distinctive ethical standards until the second decade of this century. Why did they not adopt such standards earlier? Why did they adopt them then? My guess is that engineers did not adopt ethical standards earlier for the same reason that most of today's professions, including law and teaching, did not. They did not see the need.[65]

Until this century, engineering was a clubby affair. There were relatively few engineers and those few worked in a small world in which gossip maintained what discipline was necessary. But by 1900 that time had passed. Cities grew up where small towns had been. The big cities of 1850 or 1870 had tripled, quadrupled, or quintupled in size. The same thing happened to the companies for which most engineers worked.[66] And engineering itself grew enormously. The few thousand engineers of 1870 had become more than a hundred thousand and seemed likely to continue to increase rapidly. By 1900 most engineers were young. Old systems of apprenticeship were being swamped. College or technical school was, or at least soon would be, the primary route to a career in engineering.

The old men of the profession naturally sought new means to do what they could no longer do by the old. A formal code of ethics must have seemed one way to help the young understand what was expected of them. So, early in this century, each of the major engineering societies set up a committee to draft a code of engineering ethics, but the drafting proved harder than expected. The committees found that they agreed on less than they had supposed; even determining what that little was took much effort.[67] The societies were not only writing down what they agreed on, they were also hammering out new agreements. What began as an attempt to preserve the past ended in a new profession—in two senses. First, engineers began professing something new; they committed themselves to a specific code of ethics. Second, their organizations were no longer mere technical societies; they constituted an occupation organized to carry on certain work in accordance with standards beyond what law, market, and morality demanded—they were a profession.

After World War I, there was a smaller round of code writing; after World War II, another; then, starting in the 1970s, the largest round yet. All this code writing produced much coordination among major engineering societies and substantial agreement on what a code of ethics should contain. Today, engineers have relatively clear standards of conduct they can look to for guidance and can cite when offering advice to one another, when criticizing one another's work, or when seeking to prevent certain conduct. Chapters 4 and 8 provide examples of those standards. What engineers still lack is a systematic way to protect members of their profession who act ethically when an employer or client wants something else. As with other professions, so with engineering: Ethics is unfinished business.

My Method

We all have a tendency to see institutions, professions, and even people as more or less complete, as Platonic ideas dropped into history. This is plainly a mistake when trying to understand people. We all know that however smooth the surface we show the world, we are all beings ever changing or, at least, ever capable of change.[68]

Because I believe this to be true of professions as well, I try to describe engineering as an evolving institution, one that people much like us have made, not always intending what they achieved, imperfect, as all human works are, and therefore capable of improvement. I believe that thinking of engineering in this way will help engineers both to understand and to resolve the ethical problems they face. I also believe that thinking of engineering in this way helps the rest of us understand engineering. In the chapters to follow, we shall see whether that is so.

3

Are "Software Engineers" Engineers?

> Today, the field has emerged as a true engineering discipline."
>
> John J. Marciniak, "Preface," *Encyclopedia of Software Engineering* (1994)

> If you are a " engineer," you could be breaking the law. It is illegal in 45 states to use that title, warns Computerworld newspaper. People who aren't educated and licensed in 36 recognized engineering disciplines can't call themselves "engineers," and computer professionals often don't qualify.
>
> *Wall Street Journal*, June 7, 1994, p. 1.

For those interested in professions, the emergence of what may be a new profession should generate the same excitement that the discovery of a new class of objects in the sky generates among astronomers. Not only is it inspiring to watch, it is a chance to put theory to work in unexpected ways, a chance to separate the charming from the true. This chapter begins with the emergence of software engineering as a distinct discipline, occupation, and, perhaps, profession.

The term "software engineering" came into currency after a 1967 North Atlantic Treaty Organization conference on software design and testing used that term in its title.[1] Today, thousands of people are called software engineers, do something called software engineering, and have sophisticated employers willing to pay them to do it.[2] Yet, software engineering is no ordinary engineering discipline. Few software engineers have a degree in engineering. Some are graduates of a program in computer science who had a single course in "software engineering." (Typically, that course is taught by someone with a degree in computer science rather than engineering.) Most software engineers are programmers with no formal training in engineering.[3] Are software engineers nonetheless engineers? What, if anything, makes this question worth answering?

Let me answer the last question first: Defining a field is more than semantics. How we define a field can affect how it develops. Software engineering may be a field whose progress is threatened by the analogy with engineering, a field pushed toward an unnecessarily rigid curriculum.[4] That is the first reason our questions about software engineering are worth answering. Second is that trying to answer them will help us understand engineering. What are its boundaries? What is at stake when we draw such boundaries? A third is that trying to answer such questions tests the utility of our history of engineering. What insight can this history give us?

The insight may be disappointing. What I show is that we can't tell whether software engineering is engineering. Only the future can tell. The best we can get from engineering's history is insight into why that is so. Getting that insight leads me to defend two theses: First, that software engineers are not engineers merely because they do much that engineers do or know much that engineers know; second, that whether software engineering can or should be a field of engineering depends on whether software engineers can or should be educated in the way engineers are. These two theses rest on a third: Engineering is (or, at least, should be) defined primarily by its curriculum rather than, as we might expect, by what engineers in fact do or know. Because the defense of the other two theses rests on the third, it is with the third that we must begin.

The Standard Definition of Engineer

The standard definition of engineer is something like this: An engineer is a person who has at least one of the following qualifications: (1) a college or university B.S. from an accredited engineering program or an advanced degree from such a program, (2) membership in a recognized engineering society at a professional level, (3) registration or licensure as an engineer by a government agency, or (4) current or recent employment in a job classification requiring engineering work at a professional level.[5] The striking feature of this definition is that it *presupposes* an understanding of engineering. Three of the four alternatives actually use the term "engineering" to define engineer; and the other, alternative (3), avoids doing the same only by using "as an engineer" instead of "to practice engineering."[6]

This definition and others like it are important. They determine who is eligible for admission to engineering's professional societies, who may be licensed to practice engineering, and who may hold certain jobs. Such definitions are also eminently useful. For example, they help the Census Bureau exclude from the category of engineer drivers of railway engines, janitors who tend boilers in apartment buildings, and soldiers wielding shovels in the Army's Corps of Engineers. These, though still called engineer, clearly are not engineers in the relevant sense. They are engineers only in a sense now obsolete.

However, the standard definitions do not suit our purpose. They do not tell us whether a software engineer is an engineer—or even how to go about finding out. A software engineer may, for example, work at a job classified as requiring software engineering (at a professional level). That will not settle whether a software engineer is an engineer: What an employer classifies as "engineering" (for lack of a better word) may or may not be engineering in the relevant sense.[7]

What will settle the question? In practice, the decision of engineers. An organization of engineers accredits baccalaureate and advanced programs in engineering. Other organizations of engineers determine which societies with "engineer" in the title are engineering societies and which—like the Brotherhood of Railway Engineers—are not. Engineers also determine which members of their societies practice engineering "at a professional level" and which do not. Government agencies overseeing registration or licensure of engineers, though technically arms of the state rather than of engineering, generally consist entirely of engineers. And, even when they do not, they generally apply standards (education, experience, proficiency, and so on) developed by engineers. Engineers even determine which job classifications require professional-level engineering work and which do not.

The standard definition settles many practical questions, but not ours. Because engineers divide concerning whether software engineering is really engineering, to say that software engineers are engineers if they engage in professional engineering is—for engineers and those who rely on their judgment in such matters—merely to restate the question.[8]

That is a practical objection. There is a related theoretical objection. A definition of engineer that amounts to "an engineer is anyone who does what engineers count as engineering" violates the first rule of definition: 'Never use in a definition the term being defined.' That rule rests on an important insight. Though a circular definition can be useful for some purposes, it generally carries much less information than a noncircular definition. So, for example, a dictionary that defines ethics as "morality" and then defines morality as "ethics" helps only those who understand one of the terms but not the other. The smaller the circle, the less helpful a circular definition is.

How can we avoid the standard definition's circularity? The obvious way may be to define engineering without reference to engineer and then define engineer in terms of engineering. The National Research Council (NRC) in fact tried that approach, coupling its definition of engineer with this definition of engineering:

> Business, government, academic, or individual efforts in which knowledge of mathematics and/or natural science is employed in research, development, design, manufacturing, systems engineering, or technical operations with the objective of creating and/or delivering systems, products, processes, and/or services of a technical nature and content intended for use.[9]

This definition is certainly informative insofar as it suggests the wide range of activities which today constitute engineering. It is nonetheless a dangerous jumble. Like the standard definition of engineer, it is circular: "Systems *engineering*" should not appear in a definition of engineering. The same is true of "technical" if used as a synonym for engineering. (If not a synonym, technical is even more in need of definition than engineering is and should be avoided for that reason.) The NRC's definition also substitutes uncertain lists—note the "and/or"—where there should be analysis. Worst of all, the definition is fatally overinclusive. Not only are software engineers engineers according to the definition, but so, too, are many whom no one supposes to be engineers, not only applied chemists, applied mathematicians, architects, and patent attorneys but, thanks to the and/or between mathematics and natural science, even actuaries, accountants, financial analysts, and others who use mathematics to create financial instruments, tracking systems, investment reports, and other technical objects for use.

Though much too inclusive, this definition of engineering shares with most others three characteristic elements. First, it makes mathematics and natural science central to what engineers do.[10] Second, it emphasizes physical objects or physical systems. Whatever engineering is, its principal concern is the physical world *rather than* rules (as in law), money (as in accounting), or even people (as in management). Third, the definition makes it clear that, unlike science, engineering does not seek to understand the world but to remake it. Engineers do, of course, produce knowledge (for example, tables of tolerances or equations describing complex physical processes), but such knowledge is merely (or, at least, primarily) a means to making something useful.[11]

Those three elements, though characteristic of engineering, do not define it. If they did, deciding whether software engineers are engineers would be far easier than it has proved to be. We could, for example, show that software engineers are not engineers simply by showing that they generally do not use the natural sciences in their work. That many people, including some engineers, believe software engineers to be engineers is comprehensible only on the assumption that these three characteristics do not define engineering (except in some rough way). But if they do not define engineering, what does?

Before answering, I describe three common mistakes about engineering to be avoided in any answer. While these mistakes may seem far from software engineering, they bring us to the best point for understanding the relation between software engineering and engineering proper.

Three Mistakes about Engineering

The NRC's definition of engineering uses "technical" twice, once as a catch-all ("or *technical* operations") and once to limit the domain of engineering ("of a *technical* nature and content"). It is the second use of technical that concerns us now. It seems to be a common mistake in usage, one even engineers make. We might summarize the mistake this way: *Engineering equals technology.*

There are at least three objections to this way of understanding engineering. First, engineering can equal technology only if we so dilute what we mean by engineering that any tinkerer would be an engineer (or, at least, be someone engaged in engineering).[12] Once we so dilute engineering, we are left to wonder why anyone might want an engineer rather than some other technologist who could do the same job.[13] Why demand a software engineer rather than a programmer, software designer, or the like to do software design or development? What was the point of inventing the term "software *engineering*"?[14]

Second, the proposition "engineering equals technology" makes writing a history of engineering (as distinct from a history of technology) impossible. The history of engineering, according to this proposition, is the history of technology. Every successful inventor is an engineer; every successful manager of industry is an engineer; and so on. We are left to wonder why our term for engineer—unlike our term for architect, mathematician, or artisan—is so recent. Why does engineering have a history distinct from technology when engineering is technology?[15] Why do engineering organizations devote any effort to defining engineering? Why don't they just define technology and technologist and then say, "Ditto engineer"?

Third, "engineering equals technology" transforms talk of engineering ethics into talk of the ethics of technology. It turns professional ethics into public policy. Whatever engineering ethics is, it is, in part at least, the ethics of a *profession*—not merely standards governing the development, use, and disposal of technology but standards governing a certain group of technologists.

That reference to profession suggests a second mistake commonly made about engineering, one we might summarize this way: *Engineering is, by nature, a profession.* What makes this mistake attractive is the idea that a professional is a "knowledge-worker," that special knowledge defines each profession (as well as the underlying occupation). Any occupation that requires a lot of training is a profession.[16] Engineering requires a lot of training; hence, it must be a profession. Connecting profession with knowledge helps exclude from the profession of engineering those who, though they may function as engineers (or, rather, as "mere technicians"), lack the requisite knowledge to be engineers strictly so called ("engineers at the professional level"). Claiming that engineering is, by nature, a profession provides an antidote to the first mistake, but only by making another.

What is this second mistake? Thinking of engineering as, by nature, a profession suggests that organization has nothing in particular to do with profession. As soon as we have enough knowledge, we have a profession. There could be a profession of one.

Thinking this way makes much of the history of engineering mysterious. Why, for example, did engineers devote so much time to setting minimum standards of competence for anyone to claim to be an engineer? Why did they set *these* standards rather than others? Why did they suppose setting such standards relevant to being a profession? Like other professions, engineering has a corporate history that such nonprofessions as shoe repair, inventing, and politics lack. Any definition of engineering must leave room for that history. What is striking about the history of engineering—indeed, of all professions—is the close connection between organization, special standards, and claims of profession.

A third mistake may help explain the appeal of the second. We might summarize it this way: *The engineering profession has always recognized the same high standards.* There are at least two ways that this mistake is defended. One appeals to the "nature" (or "essence") of engineering. Any occupational group that did not recognize certain standards would not be engineers—or, at least, would not be engaged in engineering. Engineers have organized to set standards to avoid being confused with those who are not "really" engineers. The standards simply record what every good engineer knows; they codify rather than legislate.

The other argument for this mistake appeals to the moral nature of the engineer. It is said that engineers are always generally conscientious. To be conscientious is to be careful, to pay attention to detail, to seek to do the best one can. To do this is to be ethical. Professional ethics is being conscientious in one's work. To be a conscientious engineer is, then, to be by nature an ethical engineer.[17] Engineering societies adopt standards to help society know what it should expect of engineers, not to tell a conscientious and technically adept engineer what to do. Informing society is, according to this view, enough to explain the effort engineers put into codes of ethics.

What is wrong with the proposition that engineering is, by nature, ethical? Like the other two mistakes, this third makes understanding the history of engineering harder. Why have engineers changed the text of their codes of ethics so often? Why do experienced engineers sometimes disagree about what should be in the code of ethics (as well as about what should be in their technical standards)? Why do these disagreements seem to be about how engineers should act, not about what to tell society?

If we examine a typical code of engineering ethics, we find many provisions that demand more than mere conscientiousness—provisions requiring, for example, engineers to help engineers in their employ to continue their education or to make public statements only in a truthful and objective manner.[18] Such codes are less than a hundred years old.[19] Before they were adopted, an engineer only had to be morally upright and technically proficient to do all that could reasonably be expected. In those days, engineers had no responsibilities beyond what law, market, and ordinary morality demanded (and, so, had no need to inform society what to expect). The claim that engineering has always accepted the same high standards—that, for example, failing to inform a client of a conflict of interest was always unprofessional—is contrary to what we have learned about engineering.

Membership in the Profession of Engineering

As we saw in chapter 2, engineering education in the United States, almost from its beginning, had two strands: One was a series of unsuccessful experiments with various alternatives to the West Point curriculum; the other was the evolution of the West Point curriculum into the standard for engineering education in the United States. The details of that story do not matter now.[20] What does matter is that the education of engineers became more and more the province of engineering schools, and these in turn became more and more alike. For engineers, an engineer became someone with the appropriate degree from an engineering school or, absent that, with training or experience that was more or less equivalent; hence, the standard definition of "engineer" with which this chapter began.

The point of this story is not that engineering will always have the same curriculum it does today. The engineering curriculum has changed a great deal since West Point was founded in 1802; for example, there is now more calculus and less drafting. No doubt, the curriculum will continue to change. Perhaps the second year of calculus will disappear, with ecology or industrial psychology taking its place. The point of the story of engineering as I told it is, rather, that just as today's curriculum grew out of yesterday's, so tomorrow's will grow out of today's. Any new field of engineering has to find a place in that curriculum. Finding a place may mean changing the curriculum; what it cannot mean is starting fresh. Finding a place in a curriculum is a complex negotiation of social arrangements. It is like joining a family. You can change your name to Davis if you like, make yourself look like a member of my family (perhaps even genetically), and declare yourself a member of my family, but that won't make you one. To be a member of my family, you must come in by birth, marriage, or adoption.

Some fields of engineering (for example, nuclear) seem to be born engineering, but others (mining, for example) seem to come in by the occupational equivalent of marriage or adoption. For any field not born engineering, the only way to become a field of engineering is by "marriage" (or "adoption"). Failing that, it cannot be a field of engineering. It can only don quotation marks to show irony, start another family of the same name—as railway engineering has, but without its historical justification—or choose a more suitable name.

The history of a *profession* tells how a certain occupation organized itself to hold its members to standards beyond what law, market, and morality would otherwise demand. The history of a profession is the history of organizations, standards of competence, and standards of conduct. For engineering in the United States, that history began after the Civil War. It is a confused story because the profession was taking shape along with the occupation. Many early members of its professional societies would not qualify for membership today.

Nonetheless, I think we can see that as engineers became clearer about what engineers were (or, at least, should be), they tended to shift from granting membership in their associations ("at a professional level") based on connection with technical projects, practical invention, or other technical achievements to granting it based on two more demanding requirements: (1) specific knowledge and (2) commitment to use that knowledge in certain ways (that is, according to engineering's code of ethics). The first is occupational. This requirement is now typically identified with a degree in engineering. The second is professional. Although many professions (law, especially) make a commitment to the profession's code of ethics a formal requirement for admission, engineering has not (except for licensed professional engineers, or P.E.s). Instead, the expectation of commitment reveals itself when an engineer is found to have violated the code of ethics. The defense, "I'm an engineer but I didn't promise to follow the code and therefore did nothing wrong," is never accepted. The profession answers, "You committed yourself to the code when you claimed to be an engineer."[20]

Attempts to understand software engineering as engineering have, I think, generally missed this complexity in the concept of the *profession* of engineering. Consider, for example, Mary Shaw's observation: "Where, then, does current software practice lie on the path to engineering? It is still in some cases craft and in some cases commercial practice. A science is beginning to contribute results, and, for isolated examples, you can argue that professional engineering is taking place.[21] Substitute "applied science" for "engineering" in the first sentence in this passage and for "professional engineering" in the second, and there is little to argue with. But, as it stands, its final sentence is simply false. There is nothing in what Shaw describes to suggest that "*professional* engineering is taking place."

The Fundamental Problem in Software Engineering

The term "software engineering" was coined in the mid-1960s to describe "the need for software manufacture to be [based] on the types of theoretical foundations and practical disciplines that are traditional in the established branches of engineering."[22] Thinking about software engineering thus began with the assumption that the established branches of engineering share certain theoretical foundations and practical disciplines. This is an assumption that engineers generally share, calling the theoretical foundation "science" or "engineering science" and the practical discipline "engineering method." Yet, even the history of software engineering puts that assumption in doubt.

The early proponents of software engineering disagreed concerning what engineering's theoretical foundations and practical disciplines are. Some understood engineering as essentially applied science, with a theoretical foundation in physics, chemistry, and mathematics. Others understood engineering as primarily a body of techniques for design. For them, engineering was primarily a way of moving from conception, through specification, to prototype, testing, and final fine-tuning. For most, however, engineering was primarily a way of organizing and managing a process of design, development, and manufacture, of ensuring that work would be completed on time, within budget, and to the customer's satisfaction.[23]

In fact, what the established branches of engineering share, perhaps all they share, is a common core of courses (physics, chemistry, mathematics, and so on), which may or may not provide a theoretical foundation for engineering. Beyond that, there are important overlaps between this and that field, many family resemblances and analogies, but nothing more (or, at least, nothing more of importance). For a long time, perhaps from its very beginning, engineering was a protean mix of activities held together by a common education. The common education clearly had connections with what engineers did, but the connections were not always clear, even to engineers.[24]

So, if software engineering is to be, strictly speaking, a field of engineering, it has to require of its practitioners a degree in engineering (or its equivalent).[25] Right now, the software engineering curriculum is more flexible than engineering's. It is, I think, an empirical question, one that remains open, whether students of software engineering would be better software engineers if they followed engineering's more rigid curriculum rather than, say, taking more computer science, psychology, and management courses than engineering's curriculum allows. How much physics, calculus, thermodynamics, and the like does one need to design, develop, and maintain software?

The answer to this question is not obvious. Indeed, in its present form, the question is probably unanswerable. How much physics, calculus, thermodynamics, and the like a software engineer needs may well depend on the kind of software in question (not whether or not it is "life critical" but what sort of knowledge its designer should have to do it right). Although we might worry about someone developing software for engineering applications who didn't know what engineers know, would we feel the same about such a person developing a computer game for children or a diagnostic program for physicians?

Software engineering was not born engineering. If it is ever to be part of engineering ("an engineering discipline"), it must come in by "marriage" or "adoption". That will require substantial changes in software engineering, engineering proper, or both. Software engineering may have to bring its curriculum up to standards for engineering accreditation, or engineering may have to change its curriculum to make room for software engineering (for example, by dropping the required chemistry course), or both engineering and software engineering may have to change. Software engineering cannot become engineering simply by adopting the name, by copying engineering methods, or even by having some authoritative body like the IEEE declare it engineering. Indeed, software engineers will not necessarily be members of the engineering profession even if they receive an engineering education.

Education only satisfies the occupational requirement. There is also the professional requirement, commitment to the engineers' code of ethics.[26] So far, software engineers seem to believe they can have a code of their own.[27]

Like the occupational requirement, the professional requirement leaves some room for maneuver. Software engineers can have their own code *in addition* to the engineers' code (that is, a code with obligations beyond those all engineers share). Software engineers can also try to work out a common code with engineers, changing what engineers require of themselves. What they cannot do is be engineers "at the professional level" yet refuse to share engineering's professional commitments.

Will software engineering ever join engineering's family? That is a question for prophets. What I tried to do here is to use software engineering to reveal the complexity in the concept of a profession of engineering. However, I must add that the benefits of making software engineering a "true engineering discipline" strike me as less certain than the discussion so far makes them seem. Training in engineering as such will not ensure that projects come in on time, within budget, or to the customer's satisfaction. Although engineering education has always had elements of management—more in the first half of this century than now—engineers always have problems delivering on time, within budget, and to the customer's satisfaction, especially in fields such as computer development, where experience is thin. The obvious ability of engineers in many fields to keep their promises seems more an indication of the maturity of the field than of any special knowledge of engineers as such. Aren't physicians and auditors just as able to deliver on their promises?

Nothing said here is meant to raise questions about the status of software engineering as a discipline, an occupation, or even a profession. My concern is how to conceptualize this new but already respectable occupation. Perhaps we would understand it better if we stopped trying to borrow concepts from engineering and instead borrowed them from architecture or industrial design, areas in which chemistry, physics, and mathematics are less important, pure invention more so, and codes of ethics less detailed. Or, perhaps we should borrow concepts from construction management. Software engineering may be more like overseeing the building of a great public work (a bridge, skyscraper, or power plant) than like doing the engineering for it. Construction managers are at least as good as engineers at delivering on time, within budget, and to the customer's satisfaction.[28] Or, perhaps software engineering is more like what lawyers do when they create new negotiable instruments or complex land-use agreements.

The question to be asked, then, is not whether software engineers are engineers. Clearly, while some are, most are not. The question is, rather, whether (or when) they *should* be.

My conclusion is that there is no fact of the matter here, only a complex of social decisions about standards of training and conduct in need of attention. Like engineering, software engineering is a social project, not a natural species.

PART II

ENGINEERS IN CONTEXT

Having defined engineering, we are ready to identify the place of ethics in the practice of engineering today. Though this, too, requires some history, I begin with a recent event, the Challenger explosion. Of course, that event is itself important to engineering. For the public, that event was the most traumatic engineering disaster in recent memory, more traumatic even than the two nuclear disasters, Three Mile Island and Chernobyl. Unlike these, it produced an engineer hero, Roger Boisjoly. Engineers found in the Challenger explosion confirmation of much they feared was wrong with corporate decision making. However, I have two other reasons for beginning with the Challenger, both more mundane. First, the enormous documentation the disaster produced allows us to get closer to decisive events than is possible in most engineering. Here is a drama from which we can learn much; here, too, are details to provoke thought about engineering's "mission" and the place of a code of ethics in accomplishing it. Here we may see the profession in action. Second, however dramatic, the events leading up to the disaster have many characteristics of ordinary engineering—especially, a large organization, cooperation and conflict between engineer–managers and ordinary engineers, a mix of technical and business considerations, the problem of defining what is and what is not a question of engineering, and even ethical considerations in what may at first seem mere technical decisions. The Challenger disaster is, in many respects, no more than ordinary engineering writ large. Both here and in part IV, it will help us understand what engineers do, what can go wrong ethically, and what can be done to prevent ethical wrongdoing.

Notes

Preface

1. Charles Harris, Michael Pritchard, and Michael Rabins, *Engineering Ethics: Concepts and Cases* (Wadsworth: Belmont, Mass., 1995).

2. Walter G. Vincenti, *What Engineers Know and How They Know It* (Johns Hopkins University Press: Baltimore, 1990).

3. Samuel Florman, *The Existential Pleasures of Engineering* (St. Martin's Press: New York, 1976); and The Civilized Engineer (St. Martin's Press: New York, 1987).

Chapter 1

This chapter began as a GTE Lecture at the University of Wisconsin Center/Fond du Lac, October 13, 1992. I should like to thank those present, as well as my colleagues, Wilbur Applebaum (history) and Sid Guralnick (civil engineering) and my friend, Mike Rabins (Texas A & M) for help in sorting through the issues discussed here. The chapter appeared in a somewhat longer version and under the title "An Historical Preface to Engineering Ethics," in *Science and Engineering Ethics* 1 (January 1995): 33–48. Reprinted by permission.

1. See, especially, Paolo Rossi, *Philosophy, Technology, and the Arts in the Early Modern Era*, translated by S. Attanasio (Harper and Row: New York, 1970). The *Oxford English Dictionary* gives 1615 as the first known use of the word "technology" in English.

2. David Noble claims that Jacob Bigelow, a Boston physician who helped found the Massachusetts Institute of Technology (1865) was instrumental in introducing "technology" (in its modern sense) into general usage. To establish his claim, Noble offers this quotation from Bigelow's *Elements of Technology* (1829):

> There has probably never been an age in which the practical applications of science have employed so large a portion of talent and enterprise of the community, as in the

> present. To embody . . . the various topics which belong to such an undertaking, I have adopted the general name of Technology, a word sufficiently expressive, which is found in some of the older dictionaries, and is beginning to be revived in the literature of practical men at the present day. Under this title is attempted to include an account . . . of the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve the application of science, and which may be considered useful, by promoting the benefit of society, together with the emoluments of those who pursue them. (David Noble, *America by Design* [Alfred A. Knopf: New York, 1977] pp. 3–4)

My reading of this passage does not agree with Noble's. Bigelow refers to a revival of the term already beginning; hence, by his own admission, Bigelow probably is not "instrumental" in its revival. Further, Bigelow's own use of the term is barely distinguishable from that found in the old dictionaries to which he refers. The chief difference is the observation that *some* of the more "conspicuous arts" he describes "involve the application of science." He still seems far from the modern idea of technology as either inventions or the "science of invention."

3. See, for example, Plato's *Theaetetus* (III: 172–173): "[A] philosopher is a gentleman, but a lawyer is a servant. The one can have his talk out, and wander at will from one subject to another, as the fancy takes him . . . [but] the lawyer is always in a hurry."

4. Hannah Arendt, *The Human Condition* (Doubleday: Garden City, N.Y., 1959) p. 323n.

5. "If we assume that the Middle Ages ended with the fifteenth century, then a simple count of inventions made or adopted by Europeans during the period confirms that it was, as regards technics, more creative than any previous epoch in recorded history." (*Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas*, edited by Philip P. Weiner [Charles Scribner's Sons: New York, 1973] vol. 4, p. 359 [D. S. L. Cardwell, technology]) I am, of course, still comparing Greece's Golden Age with a similar stretch of time during the Dark Ages. Were I to compare the Dark Ages with the Hellenistic Period, I would hedge my claim a bit (and begin to worry about how to count inventions).

6. See, for example, Spencer Klaw, "The Faustian Bargain" in *The Social Responsibility of the Scientist*, edited by Martin Brown (Free Press: New York, 1971) pp. 3–18.

7. Who is this "we"? Certainly, you and I, but probably, as well, most inhabitants of the planet.

8. The modern prejudice against manual labor seems to vary from place to place and time to time. It is certainly less in the United States today than, say, in France a century ago. So, for example, it is today hard to imagine the events a French mechanical engineer (or mechanic) of the nineteenth century recalled. After church, he struck up a conversation with a young woman (with her mother standing by). When she found out that he built steam engines for a living, she shuddered:

> "What! You work, you are therefore exposed to all the filth that trade includes?" A bit vexed I responded, "But yes, miss, and I dare to believe that none is apparent at this moment." The mother turned her back and the eyes of my beautiful neighbor fell on my well-ground hands, which did not betray me, and she moved away. For her, I was a plague-stricken person. (Eda Kranakis, "Social Determinants of Engineering Practice: A Comparative View of France and America in the Nineteenth Century," *Social Studies of Science* 19 (February 1989): 5–70, at 13)

The whole paper is well worth reading both for the contrast it draws between French and American practice and for the cultural explanation it offers.

9. Though this description of science is no doubt biased in favor of the natural or physical sciences, it also applies (with a bit of stretching) to the social sciences. The social sciences can be practiced as an attempt to understand human society from the outside, that is, as a part of nature. Of course, many social scientists now consider such value-free science to be impossible and its attempt likely to mislead.

10. *World Almanac* (World Almanac: New York, 1989) p. 158. This number must be taken only as a rough approximation. The Labor Department (three years later) set the number of engineers at 1,519,000 (*Occupational Outlook Handbook* [U.S. Department of Labor, Bureau of Statistics, Washington, D.C., May 1992], p. 64); whereas the National Science Foundation put the number at 2,849,800 (*U.S. Scientists and Engineers: 1988 Estimates*, Surveys of Science Resources Series, National Science Foundation, NSF 88-322, p. 6). Apparently, it is not easy to count engineers. Why?

11. "Principles of Medical Ethics" in *Codes of Professional Responsibility*, edited by Rena A. Gorlin (Bureau of National Affairs: Washington, D.C., 1986) p. 99.

12. The first of these modern professions was the apothecaries, a profession now deceased, which reorganized in 1815. The other liberal professions followed only slowly, beginning with the solicitors in the 1830s. See W. J. Reader, *Professional Men: The Rise of the Professional Classes in Nineteenth-Century England* (Basic Books: New York, 1966) esp. pp. 51–55.

13. Thomas Percival, *Medical Ethics; or A Code of Institutes and Precepts Adapted to the Professional Conduct of Physicians and Surgeons* (1803). The word "institutes" suggests that Percival's model here is in part at least jurisprudence. (Since the emperor Justinian's famous textbook, "institutes" signals that a book so titled is a textbook or summary of the law, the rest of the title telling the particular jurisdiction, for example, Coke's *Institutes of the Laws of England*.) Percival in fact makes this connection in his introduction, indicating that he originally intended to call his text "medical jurisprudence." About half the text is a summary of English law a physician should know. Much of the rest consists of "precepts" (i.e., advice) rather than of standards of conduct (ethics strictly so-called). Medical ethics in the modern sense is actually a small part of that seminal work.

14. See, for example, M. David Burghardt, *Introduction to the Engineering Profession* (HarperCollins: New York, 1991) p. 26: "We shall assume that wherever there was an invention or innovation, engineering was required." Burghardt does not say the same about engineers. Can there be engineering without engineers? Or Billy Vaughn Koen, *Definition of the Engineering Method* (American Society of Engineering Education: Washington, D.C., 1985) p. 26: "After 20 or 30 centuries, the engineer learned how to correct this problem by allowing the front axle to pivot on a king bolt as stage three in the evolution of cart design." Engineers three or four thousand years ago?

15. See, for example, Ralph J. Smith, *Engineering as a Career, 3rd* (McGraw-Hill: New York, 1969) p. 22: "It has been said that the history of civilization is the history of engineering. Certainly it is true that the highly developed civilizations have all been noted for their accomplishments in engineering." Substitute "building" for engineering and there would be nothing to object to. The same is true of scholarly works such as Donald Hill, *A History of Engineering in Classical and Medieval Times* (Croom Helm: London, 1984). A careful researcher and writer, Hill argues for his application of "engineer" to ancient builders (rather than, as most writers do, just assuming the application to be obviously justified). Yet he soon admits that "classical and medieval engineers did not have a quantified, scientific basis for their designs" (p. 5), that they lacked the formal training characteristic of modern engineers, and that they even lacked a full-time occupation (p. 7). They did engineering (read "building") as a sideline. So, whatever they were, they were not a profession—or even an occupation.

16. Though we now translate *corps du génie* as "corps of engineers," there is in fact no exact English equivalent. While *génie* corresponds to the English "gin" (as in "cotton gin") and perhaps "jenny" (as in "spinning jenny") the French has less suggestion of "engines." Perhaps the best translation would be "corps of the contriver"—though this lacks the sug-

gestion of magic (as in the English "genie"). Unlike the *corps du sappeur* ("the corps of spaders") for example, the *corps du génie* seems not to have taken its name from the implements it used but to have given those implements its name. This suggests an inherent novelty in what it did.

17. See Frederick B. Artz, *The Development of Technical Education in France, 1500–1850* (MIT Press: Cambridge, Mass., 1966) p. 48; or W. H. G. Armytage's history of engineering in Britain, (misnamed) *A Social History of Engineering* (Faber and Faber: London, 1961) pp. 96, 99.

18. Of course, many changes were made in the engineering curriculum (as well as many experiments with less demanding curriculum). Whole new subjects, such as thermodynamics or electricity, were added, and geometry and trigonometry gave way to a second year of calculus. For engineers, these may appear more than improvements in detail—and, for many purposes, they certainly are. Yet, for our purposes, such differences between the French curriculum of 1799 and today's typical engineering curriculum hardly affect the gap between what engineers learn and what lawyers, physicians, or even architects learn. Those who wish to understand what distinguishes engineering from other professions must pay attention to what engineers have in common, especially over long stretches of time, rather than what divides them.

19. Artz, *Technical Education*, 47–48. I should perhaps warn that the members of this corps do not seem to have been known as "civil engineers" (*ingénieurs civils*) but as "road and bridge engineers." The French seem to have reserved "civil engineer" for engineers employed by private persons. All members of a corps, whether of the *corps du génie (militaire)* or of the *corps des ponts et chaussées*, were state employees. The English term "civil engineer" may have derived from a misunderstanding of the French term (since the English, with a relatively weak state, had no exact counterpart to the *corps des ponts et chaussées*). Here is work for historians. Compare Kranakis, "Social Derterminants," esp. pp. 29–30.

20. Engineers also had some secret methods (for example, Monge's descriptive geometry). Artz, *Technical Education*, 106.

21. Ibid., 81–86.

22. But note Peter Michael Molloy's remark in *Technical Education and the Young Republic: West Point as America's École Polytechnique* (unpublished dissertation, Brown University, 1975) p. 105: "From a description of the curriculum, there should be no mystery for the change in the School's name in 1795 from *École des Travaux Publics* to *École Polytechnique*." It remains a mystery to me.

23. Artz, *Technical Education*, 154–155.

24. Ibid., 160. I should, perhaps, say "this École Polytechnique." By 1830, the École Polytechnique had become so devoted to mathematics that (by American standards of the day) its graduates generally did not seem to practice engineering. This later École Polytechnique may, then, provide an early example of the ability of science education to crowd out engineering. See Molloy, *Technical Education*, esp. pp. 119–130. On the other hand, this interpretation may simply be unfair (within the French context). See Kranakis, "Social Determinants," esp. pp. 22–29, for reasons to think that the École Polytechnique remained an engineering school throughout the nineteenth century.

25. Artz, *Technical Education*, 160–161. I should perhaps add that only practical difficulties seem to have prevented all this from happening as early as 1802. Malloy is very good on this.

26. Eugene Ferguson, "The Imperatives of Engineering" in John G. Burke et al., *Connections: Technology and Change* (Boyd and Fraser: San Francisco, 1979) pp. 30–31. Ferguson's "imperatives" are, of course, Koen's "heuristics."

27. For a detailed study of one of these proxy measures that, in the end, had to be discarded, see Walter G. Vincenti's discussion of "stability" in *What Engineers Know and How They Know It* (Johns Hopkins University Press: Baltimore, 1990) pp. 51–108.

28. In the absence of government action, engineering societies developed codes both to enhance efficiency (by promoting standardization) and to maintain safety. These codes set standards for engineers to follow "voluntarily" and provide "model codes" legislatures can adopt. For more on this point, see chapter 7 (in this volume). Since this activity has been criticized as a usurpation of a governmental function, Ferguson's complaint that engineers should have done more of it seems unfair—at least until he offers a theory of which activities belong to government and which to private organizations or individuals.

29. Not all engineering designs dumb down a job. Many engineering designs "automate," that is, eliminate the routine work of many while creating technically sophisticated jobs for a few. These designs may be regarded as the limiting case of dumbing down or as an entirely different way of doing without large numbers of highly skilled workers. I don't think much turns on how it is categorized.

30. For more on the military connections of engineering, together with the connections between the military and technology, see Barton Hacker's, "Engineering a New Order: Military Institutions, Technical Education, and the Rise of the Industrial State," *Technology and Culture* 34 (April 1993): 1–27.

31. Artz, *Technical Education*, 162.

32. Is this a description or a prescription, a statement of what civil engineering is or a statement of what it should be? That is not a hard question but it is one that should give philosophers a reason to pay more attention to professions than they generally do. Thedgold's definition is probably both descriptive of civil engineers generally and, for *that* reason, prescriptive for anyone who wants to carry on his occupation under the title "civil engineer." How can that be? That is a question addressed here in chapters 4 and 10.

33. Accreditation Board of Engineering and Technology, *Code of Engineering Ethics*, first principle (1985). (emphasis added). Whereas tense suggests description, context suggests prescription. Here again we see the congruence of description and prescription characteristic of professions.

34. Compare Koen, *Definition*, esp. 63–65. Koen rightly points out that engineers sometimes go beyond science (what we now know) and sometimes ignore science (because truth is too expensive) and so at least part of the time cannot be said to be applying science. This is, I believe, an important point but one quite distinct from the one I am making. Perhaps engineering differs from applied science in enough ways that the interesting question is not how engineering differs from applied science but why they were ever thought to be the same.

35. All "exceptions" are in the electrical engineering department. Whether they are truly exceptions is a matter about which I remain uncertain. On the one hand, these professors of engineering were educated as engineers; on the other, they considered their location in an engineering department to be an accident. They admitted—indeed, declared—that they could just as well, or even better, have been lodged in a physics department. They seem, therefore, to have lost their identity as engineers along with their interest in helping to make something useful. In that respect at least, they constitute evidence for, rather than against, my claim.

36. Compare Vincenti, *What Engineers Know*, 161: "Engineers are after a theory they can use for practical calculations. . . . To obtain such a theory they are willing, when necessary, to forgo generality and precision . . . and to tolerate a considerable phenomenological component. Scientists are more likely to be out to test a theoretical hypothesis . . . or infer a theoretical model."

37. For some historical background on this use of "ethics," as well as my rationale for preferring it, see Michael Davis, "The Ethics Boom: What and Why," *Centennial Review* 34

(Spring 1990): 163–186. For those who ask why codes of professional ethics must be morally permissible. The short answer is: If not morally permissible, they cannot be morally binding; if not morally binding, they would seem to be more accurately described as an ethic, mores, ethos, custom, or practice than as ethics (strictly speaking). Insofar as this book proves how useful my way of understanding professional ethics is, it provides close to a full answer to that question.

38. I am, of course, assuming that American engineers did not have an "unwritten code" before then. That may seem a daring assumption. It is not. Most "unwritten law" is in fact written. For example, the "unwritten constitution" of England is recorded in royal charters, parliamentary debates, case law, and even newspaper reports. It is unwritten only in the sense that there is no authoritative document such as the U.S. Constitution. Humans have great trouble coordinating what they do without putting expectations into words and, in large organizations, without putting those words on paper. So, the apparent absence of any written codes of engineering ethics in the United States before 1900—even in the unofficial form that Percival produced for English physicians a century earlier or that Sharswell produced for American lawyers in the 1830s—is, I think, decisive evidence against the existence of any unwritten code.

39. Compare chapter 8 (in this volume).

40. Though I make this claim about what morality demands without argument, and in the belief that it is both true and obvious, I should admit that certain utilitarians, those moral theorists who think morality consists in maximizing overall happiness or social utility, do not. Their theory makes morality much more demanding, which has proved a problem for their theory, not a problem for ordinary moral agents.

Chapter 2

This chapter began as the first Annual Engineering Ethics Lecture, funded by GTE, at Wayne State University, Detroit, Michigan, November 19, 1992. I would like to thank those present for a useful discussion. I should also thank Mike Rabins (mechanical engineering, Texas A&M) and my colleagues Tom Misa (history) and Sid Guralnick (civil engineering) for many helpful comments on an earlier draft, and Bill Pardue for helping to track down many of the references given here.

1. See, for example, Lawrence P. Grayson, "The American Revolution and the 'Want of Engineers,' " *Engineering Education* 75 (February 1985): 268–276.

2. See chapter 1 for a defense of this claim.

3.

> Sylvanus P. Thayer was appointed director in 1817, by which time enrolment and teaching staff had increased to 250 cadets and 15 professors covering mathematics, "engineering," and natural philosophy, recently joined by Claude Crozet (1790–1864) a graduate of the École Polytechnique, who introduced the teaching of descriptive geometry to the college, and in 1821 published the first textbook on the subject. . . . Thayer graduated from Dartmouth in 1807, and from the Military Academy in 1808. He had studied military engineering developments in France and this influence was evident in his reorganization of the curriculum and mode of instruction at West Point. He used texts employed at the École Polytechnique, divided classes into small sections, required weekly class reports, and developed a grading system. (George S. Emmerson, *Engineering Education: A Social History* [Crane, Russak & Company: New York, 1973], pp. 140–141).

While Thayer seemed to dislike the overly theoretical approach the French took to engineering education, his primary reason for not taking over more of the curriculum of the École Polytechnique seems to have been the relatively poor preparation of American students (and the desire, or necessity, not to make admission too difficult).

4. Though Partridge did now and then teach a course in civil engineering at West Point, he was not a civil engineer (and, apparently, was barely qualified to teach the course). Because he rejected most of the innovations introduced by his successor as superintendent, Sylvanius Thayer, the West Point Partridge tried to reproduce was the pre–1817 version (which may have much to do with the failure of Norwich to equal Thayer's West Point in either quality or quantity of engineers graduated). For more on this subject, see Thomas J. Fleming, *West Point: The Men and Times of the United States Military Academy* (William Morrow: New York, 1969) esp. pp. 3–14, 34.

5. Daniel Hovey Calhoun, *The American Civil Engineer: Origins and Conflict* (Technology Press [MIT]: Cambridge, Mass., 1960) p. 45. Compare James Gregory McGivern, *First Hundred Years of Engineering Education in the United States (1807–1907)* (Gonzaga University Press: Spokane, Washington, 1960) pp. 38, 42–45; and Emmerson, *Engineering Education*, 141–142. I have not found the corresponding figures for the number of military engineers (though, given that the Army does not seem to have been able to absorb all West Pointers, few Norwich graduates could have found work as military engineers during this period).

6. All the histories of engineering education cited here ignore both the Virginia Military Institute and the Citadel. Most also ignore both Annapolis and the impact of naval engineers on the development of mechanical engineering in the land-grant schools after the Civil War. For one who does not, see Monte A. Calvert, *The Mechanical Engineer in America, 1830–1910* (Johns Hopkins Press: Baltimore, 1967) esp. pp. 48–51. A surprising number of engineering schools were—like Texas A&M—virtually military academies until the 1960s. Such facts lead me to suspect that the relation between engineering and military education was, until quite recently, a lot closer than the histories of engineering education indicate. That relationship might explain much about the characteristic attitudes of American engineers in times past—and why some of these may be fading (for example, engineers' political conservativism).

7. McGivern, *First Hundred Years*, 50–51. See also Ray Palmer Baker, *A Chapter in American Education: Rensselear Polytechnic Institute, 1824–1924* (Charles Scribner's Sons: New York, 1924) pp. 48–56.

8. Baker, *American Education*, 35, 44–46. But about twenty-five of Rensselear's graduates from the period before 1840 eventually became engineers. Calhoun, *American Civil Engineer*, 45.

9.

> Though Eaton [the school's first director] had insisted that most colleges attempted to teach so many subjects that they could teach none of them well, and that Rensselaer should limit its activities primarily to the sciences, progress in them had been so rapid that Greene [the new director in 1847] concluded that it was again time [for the school] to narrow its field. (Baker, p.p. 39–40).

Note that engineering is here considered part of "the sciences."

10. Frederick B. Artz, *The Development of Technical Education in France, 1500–1850* (MIT Press: Cambridge, Mass., 1966) p. 267.

11. Emmerson states (without evidence) that Rensselear's new curriculum was modeled not on that of the École Polytechnique but on the École Centrale [d'Arts et Metiers] of Paris. Emmerson, 148, 153–156. McGivern says the same. See McGivern, 59. But neither tries to explain Rensselaer's "Polytechnic" (or what difference Greene would have seen between these institutions).

12. The British did, it is true, establish a school of military engineering at Woolwich in 1741. The school retained a number of notable applied mathematicians who wrote some elementary textbooks engineers found useful. Emmerson, *Engineering Educaton*, 33. Yet, unlike West Point, Woolwich seems to have had little influence on engineering generally, or on engineering education in particular, even in England, until the second half of the nineteenth century (if at all), that is, not until after talent replaced patronage as the primary means of gaining entry (and something like the French curriculum was adopted). Reader, *Professional Men*, 96–97. Compare Artz, *Technical Education*, 261.

13. W. H. G. Armytage, *Social History of Engineering* (Faber and Faber: London, 1961) pp. 160–161. Jonathan Williams, the first superintendent of West Point, observed in 1802: "To be merely an *Engineer* . . . is one thing, but to be an *Officieur du Génie* is another. I do not know how it happened but I cannot find any full English Idea to what the French give to the profession." Quoted in Peter Michael Molloy, *Technical Education and the Young Republic: West Point as America's École Polytechnique, 1802–1833* (unpublished dissertation, Brown University, June 1971) 241–242. The irony, of course, is that (as I explained in chapter 1) when the term "engineer" was brought into English, it was brought in to name people who had special skills similar to those that distinguished the French *officieur du génie* from the architects, millwrights, and the like that the English already had. Because the English (and Americans) were not yet able to copy the French method of educating engineers, "engineer" in English could not carry the same import as *officieur du génie*. Perhaps today, the term Williams so felt the need for would be "professional engineer" (or "degreed engineer"). Molloy is very good on American backwardness in understanding engineering. See, esp., pp. 425–463.

14. For a more or less complete listing of the dozen or so "engineers or quasi-engineers" available for public works in the United States before 1816, see Calhoun, *American Civil Engineer*, 7–23. Calhoun is also good on what in American ways of doing things made it hard for even these few to find employment.

15. McGivern, *First Hundred Years*, 15–23.

16. Charles F. O'Connell, Jr., "The Corps of Engineers and the Rise of Modern Management, 1827–1856," in *Military Enterprise and Technological Change*, edited by Merritt Roe Smith (MIT Press: Cambridge, Mass., 1985) pp. 95–96.

17. Merritt Roe Smith, "Army Ordnance and the 'American System' of Manufacturing, 1815–1861," in *Military Enterprise*, pp. 40–86.

18. James Kip Finch, *The Story of Engineering* (Doubleday: Garden City, N.Y., 1960) pp. 262–265. This Erie Canal school is, then, a throwback to the first days of the *corps du genie*. See chapter 1 (in this volume).

19. Finch, *Story*, 267–269.

20. Ibid, 268–269.

21. O'Connell, in *Military Enterprise*, 100–106. Note the initial resistence of the civilians to army-style standardization.

22. Smith, in *Military Enterprise*, 77–78. See also David A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Johns Hopkins University Press: Baltimore, 1984).

23. Edwin T. Layton, Jr., *The Revolt of the Engineers* (Case Western Reserve University Press: Cleveland, 1971) p. 3. The Census used the term "civil engineer." Layton believes that term would, at that time, probably have included mechanical engineers (and, indeed, all other nonmilitary engineers). My guess is that "civil engineer" probably excluded most engineers (or proto-engineers) in mining and manufacture, who did not call themselves engineers (and certainly would not have called themselves "civil engineers"). Note, for example, the fields listed for the Lawrence Scientific School at about this time. This disagreement with Layton is, nonetheless, probably a quibble. Before the Civil War, the number of these other engineers was probably small compared to the number of civils. Here, though, it would be good to have more information.

24. The phrase in quotes is Steve Goldman's. See "The Social Captivity of Engineering" in *Critical Perspectives on Nonacademic Science and Engineering*, edited by Paul Durbin (Lehigh University Press: Bethlehem, Pa., 1991) pp. 121–146. But the sentiment seems to be widespread. See, for example, David Noble, *America by Design* (Alfred A. Knopf: New York, 1977). Noble's nostalgia for the lost shop culture seems to confuse inventing in general, which, indeed, can exist in small, and even isolated, organizations, and engineering (which is a special kind of inventing: centralizing, standardizing, and so on), which probably cannot. The shop culture, however admirable, seems to lose out to engineering in certain environments—capitalist or not. (For example, engineers had much the same role in the Soviet Union as in the United States.) Noble contributes to our understanding of what might give engineering an advantage over shop culture (while giving that advantage a cast more sinister than necessary on the facts even as he presents them).

25. An ASCE was actually founded in 1852, its membership almost entirely in New York City. But, like other attempts at organizing engineers before the Civil War, that ASCE seems to have died out within a few years. The connection with the ASCE of 1867 is tenuous, another example of professions trying to add to their lineage. For a bit more on this, see Layton, *Revolt*, 28–29.

26. For some of this history, see also Bruce Sinclair, *A centennial History of the American Society of Mechanical Engineers, 1880–1980* (University of Toronto Press: Toronto, 1980); Terry S. Reynolds, *75 Years of Progress: A History of the American Institute of Chemical Engineers* (American Institute of Chemical Engineers: New York, 1983).

27. A. Michal McMahan, *The Making of a Profession: A Century of Electrical Engineering in America* (Institute of Electrical and Electronic Engineers: New York, 1984) chap. 11.

28. Perhaps the first branching came even earlier, with the split between artillery and military engineering. The roots of the two words—"engine" (from Latin *ingenium* for a natural ability or genius) and "artillery" (from Latin *ars* for skill or art)—suggests how close their relationship originally was.

29. James Kip Finch, *A History of the School of Engineering, Columbia University* (Columbia University Press: New York, 1954) pp. 65–66. This was also the time when the faculty of the school was renamed "the Faculty of Applied Science." French engineering seems to have grown from a single seed, but the American looks much more like three trees that grew into one (the French civil and military engineers, the German mining and metallurgical "engineers," and the American and perhaps English mechanical "engineers") branching even as they combined.

30. Layton, *Revolt*, 3.

31. Compare Billy Vaughn Koen, "Toward a Definition of the Engineering Method," *Engineering Education* 75 (December 1984): 150–155.

32. Vincenti is very good on this subject.

33. Consider, for example, the expression "rocket scientist." In fact, there are virtually no rocket scientists. Almost everyone associated with the design, development, testing, deployment, and operation of rockets is an engineer. Whatever success rocketry has

had is largely due to engineers. "Rocket scientists" should not be getting credit for any of it.

34. Engineers also have a tendency to claim successes for engineering whether or not the person responsible was in fact an engineer by training. It is this tendency that leads engineers to claim, for example, that the builder of an Egyptian pyramid or the inventor of the cotton gin was an engineer. There is, it seems to me, considerable unfairness in claiming the successes for engineering while (as generally happens) blaming the failures on others, for example, "managers," "tinkerers," "technicians," or "scientists." I have therefore tried to develop a more even-handed concept of engineering.

35. The only exception I know of is recent: in some "software engineering," where engineers (or other programmers) directly—on a computer—construct programs for computers. They do not write instructions for human beings (even in the indirect way engineers in research and development do) except insofar as they prepare the necessary documentation. Through their computer, software engineers actually give directions directly to "mechanical workers." Of course, as chapter 3 demonstrates, there are other reasons to wonder whether software engineering is engineering at all. For our purposes now, however, it is enough to point out that even these engineers, if that is what they are, must, while instructing machines, take into account the human environment in which the machines operate. Their technical knowledge, like that of most engineers, still includes much about how people and things work together.

36. Compare Calhoun, *American Civil Engineer*, 77: "The engineer role was specialized out of the executive role." Even an engineer working in research and development is engaged in developing instructions for production of some safe and useful physicial system—if she is working as an engineer—however many steps may stand between the original research and the final product. Koen's otherwise intelligent discussion of design seems to miss entirely the role of design as instruction to others.

37. Several professors of engineering have told me that this is now changing, that engineers are increasingly working in groups bringing together engineers from different fields. This may be, but my own interviews with working engineers did not reveal much integration, even in research. Here we have an empirical question about which it would be good to have more information. But, whatever turns up, I am sure that engineers will not for many years achieve the integration of fields commonplace in law offices or hospitals.

38. For example, the most scientific of the major engineering societies, the Institute of Electrical and Electronic Engineering (IEEE), is the only one to forget that it had a code of ethics (rediscovering it in the 1970s only after it had written a new one). For a bit more on this, see Michael Davis, "The Ethics Boom: What and Why," *Centennial Review* 34 (Spring 1990): 163–186, esp. pp. 173–174. The IEEE's recent efforts in ethics seem to signal an important change. But do they? It would be interesting to have a detailed analysis of what is really going on.

39. For example:

> Much time is wasted in our colleges and technical schools over higher mathematics. Every engineer will have to agree with me that the cases where the use of the higher calculus is indispensable are so few in our practice, that its study is not worth the time expended upon it, and we have the highest authority for saying unless its use is constantly kept up we become too rusty to use it at all. Unless the student possesses extraordinary genius for mathematics, I would limit its study to the ordinary analysis. (Thomas C. Clarke, "The Education of Civil Engineers," *Transactions of the American Society of Civil Engineers* 3 (1875): 557 [quoted in McGivern, *First Hundred Years*, 113]).

Because, even now, I hear practicing engineers make this point, I must wonder whether teaching calculus (two years of it at present) may not have more to do with shaping the mind (or "weeding out" a certain sort of mind) than with imparting the calculus itself. It is easy to imagine programs in which much of calculus is a technical elective and the remainder integrated (in practical form) into engineering science courses themselves. For a longer and more critical discussion of the calculus requirement (one rather hard on it) see Sally Hacker, *Doing it the Hard Way* (Unwin: Boston, 1990) pp. 139–154.

40. For an interesting discussion of this debate, though largely limited to mechanical engineering, see Calvert, *Mechanical Engineer*, 63–85.

41. Calhoun, *American Civil Engineer*, 45.

42. Ibid., 50–53.

43. The practical success of West Point is easy to underestimate. Consider, then, what was said by Francis Wayland, president of Brown University, 1827–1855. Near the end of his term, which included bringing engineering to Brown, he observed enviously that "the single academy at West Point, graduating annually a smaller number than many of our colleges, has done more toward the construction of railroads than all our one hundred and twenty colleges united." Quoted in McGivern, *First Hundred Years*, 91.

44. Ibid., 152–154.

45. Calvert, *Mechanical Engineer*, 203.

46. McMahan, *Making of a Profession*, 33–43.

47. Compare: "The Society would have been a small one and of limited influence had its membership been restricted to the type of consulting or creative engineer alone. The factory engineer is more and more a manager of men. . . . The engineer must be what he is often called, a businessman." Frederick R. Hutton (1907) Secretary of the American Society of Mechanical Engineers. Quoted in Layton, *Revolt*, 37.

48. Of course, some engineering societies, especially in their early years, admitted into membership persons who, though not school-trained, were "in responsible charge" of engineering work for a number of years. The criterion was, it should be noted, not simply "being in charge" but being in "responsible charge" for a certain length of time—long enough, presumably, for the person to show that he could do the job. And, even this criterion looks more like a political compromise than a natural definition.

49. Compare Layton, *Revolt*, esp. 58–60.

50. See, esp., ibid., 25–52. This vagueness may explain why (like the original ASCE) at least one twentieth-century engineering society, the short-lived American Association of Engineers, allowed architects to join. See Peter Meiksins, "Professionalism and Conflict: The Case of the American Association of Engineers," *Journal of Social History* 19 (Spring 1983): 403–421, esp. 406. The exclusion of rank-and-file workers may indicate a class bias, but I think it indicates more than that. Many people who called themselves engineers, for example, train drivers or scientific tinkerers, would have seemed ignorant of much engineers had in common, even engineers who came up through the ranks. What Layton in fact reports is, I think, part of the process by which "engineer" came to mean in English what it did in French (and what Williams understood by *officieur du génie*).

51. For a hilarious example of how too much emphasis on "science" can interfere with the practice of engineering, see Bruce Seely, "The Scientific Mystique in Engineering: Highway Research at the Bureau of Public Roads, 1918–1940," *Technology and Culture* 24 (October 1984): 798–831. Note also Edna Kranakis's description of the decline of French engineering during the nineteenth century, "Social Determinants of Engineering Practice: A Comparative View of France and America in the Nineteenth Century," *Social Studies of Science* 19 (February 1989): 5–70.

52. McGivern, *First Hundred Years*, 65. Note that engineering here means what we now call civil engineering. Though grouped with civil engineering, both what we call mining (and metallurgical) engineering and mechanical engineering are not conceived as engineering (properly so-called). Here is further evidence that we should be more cautious about thinking of engineering as "fragmenting" during the nineteenth century. As I would tell the story, higher education played a crucial part in giving engineering a unity it did not originally have in the United States (and might never have achieved otherwise). In this regard, it is worth noting that early civil engineers seem generally to have failed at both mechanical engineering and mining. Calhoun, *American Civil Engineer*, 82–87.

53. McGivern, *First Hundred Years*, 64–69.

54. Ibid., 79–82. Compare the history of the École Polytechnique after 1804.

55. See Bruce Seely, "Research, Engineering, and Science in American Engineering Colleges: 1900–1960," *Technology and Culture* 34 (April 1993): 344–386); and Lawrence P. Grayson, "A Brief History of Engineering Education in the United States," *Engineering Education* 68 (December 1977): 246–264, esp. 257–261.

56. Engineers were, of course, aware quite early that engineering had a creative aspect. But other aspects of engineering, especially the drudgery of drafting and calculating, may have meant that few engineers actually got to be "creative." If so, then computers may have shifted dramatically the balance between drudgery and creativity; that shift may, in turn, partially explain the current emphasis on design. But what explains the decline of "shop training"? (Even would-be employers do not seem to want engineering schools to prepare students for the shop floor.) Has engineering changed in some fundamental way in this century (or has industry)?

57. For more, see chapter 10 (in this volume).

58. This is quite clear in, for example, Walter G. Vincenti, *What Engineers Know and How They Know It* (Johns Hopkins University Press: Baltimore, 1990).

59. For others who have noted the sad state of our understanding of engineering, see James K. Feibleman, "Pure Science, Applied Science, Technology, Engineering: An Attempt at Definitions," *Technology and Culture* 2 (Fall 1961): 305–317: M. Asimov, "A Philosophy of Engineering Design," in Friedrich Rapp, ed., *Contributions to a Philosophy of Technology* (Reidel: Dordrecht, Holland, 1974) pp. 150–157; George Sinclair, "A Call for a Philosophy of Engineering," *Technology and Culture* 18 (October 1977): 685–689; Taft H. Broome, Jr. "Engineering the Philosophy of Science," *Metaphilosophy* 16 (January 1985): 47–56; Paul T. Durbin, "Toward a Philosophy of Engineering and Science in R & D Settings," in Paul Durbin,ed., *Technology and Responsibility* (Reidel: Dordrecht-Holland, 1987) pp. 309–327.

60. This is, of course, not intended as a definition of "profession" but merely as a sketch of one, one adequate for our purposes now. For more of what I mean by "profession," see chapters 4 and 10, and some of my other works on the subject: "The Moral Authority of a Professional Code," *NOMOS* 29 (1987): 302–337; "The Use of Professions," *Business Economics* 22 (October 1987): 5–10; "Vocational Teachers, Confidentiality, and Professional Ethics," *International Journal of Applied Philosophy* 4 (Spring 1988): 11–20; "Professionalism Means Putting Your Profession First," *Georgetown Journal of Legal Ethics* (Summer 1988): 352–366; "Do Cops Really Need a Code of Ethics," *Criminal Justice Ethics* 10 (Summer/Fall 1991): 14–28; "Science: After Such Knowledge, What Responsibility?," *Professional Ethics* 4 (Spring 1995): 49–74.

61. Quoted in McGivern, *First Hundred Years*, 106. At the same place, he offers similar examples from the American Institute of Mining (1873) and the American Society of Mechanical Engineers (1880).

62. Grayson, "Brief History," 254.

63. Ibid., 258. Today that organization is the Accreditation Board of Engineering and Technology (ABET).

64. This claim will seem controversial only to those, mostly sociologists and those who defer to them, who wish to equate "profession" with "skilled occupation" (or with "licensed skilled occupation"). There are at least two reasons to reject this equation. First, members of a profession are usually at pains to claim that they belong to a profession, not just a skilled occupation. The equation makes their claim false by definition, leaving the question why anyone would say such a thing. Second, as we shall see, ethical standards do seem to give considerable insight into talk about "profession."

65. For more on this, see Michael Davis, "The Ethics Boom."

66. For a good (if somewhat jaundiced) account of this period, with its effects both on industry and engineering, see Noble, *American by Design*.

67. The electrical engineers seem to have had the greatest difficulty here (an eight-year process). See McMahan, *Making of a Profession*, 112–117.

68. For an enlightening discussion of the ways people change, see Mortimer R. Kadish, *The Ophelia Paradox: An Inquiry into the Conduct of Our Lives* (Transaction: New Brunswick, N.J., 1994).

Chapter 3

I should like to thank Helen Nissenbaum, Ilene Burnstein, and Vivian Weil for helpful comments on my first draft of this chapter. A short version appeared as "Defining Engineering: How to Do It and Why It Matters," *Journal of Engineering Education* 85 (April 1996): 97–101; a full version (under the present title and, despite the date, a year later) appeared in *Philosophy and the History of Science: A Taiwanese Journal* 4 (October 1995): 1–24. Reprinted by permission.

1. Gary A. Ford and James E. Tomayko, "Education and Curricula in Software Engineering," *Encyclopedia of Software Engineering*, vol. 1 (John Wiley & Sons: New York, 1994) p. 439.

2. "In the 1991 Computer Society [of the Institute for Electrical and Electronic Engineers] membership survey, over half (54 percent) of the current full members polled indicated that they consider themselves software engineers, as did 40 percent of the affiliate members." Fletcher J. Buckley, "Defining software engineering," *Computer* 2 (August 1993): 77.

3. There are no hard numbers for software engineers (though I have heard estimates as high as three million worldwide). The claims made here merely constitute my compilation of the opinions of those who seemed to have the best chance of being right.

4. See, for example, Mary Shaw, "Prospects for an Engineering Discipline of Software," *IEEE Software* (November 1990): 15–24. Though she begins this intelligent article with a definition of engineering and devotes much of its body to the history of engineering, her topic is really the growth of disciplines generally. She could have written much the same article, using law, medicine, or even auditing, rather than engineering, as the paradigm of a discipline—with more clarity about what she was doing.

5. This definition, the work of the National Research Council's Committee on the Education and Utilization of the Engineer, appears in Samuel Florman, *The Civilized Engineer* (St. Martin Press: New York, 1987) pp. 64–65.

6. Compare the more elegant Canadian definition:

> The "practice of professional engineering" means any act of planning, designing, composing, evaluating, advising, reporting, directing or supervising, or managing any of

> the foregoing that requires the application of *engineering* principles, and that concerns the safeguarding of life, health, property, economic interests, the public welfare or the environment. (Emphasis added)

Canadian Engineering Qualifications Board, *1993 Annual Report* (Canadian Council of Professional Engineers: Ottawa, 1993) p. 17. The report contains no definition of engineering principles.

7. Similar problems arise for "genetic engineer" and might arise for other "engineers," for example, "social engineers." (This problem of definition is, of course, not limited to engineers: lawyers are no more successful defining the practice of law or doctors the practice of medicine.)

8. The IEEE defines software engineering as "application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software: that is, the application of engineering to software." Buckley, "Defining Software Engineering," 77. This definition (or, rather, that "that is") begs the question whether the systematic, disciplined, and quantifiable approach in question is an application of engineering to software or the application of a different discipline. Not all systematic, disciplined, and quantifiable approaches to development, operation, and maintenance are necessarily engineering. Indeed, that software is primarily not a physical but a mathematical (or linguistic) system at least suggests that engineering principles have only limited application.

9. Florman, *The Civilized Engineer*, 65–66.

10. I charitably ignored the "or" in "mathematics and/or the natural sciences." There never was a time that the training of engineers did not include a good deal of both mathematics and the physical sciences (at least chemistry and physics). If software engineers do not generally have similar training in the physical sciences, no amount of training in mathematics will fill the gap between them and the great body of engineers strictly so called.

11. It is perhaps worth noting that engineers do in fact produce beautiful objects, for example, the Brooklyn Bridge or the typical computer's circuit board. Nonetheless, engineers are not artists in the way architects are. For engineering, beauty is not a major factor in evaluating work; utility is.

12. Compare Fletcher J. Buckley, "Background to the Motion [to have the IEEE CS Board of Governors appoint an ad hoc committee to initiate the actions to establish software engineering as a profession] (April 15, 1993)":

> In 483 B.C., Xerxes, King of Persia and Media, as part of his campaign to conquer Greece, ordered two floating bridges to be constructed across the Hellespont to provide passage for his army from Asia to Europe. After the bridges were completed, a storm arose and the bridges were destroyed. Xerxes had the engineers killed and another set of bridges constructed, thus demonstrating at that time, the existence of standards of personal accountability for professionals working in their field of competence.

This passage—like its twin in Buckley, "Defining software engineering," 76—is remarkable for its misunderstanding of both engineering and professions. Buckley has, of course, no reason to call the builders of Xerxes bridge engineers rather than bridge builders, no reason even to describe them as professionals rather than skilled men. He certainly overlooks whether the bridge's failure was due to incompetence or to forces beyond any builder's competence to manage at the time. Like a similar story about having the sea flogged, this one seems to be more about the arbitrariness of Persian rulers than about the standard of accountability to which anyone would want to be held. Its place in a motion concerned with organizing software engineering as a "profession" is therefore (at best) inauspicious.

13. Compare, for example, the Roeblings, father and son, both engineers (by today's standard definition) with the millwrights, industrialists, and other contemporary bridge builders most of whom would today not be allowed to design or build bridges. Were these other "technologists," self-taught and relatively slapdash, as much engineers as the Roeblings because much of what they built worked?

14. Consider, for example, L. A. Belady, in "Foreword," *Encyclopedia of Software Engineering*, p. xi: "[The] term software engineering expresses the continued effort to put programming into the ranks of other engineering disciplines."

15. Engineers, especially civil engineers, like to count the Roman builders among their profession. When asked why, they usually point out how enduring the Roman roads, aqueducts, theaters, and other constructions proved to be. This answer seems to me to offer evidence *against* their thesis as if it were evidence for it. Engineers are fond of the saying, "An engineer is someone who can do for one dollar what any fool can do for ten"—or, as ABET put it more prosaically, "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, *economically*, the materials and forces of nature for the benefit of mankind." That the Roman builders built so much that outlasted their empire by more than a thousand years at least suggests that they spent where an engineer would have saved. When we recall that none of Rome's great builders made a career of building but instead, oversaw public works one year and a province's government the next, we must conclude that though great builders, they could never qualify for admission to an engineering society at the "professional level." They may have "functioned as engineers" (however anachronistically), but they were not members of the profession (or even employed in the underlying occupation).

16. For a spirited defense of this mistake, see John T. Sanders, "Honor Among Thieves: Some Reflections on Professional Codes of Ethics," *Professional Ethics* 2 (Fall/Winter 1993): 83–103. If the article's title does not show what is wrong with equating competence with profession, the article's suggestion that we consider the *mafia* to be a profession should.

17. Note that Florman, generally so astute about engineering, endorses this equation of conscientiousness with ethicalness. Florman, *The Civilized Engineer*, 104.

18. Are either of these provisions, or any other, unique to engineering, an expression of its essential nature? I know of none. A particular professional code seems to me to involve a distinctive reworking of general moral ideals to fit certain conditions and aspirations, distinctive but not necessarily unique.

19. In the United States, the codes date from the second decade of this century. In Great Britain, they came almost a half century earlier. The counterpart for these codes didn't appear on the continent of Europe, or in other civil law jurisdictions, until well after World War II. Why?

20. For more details, see Lawrence P. Grayson, "A Brief History of Engineering Education in the United States," *Engineering Education* 68 (December 1977): 246–264.

21. See chapter 4 (in this volume) for a defense of this response. Meanwhile, note that the IEEE's code of ethics applies only to "IEEE members." It is a code of ethics for members of a technical society, not—like the codes of ABET or the National Society of Professional Engineers (NSPE) code—the code of a profession. Indeed, I would attribute its shortening over the years to the attempt to cover a membership in which the proportion of engineers is declining and both the number and kinds of nonengineers are increasing. Generally, codes of ethics grow with experience; shrinkage is therefore a sign of trouble.

22. Shaw, "Prospects," 22.

23. Michael S. Mahoney, "The Roots of Software Engineering," *CWI Quarterly* 3 (December 1990): 325–334, at 326.

24. Ibid., 327.

25. For example, some practicing engineers, until recently, encouraged schools of engineering to reduce the academic requirements for a degree in favor of more "shop experience." Yet, attempts to take the shop-experience approach very far seem to produce foremen rather than engineers. Apparently, the very abstractness for which the practitioners criticized engineering education contributed to success as engineers even when (as the practitioners correctly noted) the specific skills taught (for example, advanced calculus) generally went unused. Why?

26. Some electrical engineering departments offer degrees of this description, for example, in "computer engineering, software option."

27. There is, of course, more than one code of ethics for U.S. engineers. This may suggest that engineering in the United States is not one profession but several. That suggestion should not be embraced. Of the three major codes usually mentioned on such occasions, the IEEE code is not a professional code at all; it applies not to engineers (as a professional code should) but to IEEE members (whether engineers or not). Because it also contains nothing more demanding than the other codes and nothing inconsistent with them, we may ignore it here. The other two major codes do apply to engineers as such, differing only in detail (with the NSPE code generally being somewhat less demanding). Because the NSPE seems to have developed its code with state enforcement in mind, I think it reasonable to treat the ABET code as the basic professional code (especially because most engineering societies endorse it). So, when I speak of the engineer's code here, it is the ABET code that I intend.

28. See, for example, John D. Musa, "Software Engineering: The Future of a Profession," *IEEE Software* (January 1985): 55–62. Musa presents software engineering as a profession independent of engineering (though his use of the term engineering suggests the opposite).

29. Compare Shaw, "Prospects," 21:

> Unfortunately, [the term "software engineering"] is now most often used to refer to life-cycle models, routine methodologies, cost-estimation techniques, documentation frameworks . . . and other techniques for standardizing production. These technologies are characteristic of the commercial stage of evolution—'software management' would be a much more appropriate term.

Chapter 4

This chapter began as the first third of *Engineering Codes of Ethics: Analysis and Applications*, a "module" prepared with Heinz Luegenbiehl in 1986 for a series published by IIT's Center for the Study of Ethics in the Professions under a grant from the Exxon Education Foundation (the same series in which chapter 7 appeared). Though this module was never published, a shorter and substantially different version appeared as "Thinking Like an Engineer: The Place of a Code of Ethics in the Practice of a Profession," *Philosophy and Public Affairs* 20 (Spring 1991): 150–167. Reprinted by permission. I should like to thank the series' Advisory Panel, Heinz Luegenbiehl, the editors of *Philosophy and Public Affairs*, and those who listened patiently to one version or another for much useful advice.

1. David E. Sanger, "How Seeing-No-Evil Doomed the Challenger," *New York Times*, June 29, 1986, sec. 3, p. 8.

2. *The Presidential Commission on the Space Shuttle Challenger Disaster* (U.S. Government Printing Office: Washington, D.C, 1986). v. I, p. 94. The preceding narrative is based on testimony contained in that volume (esp. pp. 82–103).

3. William H. Wisely, "The Influence of Engineering Societies on Professionals and Ethics" in *Ethics, Professionals, and Maintaining Competence: ASCE Professional Activities Committee Specialty Conference, Ohio State University, Columbus, Ohio, 1977* (American Society of Civil Engineers: New York), 1977, pp. 55–56.

4. See, for example, A. G. Christie, "A Proposed Code of Ethics for All Engineers," *Annals of American Society of Political and Social Science* 101 (May 1922): 99–100.

5. What is the origin of the term "bench engineer"? I have encountered two guesses. One attributes the term to a bitter analogy with galley slaves, who rowed their life away chained to a bench. The other guess involves a more pleasing analogy with scientists, especially physicists and chemists, who worked at "benches" with their lab equipment around them. For scientists, a "bench scientist" is a real scientist; those scientists who devote themselves to supervision, to meetings, and so on are no longer doing science but administration. Neither of these analogies is appropriate for engineering. On the one hand, except for draftsmen (who did work side by side in large rooms, seldom leaving the drafting board) few engineers seem to spend even a majority of their day in one place. They have technicians to supervise, "fires to put out," and meetings to go to. Both movement and administration are more central to engineering than to science.

6. William H. Wisely, "The Influence of Engineering Societies on Profesionalism and Ethics" in *Engineering Professionalism and Ethics* (Robert E. Kreiger: Malabar, Fl. 1983) p. 33.

7. Andrew G. Oldenquist and Edward E. Slowter, "Proposed: A Single Code of Ethics for All Engineers," *Professional Engineer* 49 (May 1979): 8–11.

8. Note, for example, the quotation from A. G. Christie at the beginning of this chapter; or Morris Llewellyn Cooke, "Ethics and the Engineering Profession," *Annals of the Association for Political and Social Science* 101 (May 1922): 68–72, esp. 70.

9. See, for example, W. J. Reader, *Professional Men: The Rise of the Professional Classes in Nineteenth-Century England* (Basic Books: New York, 1966) esp. pp. 51–55.

10. Recall Thredgeld's famous definition (cited in chapter 1): "[The] profession of civil engineer [is] the art of directing the great sources of power in nature for the use and convenience of man."

11. For further defense of this theory of profession, see Michael Davis, "The Moral Authority of a Professional Code," *NOMOS* 29 (1987): 302–337; "The Use of Professions," *Business Economics* 22 (October 1987): 5–10; "Vocational Teachers, Confidentiality, and Professional Ethics," *International Journal of Applied Philosophy* 4 (Spring 1988): 11–20; "Professionalism Means Putting Your Profession First," *Georgetown Journal of Legal Ethics* 2 (Summer 1988): 352–366; "Do Cops Really Need a Code of Ethics," *Criminal Justice Ethics* 10 (Summer/Fall 1991): 14–28; "Science: After Such Knowledge, What Responsibility?," *Professional Ethics* 4 (Spring 1995): 49–74; and "The State's Dr. Death: What's Unethical about Physicians Helping at Executions?" *Social Theory and Practice* 21 (Spring 1995): 31–60.

12. Compare Michael Davis, "The Special Role of Professionals in Business Ethics," *Business and Professional Ethics Journal* 7 (1988): 83–94.

13. Devotees of decision theory will instantly recognize the convention in question as the solution to the coordination problem commonly known as the prisoner's dilemma. I avoid the term here because it seems wholly out of place when there are no prisoners and when the choice posed is far better than a dilemma. Like many other technical terms of decision theory, "prisoner's dilemma" seems more likely to mislead those not familiar with it than to grant insight.

14. I hope this appeal to fairness raises no red flags, even though the principle of fairness has been under a cloud ever since the seemingly devastating criticism it received in Robert Nozick, *Anarchy, State, and Utopia* (Basic Books: New York, 1974). I limit my use to obligations generated by *voluntarily* claiming benefits of a cooperative practice that are otherwise not available. Most attacks on the principle of fairness are on the "involuntary benefits" version. See, for example, A. John Simmons, *Moral Principles and Political Obligations* (Prince-

Bibliography

Agich, George J. "Rationing Professional Autonomy," *Law, Medicine and Health Care* 18 (Spring–Summer 1990): 77–84.

Airaksinen, Timo. "Service and Science in Professional Life" in *Ethics and the Professions*, ed. Ruth F. Chadwick (Avebury: Aldershot, England, 1994), 1–13.

Alie, Raymond E. "Professionalization in a Rationally Managed Corporate Organization," *Journal of Management* 8 (1982): 65–81.

Alpern, Ken. "Moral Responsibility for Engineers," *Business and Professional Ethics Journal* 2 (Winter 1983): 39–48.

American Society of Mechanical Engineers v. Hydrolevel Corporation 456 U.S. 556 (1982).

Arendt, Hannah. *The Human Condition* (Doubleday: Garden City, N.Y., 1959).

Arenson, Richard. "The Principle of Fairness and Free-Rider Problems," *Ethics* 92 (July 1982): 616–633.

Argyris, Chris, and Donald Schön. "Reciprocal Integrity: Creating Conditions That Encourage Personal and Organizational Integrity" in *Executive Integrity*, ed. Suresh Srivastva et al. (Jossey-Bass: San Francisco, 1988), pp. 197–222.

Armytage, W. H. G. *A Social History of Engineering* (Faber and Faber: London, 1961).

Artz, Frederick B. *The Development of Technical Education in France, 1500–1850* (MIT Press: Cambridge, Mass., 1966).

Asimov, M. "A Philosophy of Engineering Design" in *Contributions to a Philosophy of Technology*, ed. Friedrich Rapp (Reidel: Dortrecht-Holland, 1974), pp. 150–157.

Baker, Ray Palmer. *A Chapter in American Education: Rensselear Polytechnic Institute, 1824–1924* (Charles Scribner's Sons: New York, 1924).

Barnes, Chester A. *The Functions of the Executive* (Cambridge, Mass.: Harvard University Press, 1938).

Bayles, Michael. "Against Professional Autonomy," *National Forum* 58 (Summer 1978), 23–26.

———. *Professional Ethics* (Wadsworth: Belmont, Cal., 1981), pp. 133–138.

Beardsley, Charles W. "The *Hydrolevel* Case—A Retrospective," *Mechanical Engineering* 106 (June 1984): 66–73.

Bell, Trudy E. "The Fatal Flaw in Flight 51-L," *IEEE Spectrum* (February 1987): 36–51.

Bella, David A. "Organizations and Systematic Distortion of Information," *Journal of Professional Issues in Engineering* 113 (October 1987): 360–370.

Benn, Stanley I. *A Theory of Freedom* (Cambridge: Cambridge University Press, 1988).

Brady, Gene F., Ben B. Judd, and Setrak Javian. "The Dimensionality of Work Autonomy Revisited," *Human Relations* 43 (1990): 1219–1228.

Broome, Taft H., Jr. "Engineering the Philosophy of Science," *Metaphilosophy* 16 (January 1985): 47–56.

Buckley, Fletcher J. "Defining Software Engineering as a Profession," *Computer* 26 (August 1993): p. 76–78.

Burghardt, M. David. *Introduction to the Engineering Profession* (HarperCollins: New York, 1985).

Burke, John G. et al. *Connections: Technology and Change* (Boyd and Fraser: San Francisco, 1979).

Burns, Tom and G. M. Stalker. *The Management of Innovation* (Tavistock: London, 1966).

Calhoun, Daniel Hovey. *The American Civil Engineer: Origins and Conflict* (Technology Press-MIT: Cambridge, Mass., 1960).

Calvert, Monte A. *The Mechanical Engineer in America, 1830–1910* (Johns Hopkins University Press: Baltimore, 1967).

Camenisch, Paul F. *Grounding Professional Ethics in a Pluralistic Society* (Haven: New York, 1983), pp. 29–3

Canadian Engineering Qualifications Board, *1993 Annual Report* (Canadian Council of Professional Engineers: Ottawa, 1993).

Chalk, Rosemary. "Making the World Safe for Whistleblowers," *Technology Review* 91 (January 1988): 48–57.

Child, John, and Janet Fulk. "Maintenance of Occupational Control: The Case of Professions," *Work and Occupations* 9 (May 1982): 155–192.

Christie, A. G. "A Proposed Code of Ethics for All Engineers," *Annals of American Academy of Political and Social Science* 101 (May 1922), pp. 97–104.

Christman, John. ed. *The Inner Citadel* (Oxford University Press: New York, 1989).

Cooke, Morris Llewellyn. "Ethics and the Engineering Profession," *Annals of the American Academy for Political and Social Science* 101 (May 1922): 68–72.

Crime in the United States (Federal Bureau of Investigation, U.S. Department of Justice: Washington, D.C., 1980).

Daniels, Arlene Kaplan. "How Free Should Professions Be?" in *The Professions and Their Prospects*, ed. Eliot Freidson (Sage: Beverly Hills, Cal., 1971.

Davis, Michael. "Avoiding the Voter's Paradox Democratically," *Theory and Decision* 5 (October 1974): 295–311.

———. "Brandt on Autonomy" in *Rationality and Rule-Utilitarianism*, ed. Brad Hooker (Westview Press: Boulder, Colo., 1993), pp. 51–65.

———. "Conflict of Interest," *Business and Professional Ethics Journal* 1 (Summer 1982): 17–27

———. "Conflict of Interest Revisited," *Business and Professional Ethics Journal* 12 (Winter 1993): 21–41.

———. "Do Cops Really Need a Code of Ethics," *Criminal Justice Ethics* 10 (Summer/Fall 1991): 14–28.

———. "The Ethics Boom: What and Why," *Centennial Review* 34 (Spring 1990): 163–186.

———. "The Moral Authority of a Professional Code," *NOMOS* 29 (1987): 302–337.

———. "The Moral Legislature: Morality without an Archimedean Point," *Ethics* 102 (July 1992): 303–318.

———. "Nozick's Argument *for* the Legitimacy of the Welfare State," *Ethics* 97 (April 1987): 576–594.

———. *One Social Responsibility of Engineering Societies: Teaching Managers About Engineering Ethics*, Monograph #88-WA/DE-14 (American Society of Mechanical Engineers: New York, 1988).

———. "Professionalism Means Putting Your Profession First," *Georgetown Journal of Legal Ethics* (Summer 1988): 352–366

———. "Science: After Such Knowledge, What Responsibility?," *Professional Ethics* 4 (Spring 1995): 49–74.

———. "Some Paradoxes of Whistleblowing," *Business and Professional Ethics Journal* 15 (Spring 1996): 3–19.

———. "The Special Role of Professionals in Business Ethics," *Business and Professional Ethics Journal* 7 (1988): 83–94.

———. "The State's Dr. Death: What's Unethical about Physicians Helping at Executions?," *Social Theory and Practice* 21 (Spring 1995): 31–60.

———. "Technical Decisions: Time to Rethink the Engineer's Responsibilities?," *Business and Professional Ethics Journal* 11 (Fall-Winter 1992): 41–55.

———. "Thinking like an Engineer: The Place of a Code of Ethics in the Practice of a Profession," *Philosophy and Public Affairs* 20 (Spring 1991): 150–167.

———. "The Use of Professions," *Business Economics* 22 (October 1987): 5–10.

———. "Vocational Teachers, Confidentiality, and Professional Ethics," *International Journal of Applied Philosophy* 4 (Spring 1988): 11–20

———. "Who Can Teach Workplace Ethics?," *Teaching Philosophy* 13 (March 1990): 21–36.

DeGeorge, Richard. "Ethical Responsibilities of Engineers in large Organizations," *Business and Professional Ethics Journal* 1 (1981): 1–14.

Devine, Thomas M., and Donald G. Aplin. "Whistleblower Protection—The Gap between the Law and Reality," *Howard Law Journal* 31 (1988): 223–239

Durbin, Paul T. "Toward a Philosophy of Engineering and Science in R and D Settings," in *Technology and Responsibility*, ed. Paul Durbin (Reidel: Dordrecht, Holland, 1987), pp. 309–327.

———. ed. *Critical Perspectives on Nonacademic Science and Engineering* (Lehigh University Press: Bethlehem, Pa., 1991).

Dworkin, Gerald. "Concept of Autonomy" in *Science and Ethics*, ed. Rudolph Haller (Amsterdam: Rodopi Press, 1981), pp. 203–213.

———. *The Theory and Practice of Autonomy* (Cambridge University Press: New York, 1988).

Elliston, Frederick, et al. *Whistleblowing Research: Methodological and Moral Issues* (Praeger: New York, 1985).

Elster, Jan. *Ulysses and the Sirens*, rev. ed. (Cambridge University Press: New York, 1984).

Emmerson, George S. *Engineering Education: A Social History* (Crane, Russak and Company: New York, 1973), pp. 140–141.

Farh, Jiing-Lih, and W. E. Scott, Jr. "The Experimental Effects of 'Autonomy' on Performance and Self-Reports of Satisfaction," *Organizational Behavior and Human Performance* 31 (1983): 203–222.

Feibleman, James K. "Pure Science, Applied Science, Technology, Engineering: An Attempt at Definitions," *Technology and Culture* 2 (Fall 1961): 305–317.

Feldman, Steven P. "The Broken Wheel: The Inseparability of Autonomy and Control in Innovation within Organizations," *Journal of Management Studies* 26 (March 1989): 83–102.

Feynman, Richard. "An Outsider's Inside View of the Challenger Inquiry," *Physics Today* (February 1988): 26–37.

Finch, James Kip. *The Story of Engineering* (Doubleday: Garden City, N.Y., 1960).

———. *A History of the School of Engineering, Columbia University* (Columbia University Press: New York, 1954).

Fleming, Thomas J. *West Point: The Men and Times of the United States Military Academy* (William Morrow: New York, 1969).

Florman, Samuel. *The Civilized Engineer* (St. Martin Press: New York, 1987).

———. *The Existential Pleasures of Engineering* (St. Martin's Press: New York, 1976).

Ford, Gary A., and James E. Tomaykoo *Encyclopedia of Software Engineering* (John Wiley and Sons: New York, 1994).

Forsyth, Patrick B., and Thomas J. Danisiewicz. "Toward a Theory of Professionalization," *Work and Occupation* 12 (February 1985): 59–76.

Frankfurt, Harry G. "Freedom of the Will and the Concept of a Person," *Journal of Philosophy* 68 (January 1971): 5–20.

Freedman, Benjamin. "A Meta-Ethics of Professional Morality" in *Moral Responsibility and the Professions*, ed. Bernard Baumrin and Benjamin Freedman (Haven: New York, 1983), pp. 61–79.

Gellerman, Saul W. "Why 'Good' Managers Make Bad Ethical Choices," *Harvard Business Review* 64 (July-August 1986): 85–90.

Gert, Bernard. *Morality: A New Justification of the Moral Rules* (Oxford University Press: New York, 1988).

Gewirth, Alan. "Professional Ethics: The Separatist Thesis," *Ethics* 96 (1986): 282–300.

Glazer, Myron Peretz, and Penina Migdal Glazer. *The Whistleblowers: Exposing Corruption in Government and Industry* (Basic Books: New York, 1989).

Goldman, Alan H. *The Moral Foundations of Professional Ethics* (Rowman and Littlefield:, Totawa, N.J., 1980).

Gordon, Bruce F., and Ian C. Ross. "Professionals and the Corporation," *Research Management* 5 (November 1962): 493–505.

Gorlin, Rena A. ed. *Codes of Professional Responsibility* (Bureau of National Affairs: Washington, D.C., 1986).

Grayson, Lawrence P. "The American Revolution and the 'Want of Engineers,' " *Engineering Education* 75 (February 1985): 268–276.

———. "A Brief History of Engineering Education in the United States," *Engineering Education* 68 (December 1977): 246–264.

Hacker, Barton. "Engineering a New Order: Military Institutions, Technical Education, and the Rise of the Industrial State," *Technology and Culture* 34 (April 1993): 1–27.

Hacker, Sally. *Doing It the Hard Way* (Unwin: Boston, 1990).

Harris, Charles, Michael Pritchard, and Michael Rabins. *Engineering Ethics: Concepts and Cases* (Wadsworth: Belmont, Mass., 1995).

Harris, Nigel G. E. "Professional Codes and Kantian Duties" in *Ethics and the Professions*, ed. Ruth F. Chadwick (Avebury: Aldershot, England, 1994), pp. 104–115.

Heacock, Marian V., and Gail W. McGee. "Whistleblowing: An Ethical Issue in Organizational and Human Behavior," *Business and Professional Ethics Journal* 6 (Winter 1987): 35–46.

Henderson, Harold. "*McGregor v. the NRC*: Why Did the Nuclear Regulatory Commission Fire One of Its Toughest Plant Inspectors?," *Reader* (Chicago), July 22, 1988, pp. 1ff.

Henderson, Kathryn. "Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering," *Science, Technology, and Human Values* 16 (Autumn 1991): 448–473.

Herbert, Theodore T., and Ralph W. Estes. "Improving Executive Decisions by Formalizing Dissent: The Corporate Devil's Advocate," *Academy of Management Review* 2 (October 1977): 662–667.

Hill, Donald. *A History of Engineering in Classical and Medieval Times* (Croom Helm: London, 1984).

Hollis, Bruce W. "I Turned in My Mentor," *The Scientist* 1 (December 14, 1987): 1–13.

Hounshell, David A. *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Johns Hopkins University Press: Baltimore, 1984).

Jackall, Robert. *Moral Mazes: The World of Corporate Managers* (Oxford University Press: New York, 1988.

Kadish, Mortimer R. *The Ophelia Paradox: An Inquiry into the Conduct of Our Lives* (Transaction: New Brunswick, N.J., 1994).

Kanigel, Robert. "The Endangered Professional," *Johns Hopkins Magazine* 40 (June 1988): 17–43.

Kant, Immanuel. *Foundations of the Metaphysics of Morals,* 2d. ed. Lewis White Beck (Macmillan/Library of the Liberal Arts: New York, 1990).

Katz, Jack. *Seductions of Crime: Moral and Sensual Attractions of Doing Evil* (Basic Books: New York, 1988).

Kidder, Tracy. *The Soul of a New Machine* (Little Brown: Boston, 1981).

Kipnis, Kenneth. "Professional Responsibility and the Responsibility of Professions" in *Profits and Professions: Essays in Business and Professional Ethics*, ed. Wade L. Robinson, Michael Pritchard, and Joseph Ellin (Humana Press: Clifton, N.J., 1983), pp. 9–22.

Klaw, Spencer. "The Faustian Bargain" in *The Social Responsibility of the Scientist*, ed. Martin Brown (Free Press: New York, 1971).

Koen, Billy Vaughn. *Definition of the Engineering Method* (American Society of Engineering Education: Washington, D.C., 1991).

———. "Toward a Definition of the Engineering Method," *Engineering Education* 75 (December 1984): 150–155.

Kohlberg, Lawrence. *Essays on Moral Development* (Harper and Row: San Francisco, 1981).

Kranakis, Edna. "Social Determinants of Engineering Practice: A Comparative View of France and America in the Nineteenth Century," *Social Studies of Science* 19 (February 1989): 5–70.

Kultgen, John. *Ethics and Professionalism* (University of Pennsylvania Press: Philadelphia, 1988), pp. 274–306.

Kurtines, William M., and Jacob L. Gewirtz. ed., *Morality, Moral Behavior, and Moral Development* (John Wiley & Sons: New York: 1984).

Ladd, John. "Collective and Individual Moral Responsibility in Engineering: Some Questions" in *Beyond Whistleblowing: Defining Engineers' Responsibilities*, ed. Vivian Weil (Center for the Study of Ethics in the Professions, Illinois Institute of Technology: Chicago, 1983), pp. 102–103.

Larson, Magali Sarfatti. *The Rise of Professionalism* (University of California Press: Berkeley, 1977).

Layton, Edwin. *The Revolt of the Engineers* (Case Western Reserve University Press: Cleveland, 1971).

Luegenbiehl, Heinz C. "Code of Ethics and the Moral Education of Engineers," *Business and Professional Ethics Journal* 2 (Summer 1983): 41–61.

———. "Computer Professionals: Moral Autonomy and a Code of Ethics," *Journal of Systems Software* 17 (1992): 61–68.

Lyons, David. *Forms and Limits of Utilitarianism* (Oxford: Oxford University Press, 1965).

Mackenzie, Donald. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (MIT Press: Cambridge, Mass., 1990).

Mahoney, Michael S. "The Roots of Software Engineering," *CWI Quarterly* 3 (December 1990): 325–334.

Malin, Martin H. "Protecting the Whistleblower from Retaliatory Discharge," *Journal of Law Reform* 16 (Winter 1983): 277–318.

Matthews, M. Cash. "Ethical Dilemmas and the Disputing Process: Organizations and Societies," *Business and Professional Ethics Journal* 8 (Spring 1989): 1–11.

Marcus, Afred A. "Professional Autonomy as a Basis of Conflict in an Organization," *Human Resource Management* 24 (Fall 1985): 311–328.

Martin, Mike W. "Professional Autonomy and Employers' Authority" in *Profits and Professions: Essays in Business and Professional Ethics*, ed. Wade L. Robinson, Michael Pritchard, and Joseph Ellin (Humana Press: Clifton, N.J., 1983), pp. 265–273.

———. *Self-Deception and Morality* (University Press of Kansas: Lawrence, Kan., 1986).

Martin, Mike W., and Roland Schinzinger. *Ethics in Engineering*, 2nd ed. (McGraw-Hill: New York, 1989).

McGivern, James Gregory. *First Hundred Years of Engineering Education in the United States (1807–1907)* (Gonzaga University Press: Spokane, Wash., 1960).

McMahan, Christopher. "Managerial Authority," *Ethics* 100 (October 1989): 33–53.

McMahan, A. Michal. *The Making of a Profession: A Century of Electrical Engineering in America* (Institute of Electrical and Electronic Engineers: New York, 1984).

Meiksins, Peter. "Professionalism and Conflict: The Case of the American Association of Engineers," *Journal of Social History* (Spring 1983): 403–421.

———. "The 'Revolt of the Engineers' Reconsidered," *Technology and Culture* 29 (1986): 219–246.

———. "Science in the Labor Process: Engineers as Workers" in *Professionals as Workers: Mental Labor in Advanced Capitalism*, ed. Charles Derber (G.K. Hall: Boston, 1982), pp.121–140.

Meiksins, Peter F., and James M. Watson, "Professional Autonomy and Organizational Constraint: The Case of Engineers," *Sociological Quarterly* 30 (1989): 561–585.

Mele, Alfred. "Recent Work on Self-Deception," *American Philosophical Quarterly* 24 (January 1987): 1–17.

Meyer, Priscilla S. "Knocking the Competition: How Rival's Use of 'Industrial Code' Report Created Problems for a Tiny Company," *Wall Street Journal*, (July 9, 1974) p. 44.

Meyers, Diana T. *Self, Society, and Personal Choice* (New York: Columbia University Press, 1989).

Miceli, Marcia P., and Janet P. Near, "Individual and Situational Correlates of Whistle-Blowing," *Personnel Psychology* 41 (Summer 1988): 267–281.

Milgram, Stanley. *Obedience to Authority: An Experimental View* (Harper and Row: New York, 1974).

Mitcham, Carl. *Thinking through Technology: The Path between Engineering and Philosophy* (University of Chicago Press: Chicago, 1994).

Molloy, Peter Michael. *Technical Education and the Young Republic: West Point as America's École Polytechnique* (unpublished dissertation, Brown University, June 1971).

Musa, John D. "Software Engineering: The Future of a Profession," *IEEE Software* (January 1985): 55–62.

Noble, David. *America by Design* (Alfred A. Knopf: New York, 1977).

Nozick, Robert. *Anarchy, State, and Utopia* (Basic Books: New York, 1974).

Pavlovic, K. R. "Autonomy and Obligation: Is there an Engineering Ethics?" in *Ethical Problems in Engineering, 2nd ed.*, vol. 1, ed. Albert Flores (Center for the Study of the Human Dimensions of Science and Technology: Troy, N.Y., 1980), pp. 89–93.

Percival, Thomas. *Medical Ethics; or a Code of Institutes and Precepts Adapted to the Professional Conduct of Physicians and Surgeons* (1803).

Perrucci, Robert, and Joel E. Gerstl, *Professions without Community: Engineers in American Society* (Random House: New York, 1969).

Perry, Tekla S. "Antitrust Rule Chills Standards Setting," *IEEE Spectrum* 11 (August 1982): 52–54.

Petroski, Henry. "The Iron Ring," *American Scientist* 83 (May-June 1995): 229–232.

Petzinger, Thomas. "Hangar Anger: Mechanic's Woes Show How Safety Became a Big Issue for Eastern," *Wall Street Journal*, June 9, 1988, pp. 1ff.

Polman, Dick. "Telling the truth, paying the price," *Philadelphia Inquirer Magazine*, June 18, 1989, pp. 16ff.

[The] Presidential Commission on the Space Shuttle Challenger Disaster (U.S. Government Printing Office: Washington, DC, 1986).

"*Price Fixing and Bid Rigging in the Electrical Manufacturing Industry*," *Administered Prices: Hearings before the Senate Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary*, 78th Congress 1st session pt. 27, 1961.

Pritchard, Michael. "Conflict of Interest: Conceptual and Normative Issues," *Academic Medicine* 71 (December 1996): 1305–1313.

O'Boyle, Thomas F. "Chilling Tale: GE Refrigerator Woes Illustrate the Hazards in Changing a Product—Firm Pushed Development of Compressor Too Fast, Failed to Test Adequately," *Wall Street Journal*, May 7, 1990, pp. 1ff.

Occupational Outlook Handbook (U.S. Department of Labor, Bureau of Statistics: Washington, D.C., May 1992).

O'Connor, Stephen J., and Joyce A. Lanning, "The End of Autonomy? Reflections on the Postprofessional Physician," *Health Care Management Review* 17 (Winter 1992): 63–72.

Opinions of the Board of Ethical Review (National Society of Professional Engineers: Washington, D.C.).

Oldenquist, Andrew G., and Edward E. Slowter, "Proposed: A Single Code of Ethics for All Engineers," *Professional Engineer* 49 (May 1979): 8–11.

O'Reilly, Charles. "Corporations, Culture, and Commitment: Motivation and Social Control in Organizations," *California Management Review* 31 (Summer 1989): 9–25.

Ottoson, Gerald E. "Essentials of an Ethical Corporate Climate" in *Doing Ethics in Business*, ed. Donald G. Jones (Oelgeschlager, Gunn and Hain: Cambridge, Mass., 1982), pp. 155–163.

Raelin, Joseph A. "An Anatomy of Autonomy: Managing Professionals," *Academy of Management Executive* 3 (August 1989): 216–228.

———. *The Clash of Cultures: Managers and Professionals* (Harvard Business School Press: Cambridge, Mass., 1986.

———. "The Professional as the Executive's Ethical Aide-de-Camp," *Academy of Management Executive* 1 (August 1987): 171–182.

Raz, Joseph. "Autonomy, Toleration, and the Harm Principle" in *Issues in Contemporary Legal Philosophy: The Influence of H.L.A. Hart*, ed. Ruth Gavison (Oxford University Press: New York, 1987), 313–333.

Reader, W. J. *Professional Men: The Rise of the Professional Classes in Nineteenth-Century England* (Basic Books: New York, 1966).

Report of Investigation into Allegations of Retaliation for Raising Safety and Quality of Work Issues regarding Argonne National Laboratory's Integral Fast Reactor Project (Office of Nuclear Safety, U.S. Department of Energy: Washington, D.C., December 1991).

Reynolds, Terry S. *75 Years of Progress: A History of the American Institute of Chemical Engineers* (American Institute of Chemical Engineers: New York, 1983).

Rockwell, William H. "*Hydrolevel* Decision as Applied to Antitrust Violations of Standards Making Organizations," *CSEP Perspectives on the Professions* 3(3) (1983): 3–5.

Rosenbaum, Bernard. "Leading Today's Professionals," *Research-Technology Management* (March-April 1991): 30–35.

Rossi, Paolo. *Philosophy, Technology, and the Arts in the Early Modern Era*, trans. S. Attanasio (Harper and Row: New York, 1970).

Rueth, Nancy. "A Case Study," *Mechanical Engineering* 97 (June, 1975): 34–36.

Saha, Pamela, and Subrata Saha, "Ethical Responsibilities of the Clinical Engineer," *Journal of Clinical Engineering* 11 (January/February 1986): 17–25.

Sanders, John T. "Honor Among Thieves: Some Reflections on Professional Codes of Ethics," *Professional Ethics* 2 (Fall/Winter 1993): 83–103.

Sanger, David E. "How Seeing-No-Evil Doomed the Challenger," *New York Times*, June 29, 1986, sec. 3, p. 8.

Scanlon, Thomas. "A Theory of Freedom of Expression," *Philosophy and Public Affairs* 1 (Winter 1972): 204–226.

Schlossberger, Eugene. *The Ethical Engineer* (Temple University Press: Philadelphia, 1993).

Schwartz, Adina. "Autonomy in the Workplace" in *Just Business: New Introductory Essays in Business Ethics*, ed. Tom Regan (Random House: New York, 1984), pp. 129–166.

Seely, Bruce. "Research, Engineering, and Science in American Engineering Colleges: 1900–1960," *Technology and Culture* 34 (April 1993): 344–386)

———. "The Scientific Mystique in Engineering: Highway Research at the Bureau of Public Roads, 1918–1940," *Technology and Culture* 24 (October 1984): 798–831.

Shaffer, Michael J., and Michael D. Shaffer, "The Professionalization of Clinical Engineering." *Biomedical Instrumentation and Technology* (September/October 1989): 370–374.

Shapero, Albert. *Managing Professional People* (Free Press: New York, 1985).

Shaw, Mary. "Prospects for an Engineering Discipline of Software," *IEEE Software* (November 1990): 15–24.

Sherman, J. Daniel. "Technical Supervision and Turnover Among Engineers and Technicians: Influencing Factors in the Work Environment," *Group and Organization Studies* 14 (December 1989): 411–421.

Simmons, A. John. *Moral Principles and Political Obligations* (Princeton University Press: Princeton, N.J., 1979).

Sinclair, Bruce. *A Centennial History of the American Society of Mechanical Engineers, 1880–1980* (University of Toronto Press: Toronto, 1980).

Sinclair, George. "A Call for a Philosophy of Engineering," *Technology and Culture* 8 (October 1977): 685–689.

Smith, Merritt Roe. ed., *Military Enterprise and Technological Change* (MIT Press: Cambridge, Mass., 1985).

Smith, Ralph J. *Engineering as a Career, 3rd* ed. (McGraw-Hill: New York, 1969).

Spector, Paul E. "Perceived Control by Employees: A Meta-Analysis of Studies Concerning Autonomy and Participation at Work," *Human Relations* 39 (November 1986): 1005–1015.

Starbuck, William, and Frances Milliken, "Challenger: Fine-Tuning the Odds until Something Breaks," *Journal of Management Studies* 25 (July 1988): 319–340.

Thalberg, Irving. "Hierarchical Analyses of Unfree Action," *Canadian Journal of Philosophy* 8 (June 1978): 211–226.

Thomas, Robert J. *What Machines Can't Do: Politics and Technology in the Industrial Enterprise* (University of California Press: Berkeley, 1994).

Turner, Barry A. *Man-Made Disasters* (Wykeham: London, Ltd., 1978).

U.S. Scientists and Engineers: 1988 Estimates, Surveys of Science Resources Series, National Science Foundation, NSF 88-322.

Urquhart, Brian. "The Last Disaster of the War," *New York Review of Books*, September 24, 1987, pp. 27–30.

Vaughn, Diane. *The Challenger Launch Decision* (University of Chicago Press: Chicago, 1996).

Veatch, Robert M. "Medical Ethics and the Grounding of Its Principles," *Journal of Medicine and Philosophy* 4 (March 1979): 1–19.

Victor, Bart, and John B. Cullen, "The Organizational Bases of Ethics Work Climates," *Administrative Science Quarterly* 33 (March 1988): 101–125.

Vincenti, Walter G. *What Engineers Know and How They Know It* (Johns Hopkins University Press: Baltimore, 1990).

Voluntary Industrial Standards: Hearing before the Senate Subcommittee on Antitrust and Monopoly of the Committee on the Judiciary, 94th Cong., 1st sess. 153–214 (1975).

Waters, James A. "Catch 20.5: Corporate Morality as an Organizational Phenomenon," *Organizational Dynamics* 6 (Spring, 1978): 3–19.

———. "Integrity Management: Learning and Implementing Ethical Principles in the Workplace" in *Executive Integrity*, ed. Suresh Srivastva et al. (Jossey-Bass: San Fransciso, 1988).

Weiner, Philip P., ed. *Dictionary of the History of Ideas: Studies of Selected Pivotal Ideas*, (Charles Scribner's Sons: New York, 1973).

Whalley, Peter. "Negotiating the Boundaries of Engineering: Professionals, Managers, and Manual Work," *Research in the Sociology of Organizations* 8 (1991) 191–215.

Whitbeck, Caroline. "Teaching Ethics to Scientists and Engineers," *Science and Engineering Ethics* 1 (July 1995): 299–308.

Wilkins, Alan L., and William G. Ouchi, "Efficient Cultures: Exploring the Relationship between Culture and Organizational Performance," *Administrative Science Quarterly* 28 (September 1983): 468–481.

Williams, Rosalind. "Engineering's Image Problem," *Issues in Science and Technology* 6 (Spring 1990): 84–86.

Wisely, William H. "The Influence of Engineering Societies on Professionals and Ethics" in *Ethics, Professionals, and Maintaining Competence: ASCE Professional Activities Committee Specialty Conference, Ohio State University, Columbus, Ohio, 1977* (American Society of Civil Engineers, New York, 1977), p. 51–62.

———. "The Influence of Engineering Societies on Professionalism and Ethics" in *Engineering Professionalism and Ethics* (Robert E. Kreiger: Malabar, Fl., 1983), p. 28–37.

Wolff, Robert Paul. *In Defense of Anarchism* (Harper and Row: New York, 1970).

Woolgar, Steve. "The Turn to Technology in Social Science Studies," *Science, Technology, and Human Values* 16 (Winter 1991): 20–50

World Almanac (World Almanac: New York, 1989)

Young, Robert. "Autonomy and the Inner Self," *American Philosophical Quarterly* 17 (January 1980): 35–43.

Zussman, Robert. *Mechanics of the Middle Class: Work and Politics among American Engineers* (University of California Press: Berkeley, 1995).