PART ONE

Defining Technology

The ability to create and use a great variety of technologies is one of the distinguishing characteristics of humans, but what exactly is meant by "technology"? The term is a familiar one, but like many words in current circulation it carries with it a multitude of meanings. For a start, it encompasses much more than the array of digital devices that have been integral parts of our lives for only a few decades. It also goes well beyond the 'wave of gadgets' famously recounted by a student to historian T.S. Ashton as a major impetus for the Industrial Revolution. So then what is it? Chapter 1 offers a definition of technology that is meant to be precise yet elastic enough to cover the many connotations of the word. Although technology is often associated with particular items of hardware, the ultimate basis of technology is knowledge, and this chapter delineates the ways of thinking that are associated with technological advance. This chapter also includes an effort to disentangle technological advance from an even more slippery concept: "progress."

In Chapter 2, the discussion is continued by noting that many technological changes do not necessarily make things better for everyone, as is implied in the word "progress." To the contrary, they may affect individuals and groups in different ways, leaving some better off while others are left in a worse position. This aspect of technological change is often ignored, making it hard to resist the temptation to seek "technological fixes" for problems that require more than the introduction of new devices and processes. This chapter describes the kinds of situations where technological fixes are likely to be successful and others where they are doomed to failure.

CHAPTER ONE

The Nature of Technology

Today's technology leaves us both exhilarated and terrified. Recent technological developments have presented us with such marvels as spacecraft leaving the solar system, instant access to billions of internet Web pages, and diseases cured through gene therapy. At the same time, however, the seemingly inexorable march of technology has produced global pollution, overpopulation, and the threat of nuclear annihilation. On many occasions, technological change has also produced social disruptions, as when automation destroys jobs in a particular industry or a new weapon upsets the balance of power between nations. And when technologies fail, some of them do so in a big way, as exemplified by the loss of the *Challenger* and *Columbia* space shuttles, the massive oil spill in the Gulf of Mexico, the catastrophic failure of the Fukushima nuclear plant in Japan, and the disastrous breaching of the levees in New Orleans in the wake of Hurricane Katrina.

Despite all the crises, disruptions, and disasters that have accompanied it, modern technology is still viewed in a favorable light, according to public opinion surveys. Although significant minorities of respondents express their disapproval of certain technologies like nuclear power and genetically modified foods, the positive achievements of technology as a whole are seen to substantially outweigh the negative ones.[1] But this support of technology is based more on faith than on understanding. When confronting technology, most of us are poorly informed spectators, seemingly incapable of understanding an esoteric realm of lasers, microprocessors, gene splicing, and nanomaterials.

This inability to understand technology and perceive its effects on our society and on ourselves is one of the greatest, if most subtle, problems of an age that has been so heavily influenced by technological change. But ignorance need not be a permanent condition. Although no one can hope to comprehend the inner workings of even a small number of the most significant technologies, it is still possible to come to a better understanding of the major causes and consequences of technological change. All technologies, be they high-definition televisions or reinforced concrete bridges, have some basic features in common. It will be the task of this chapter to show what they are.

Defining Technology

Gaining an understanding of the meaning of words is often the beginning of knowledge. Before plunging into a discussion of the nature of technology, it is necessary to provide a more precise definition of what is meant when we use the term. The linguistic roots of the word "technology" can be traced to the Indo-European stem *tekhn-*, which seems to have referred to woodworking. It is the source of the Greek word *tekne*, which can be variously translated as "art," "craft," or "skill." It is also the root of the Latin word *texere*, "to weave," which eventually took on the larger meaning of fabrication or construction. By the early eighteenth century, the word had come close to its present meaning when an English dictionary defined it as "a Description of Arts, especially the Mechanical." In 1831, Jacob Bigelow published *Elements of Technology*, the first book in English with the word "technology" in its title. As he defined it, technology consisted of "the principles, processes, and nomenclatures of the more conspicuous arts, particularly those which involve applications of science."[2]

Tools and Techniques

Technologies are developed and applied so that we can do things not otherwise possible, or so that we can do them cheaper, faster, and more easily. The capacity of human beings to employ technologies sets us apart from other creatures. To be sure, beavers build dams, otters crack open shellfish with rocks, and chimpanzees use sticks to extract termites from their nests. But no other animal comes close to humans in the ability to create tools and techniques—the first two elements in our definition of technology—and no other creature is so dependent on them. The development of technology is in large measure responsible for the survival and expansion of a species that lacks many of the innate abilities of other animals. Left with only our innate physical capabilities, we humans cannot match the speed of a cheetah, the strength of an elephant, or the leaping ability of a kangaroo. We do not possess the eyesight of an eagle or the defensive armament of a porcupine, and we are among the 25 percent of all species that are incapable of flying. All in all, humankind is a physically puny bunch. But compensating for this physical weakness is an intelligence that is the ultimate source of technology. Humans stand apart from all other animals in their ability to gain and transmit knowledge, and to use this knowledge to develop tools and techniques. Without this capacity to invent and use a great variety of technologies, the human species would have never been able to establish itself on virtually every part of the globe.

Reliance on technology is as old as humanity itself. Whatever evils have accompanied the use of particular technologies, it is pointless to indict technology as being somehow "unnatural." Our past as well as our future as a species is inextricably linked to our capacity to shape our existence through the invention and application of implements and techniques that allow us to transcend our meager physical endowments. It is certainly true, as Jacob Bronowski observed, that "to quarrel with technology is to quarrel with the nature of man—just as if we were to quarrel with his upright gait, his symbolic imagination, his faculty for speech, or his unusual sexual posture and appetite."[3]

Organizing Humanity

Tools and techniques have been of unquestioned importance in allowing the physical survival of the human species. Still, they are not the whole story. It is necessary to add some elements to our definition of technology that go beyond the usual identification of technology with pieces of hardware and ways of manipulating them. The first of these is *organization*. This follows from the fact that the development, production, and employment of particular technologies require a group effort. Even a relatively simple technology, such as one centering on the use of earthenware pots, requires a complex network of material suppliers, potters, toolmakers, marketing agents, and consumers capable of making good use of the pots. Of course, one person can learn all these skills adequately if not expertly, but the day is not long enough for him or her to do them all on a scale that produces a reasonable degree of efficiency. In the case of a complex technology like a computerized manufacturing system, there is no possibility of a single individual developing even a tiny fraction of the requisite skills.

For a technology to be developed and used, the energies and skills of many individuals have to be combined and coordinated through some organizational structure. Organization may be likened to the software that controls and guides a computer; without an operating system and application programs, a computer is a useless arrangement of capacitors, transistors, resistors, and other bits of hardware. In similar fashion, an organizational structure allows the integration of diffuse human and material inputs for the attainment of particular tasks. From this standpoint, there is considerable merit in Lewis Mumford's assertion that the first "machine" was not a physical object, but the organizational structures that the Egyptian pharaohs employed to build the pyramids.[4]

Construction of the Pyramids, 1862 (coloured engraving)/Leutemann, Heinrich (1842–1905)/INDEX Fototeca/Index, Barcelona, Spain/Bridgeman Images

According to one perspective, the workers who labored to build the pyramids were components of a kind of machine.

When technology is seen as a combination of devices, skills, and organizational structures, it becomes natural to think of it as a *system*, the next element in our definition. For an individual technology to operate effectively, more is required than the invention of a particular piece of hardware; it has to be supported by other elements that are systematically interconnected. When Thomas Edison began to work on electrical illumination, he realized that this technology would require the development of such a system. The invention of a practical, long-lasting lightbulb rested on the development of a serviceable filament and the use of an improved vacuum pump that evacuated the interior of the bulb, thereby preventing the combustion of the filament. But by itself, a lightbulb was useless. An effective electrical generator was needed to supply the current that produced the incandescence of the filament. A network of electrical lines had to be strung up between the generator and individual homes, shops, and factories. And metering devices were necessary so that users could be accurately billed for the electricity they used. Edison and his associates worked out all of these problems, and in so doing brought large-scale electrical illumination to the world.[5]

The development of all the elements of a technological system can be an uneven process, for technological advance often entails the resolution of tensions that are generated when one part of the technological system changes. This process is exemplified by the development of the modern airplane. Early biplanes with their drag-inducing wires and struts could not make effective use of more powerful engines. The availability of these engines became a strong inducement to the design of aerodynamically cleaner aircraft. The faster aircraft that resulted from the marriage of streamlined airframes and powerful engines produced a new problem: dangerously high landing speeds. This, in turn, stimulated the invention of wing flaps and slots. By the 1940s, it had become apparent that improved airframes could achieve still higher speeds if provided with more powerful engines; this possibility gave a strong stimulus to the development of the turbojet.[6]

For an example of the interplay of devices, skills, and organizational patterns, we can take note of Lewis Mumford's analysis of the technology of handwriting.[7] Two hundred years ago, the standard writing instrument was a goose-quill pen. Based on an organic product and sharpened by the user, it represented the handicraft technologies typical of its time. Cheap and crude, it called for a fair degree of skill if it was to be used effectively. In contrast, the steel-nib pen of the nineteenth century was a typical artifact of the industrial age, the product of a complex manufacturing process. Less adaptable than the quill, it was mass-produced in many different forms in order to meet specialized needs. Although Mumford's ideas were formulated before the invention of the ballpoint pen in the 1940s, his analysis fits this implement perfectly. Made from a variety of artificial materials and manufactured to close tolerances, the ballpoint pen could only be produced through sophisticated industrial processes. It is completely divorced from the organic world and requires very little skill from its user. Indeed, the technological artistry embodied in the pen itself stands in sharp contrast to the poor quality of the writing that so often comes from the hand that wields it.

A technological system does not emerge all at once with every one of its components neatly fitting together. In addition to changes in tools, techniques, and organizational structures, many social, psychological, economic, and political adjustments may be required for the support of a technological system. Technological change is not always a smooth process, and many of the necessary changes may entail considerable pain and disruption. Seeing technology as a system should help us to understand that technological change is closely connected with a variety of associated changes, and that the creation of a technological system may be fraught with tension and discomfort.

Much of what has just been said can be incorporated into a schematic definition of technology: **a system created by humans that uses knowledge and organization to produce objects and techniques for the attainment of specific goals**.

Useful as it may be, this definition of technology is incomplete and possibly misleading in one important respect. The last part of the definition implies that technological change comes about as a response to existing needs: its purpose is "the attainment of specific goals." In the first place, one could legitimately ask *whose* goals are to be attained. This is an important issue, but it is best left for the next chapter. For now, we should note that although it is a human creation, technology does not always respond to existing needs; a new technology may in fact create its own needs. The development of technology on occasion exemplifies a phenomenon that has been dubbed "the law of the hammer": give a six-year-old a hammer, and to the child everything starts looking like a nail.

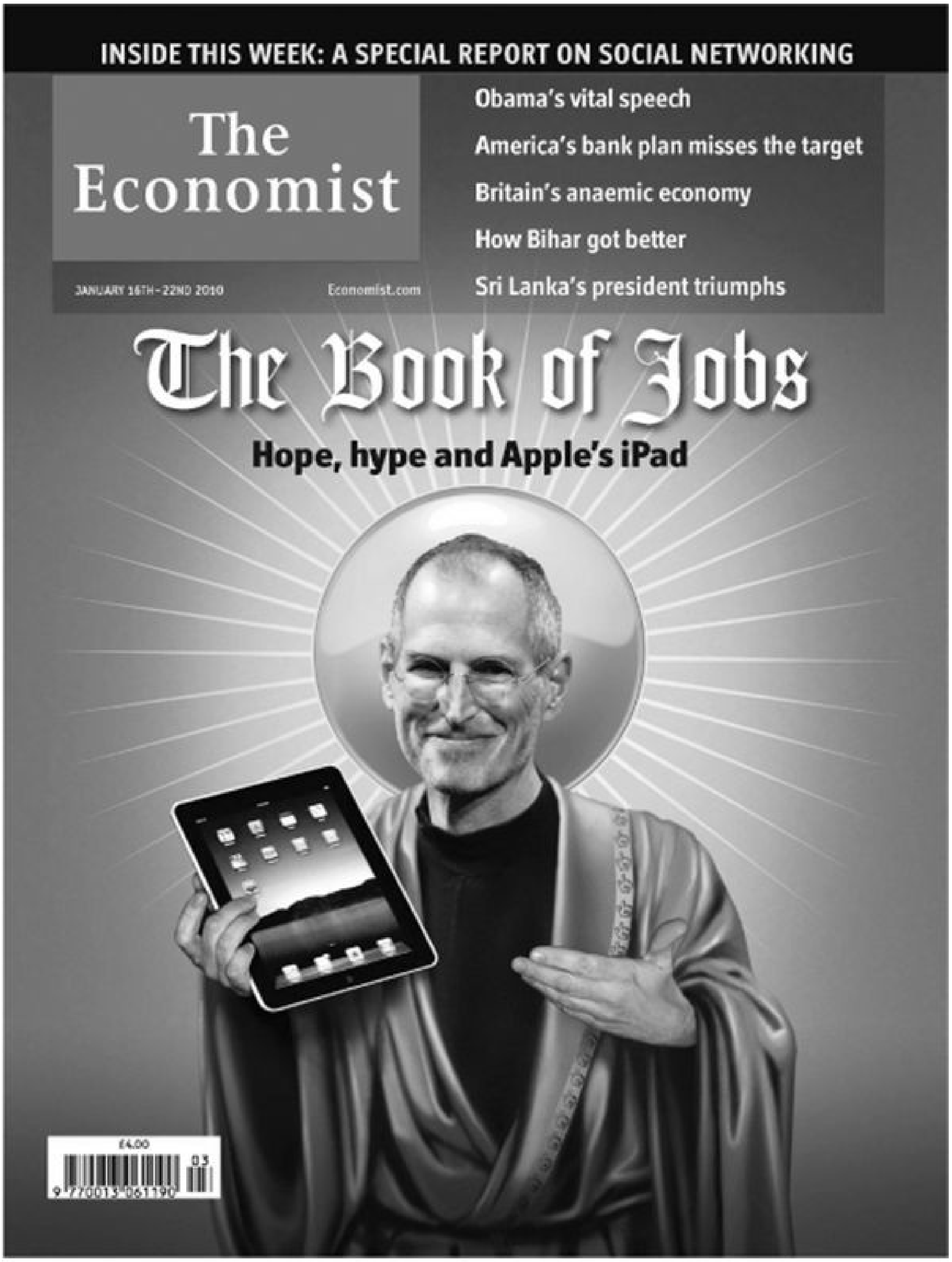
The history of technology is replete with examples of inventions looking for problems to solve. One example that illustrates this point is found in almost every medicine chest: a bottle of aspirin. One of the most common uses of aspirin is to suppress fevers that accompany various illnesses. But medical research (as well as some ancient practices) has demonstrated that running a fever is a therapeutic process that aids in a patient's recovery; it is the body's way of naturally combating infection. Yet since the introduction of aspirin in the early 1900s fever has been seen as a problem requiring intervention. As one medical researcher has noted, "It's no surprise that society's deep worries about fever closely followed the synthesis of aspirin, the first drug that could safely reduce it."[8] In short, a new technology created its own need.

It is also important to note that the goals achieved through the use of a technology do not have to be "practical" ones. Some technologies have been developed so that we can grow more food or construct more comfortable buildings, but others have been developed simply for the challenge and enjoyment of solving technological problems, a proclivity that Robert Post has described as “technological enthusiasm.”[9] The prodigious efforts that went into the Daedalus project, a successful attempt to build a human-powered aircraft capable of flying 40 miles across the open sea, were certainly not motivated by an effort to produce a new form of transportation. A major reason for creating the aircraft was that its construction posed an intriguing technological challenge to those who designed, built, and flew it.

Flight seems to be a particularly attractive object for this kind of spirit. Immensely expensive technological endeavors such as the supersonic Concorde airliner and manned space exploration programs are hard to justify on practical grounds, although their supporters have made valiant efforts to do so. Their primary purpose seems to be the elevation of national prestige by demonstrating a nation’s collective ability to solve daunting technological problems. At the same time, many other technologies have a dual nature; they serve a practical purpose, but they are not valued only for this reason. An outstanding example is the automobile. It would be hard to justify the enormous resources employed for the building and operation of cars if transportation were the only goal. For many people (the author included), cars are objects of inherent fascination. Technological features like variable valve timing and active suspension systems have little to do with utilitarian transportation. The appeal is at least as much in the sophisticated technologies themselves as in the purposes that they serve.

Technological Advance and the Image of Progress

The development of technology is an inherently dynamic and cumulative process. It is dynamic because a technology is never perfect; there is always room for improvement. As Henry Ford said of his firm, “If we have a tradition it is this: Everything can always be done faster and better.”[10] It is cumulative, for one advance paves the way for another. The lessons learned in working with an existing technology very often provide materials, tools, and, most importantly, a knowledge base for the next stage of development.



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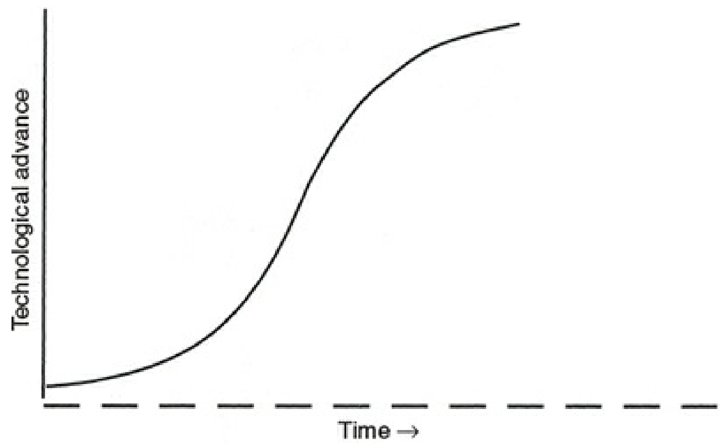
Sometimes we are inclined to look to technology for our salvation, as personified in this tongue-in-cheek rendition of a sanctified Steve Jobs.

The dynamic and cumulative nature of technological change sets it apart from many other human endeavors. Ignoring for the moment the social consequences of technology, the process of technological change is usually one of continuous improvement in the internal workings of a particular technology: as they evolve, engines develop more power and are more efficient, integrated electronic circuits pack more components on a single chip, aircraft fly higher and faster.

The process of technological advance can be graphically portrayed according to the following diagram, in which the horizontal axis represents time and the vertical axis represents just about any aspect of technological advance: the speed of commercial airliners, the production of synthetic materials, or the number of articles in engineering journals. Although there are inevitable fits and starts over time, the general trend can be depicted as a sigmoid, or S-shaped curve (see figure below).

Note that at first the curve rises rather slowly, inclines steeply in the middle, and then begins to slow down. That is, after an initial period of slow growth, the rate of advance accelerates, reaches a maximum, and then begins to proceed at a slower pace but never completely levels off. Although the rate of increase is smaller as the curve moves toward the right, this rate is applied to an increasingly larger base, so the actual addition is still substantial.

Not all human endeavors can be fitted to this sort of curve. While technology tends to be dynamic and cumulative, the same cannot always be said of other manifestations of human creativity. Although there is ample room for debate, a good case can be made that succeeding generations of writers, composers, and painters have not produced works superior to the ones created by Shakespeare, Beethoven, and Vermeer. And while we continue to take great pleasure in the artistic creations of eras long past, few of us would be satisfied with the technologies that were prevalent in those times. We also see few indications that people are more humane than they were centuries ago. The present era certainly provides a multitude of horrifying examples of human cruelty, many of them augmented by enlisting technology in the service of slaughter and destruction.



Volti, *Society and Technological Change*, 8e, © 2017 Worth Publishers

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Built with slave labor, the V-2 rocket exemplified the technological progress of Nazi Germany.

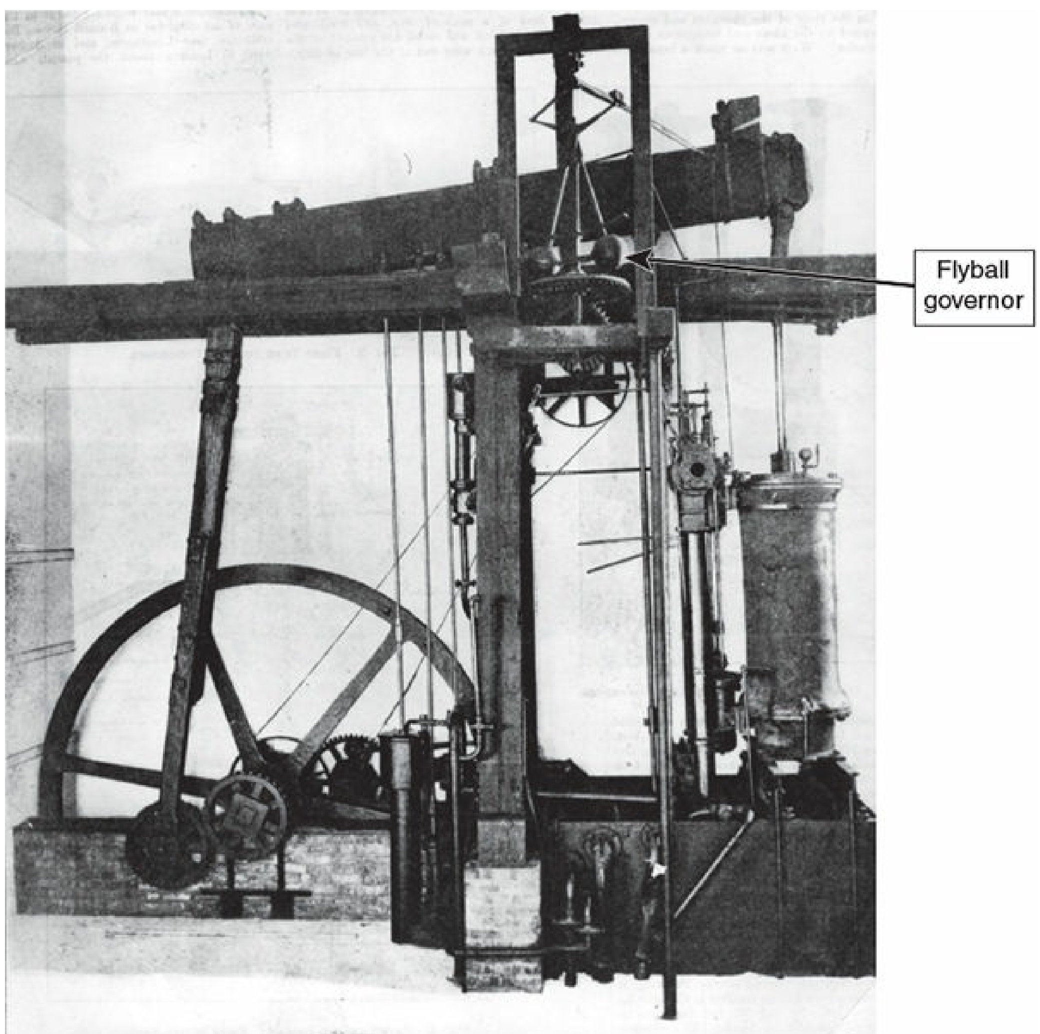
Still, when judged solely according to internal criteria, technology is one of the best examples of humankind's largely unrealized dream of continual progress. Technological progress, however, is not the same thing as progress in general. The fact that a society is able to develop and make use of advanced technologies does not guarantee that it will be equally advanced in other areas.[11] Nazi Germany produced many technological triumphs, such as the all-conquering Mercedes and Auto Union grand prix racing cars of the late 1930s and the V-2 rocket used during World War II, but in its ideology and treatment of people it can only be described as barbaric. Conversely, many technologically primitive peoples have exhibited a high level of sophistication in their artistic creations, religious beliefs, and social relationships. The term "progress" can be used with some precision when applied to the development of technology per se, although even here problems can crop up because different standards of evaluation may lead to conflicting conclusions. Is it really "progress" when a new medical technology maintains an individual's life, but does so only at enormous expense while preserving nothing but the maintenance of organic functions? Does maintaining a "life" of this sort justify expenditures that otherwise might be used for expanded prenatal care or other preventative measures? Given all of the value judgments, ambiguities, and complexities surrounding the word "progress," its use is avoided here unless its meaning is clearly defined.

Technology as a Metaphor

Despite these qualifications, it is evident that beginning in the late eighteenth century and continuing today, technology's stunning advances have fueled a belief in generalized human progress. In this way, technology has operated as a metaphor—the transference of an idea from one area to another. Technology has provided many other metaphors that have affected our way of looking at ourselves and the world, as when human thought is made analogous to the operation of a digital computer.

A further example of the power of a technology to shape our way of thinking comes from the late eighteenth century. At that time, the designers of windmills and steam engines discovered the important principle of *feedback*, which the great twentieth-century mathematician Norbert Wiener defined as "a method of controlling a system by reinserting in it the results of its past performance."[12] When a steam engine begins to rotate too rapidly, a feedback device such as a flyball governor closes the valve that admits the steam, thereby bringing the engine back into its proper operating range. When it slows down, the reverse happens, and the governor opens the valve to admit more steam.

During the late eighteenth century, the feedback principle offered a suggestive metaphor for the workings of the economic system: instead of being guided by a centralized authority, an economy might best be organized through the operation of a self-regulating market, with the actions of independent buyers and sellers providing the feedback. Thus, when buyers wanted a particular commodity, its price would be high, motivating sellers to produce more of it. If the price were low, less would be produced. In similar fashion, an increase in production would cause the price of a commodity to fall, so more of it would be purchased, while a drop in production would cause the price to rise, leading to a reduction of purchases. In this way, the actions of buyers and sellers in the market provide a feedback mechanism through which supply and demand are supposedly brought into equilibrium. It is probably no coincidence that the Scottish economist Adam Smith developed this basic concept at the same time that the steam engine was being put into service.[13] Today, the widespread use of the feedback principle makes its apparent applicability to the economic system even more appealing, even though the real-world economy is hardly a neat closed system like a steam engine. Laws and regulations, as well as a host of other extraneous elements, may strongly affect individual feedback loops, thereby preventing a complex economy from operating solely on the basis of supply-and-demand signals. Technological development has supplied a useful metaphor in the feedback principle, but like all metaphors it cannot be taken as a literal depiction of reality.



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A steam engine with a flyball governor. Changes in the rotational speed of the vertical shaft at the top of the engine causes the two balls to move up or down, thereby controlling the linkage that opens and closes the throttle.

Technology and Rationality

The development of technology has stimulated a belief that progress is a natural part of human life. At the same time, the progressive development of technology has itself been the product of a distinctive set of cultural values and mental processes that are characterized by a rational approach to the world and how it is to be controlled. Technological development is more than the random accumulation of tools, techniques, and organizational forms. Underlying the process is a set of attitudes and orientations that are collectively described as "rational."

What makes a technologically progressive society different from others is that its methods of problem solving are oriented toward an objective scrutiny of the problem at hand, coupled with a systematic, empirically based examination of possible solutions and a logical selection of the most appropriate ones. Beyond this approach to the solution of problems lies another cultural attribute: the belief that solutions are *possible* and that constant changes are necessary in order to realize them. A society imbued with a rational ethos is dynamic and essentially optimistic, and it exhibits the confidence necessary to alter existing ways of doing things in order to gain particular benefits.

These abstract concepts may be illustrated through a simple example. All societies are faced with the problem of coping with the capriciousness of the weather. A great deal of human suffering has been the result of the vagaries of rainfall, and history provides many examples of the tragic consequences of drought. A number of responses are possible when people are confronted with this problem. The simplest is to succumb to despair, and perhaps try to find meaning in it by attributing the drought to fate or God's will. A more active approach might be to offer prayers, perform a special ceremony, or sacrifice a member of the community. These latter activities are not likely to meet with success. There is no logical or empirically verifiable connection between them and the circumstances that produced the drought, a fact that could be demonstrated by a systematic inquiry into the long-term connection between prayers, ceremonies, or human sacrifices and the incidence of rainfall.

Attitudes and behaviors of this sort stand in sharp contrast with rational ones. Through the use of logic and empirical observation it is possible to develop ways of dealing with problems like drought that are both more effective and more closely connected to the way the world actually works. A systematic and empirical observation of weather patterns might allow the prediction of a drought so that necessary steps can be taken to alter farming practices and conserve water. Other solutions could be the development of drought-resistant crops, improved methods of conserving water, and the distillation of seawater. It might also be possible to artificially stimulate rainfall through cloud seeding. In short, a rational approach to problem solving is continuously concerned with identifying and developing appropriate means for achieving particular ends.

The Limits of Rationality

These remarks are not meant to convey the ethnocentric belief that modern Western culture is superior to all others. The intention here is not to ridicule the beliefs and practices of people and societies that use nonrational approaches to problem solving. There is no reason to believe that rationality has been and always will be the special attribute of a particular group of people. Moreover, modern societies often manifest behaviors and patterns of thought that are anything but rational, as when large numbers of people continue to find value in astrology, numerology, and the predictions of supposed psychics.

PA Images/Alamy

Science cannot prevent natural disasters, such as tornados, but it can and has helped develop better ways of predicting when they will occur to reduce injuries and fatalities.

It is also important to recognize that rational ways of thinking do not confer moral superiority. To the contrary, the rigorous development and use of rational procedures can be accompanied by major moral and ethical transgressions. The rational method of problem solving, with its overarching concern for devising appropriate means for attaining particular ends, makes no distinction concerning the ends being pursued. There is nothing in the rational approach to the world that prevents the use of logically and empirically derived means in the service of goals that are neither rational nor ethically justifiable. We can take note of the words of Captain Ahab, the main figure in Herman Melville's novel *Moby Dick*: "All my means are sane, my motive and subject mad." Nazi Germany provides many ghastly historical examples of human destruction ensuing from rational thinking and its resultant technologies. As Albert Speer, Hitler's Minister of Armaments, ruefully noted, "The criminal events of these years were not only an outgrowth of Hitler's personality. The extent of the crimes was also due to the fact that Hitler was the first to be able to employ the implements of technology to multiply crime."[14]

Even when rationality is not used for manifestly immoral purposes, it can still leave a dubious spiritual legacy. The very strength of rationality and the scientific and technological accomplishments that flow from it lie in their matter-of-fact approach to the world. A rational approach to things is often accompanied by a reluctance to admit there are any forces incapable of withstanding logical and empirical scrutiny. As the great German sociologist Max Weber put it, the world defined by rational thought processes had become "disenchanted," for it was bereft of the gods, genies, and spiritual forces that people not imbued with the spirit of rationality used to explain their world.[15] But "disenchantment" is a two-edged sword, as the everyday meaning of the word makes clear. To be disenchanted is to lose the sense of awe, commitment, and loyalty that is a necessary part of a meaningful existence. Weber's melancholy analysis of a world that has lost its enchantment is summarized by the French sociologist Julian Freund:[16]

> With the progress of science and technology, man has stopped believing in magic powers, in spirits and demons; he has lost his sense of prophecy and, above all, his sense of the sacred. Reality has become dreary, flat and utilitarian, leaving a great void in the souls of men which they seek to fill by furious activity and through various devices and substitutes.

Similar misgivings were voiced by the eighteenth-century political philosopher Edmund Burke. Burke's primary concern was the destruction of traditional authority by modern mass movements, as exemplified by the French Revolution. Burke attributed much of the demonic energy of that movement to the spread of rational modes of thought that left no room for the traditional attitudes, values, and political structures that had long sustained European civilization. Burke's comment on the downfall of the queen of France, Marie Antoinette, thus contains a sharp indictment of the bearers of rational values who, in his estimation, were leading Europe to its doom:[17]

> Little did I dream that I should have lived to see such disasters fallen upon her in a nation of gallant men, in a nation of men of honor and of cavaliers. I thought ten thousand swords must have leaped from their scabbards to avenge even a look that threatened her with insult. But the age of chivalry is gone. That of sophisters, economists, and calculators, has succeeded; and the glory of Europe is extinguished forever.

Rationality also implies objectivity; coolness and detachment are part of the rational approach to understanding and changing the world. Guided by a rational outlook, scientific inquiry and technological application are usually based on the abstraction or isolation of the part of the natural world that is being studied or manipulated. This is not always a good thing, for it can produce a sharp separation between the individual and the rest of the world. The scientist or technologist stands apart from the system that is being studied and manipulated, resulting in a kind of tunnel vision that may ignore the larger consequences of gaining and applying knowledge.[18] For example, in discovering a genetic marker for a serious disease, a researcher might not consider potential abuses of that discovery, such as insurance companies refusing coverage of people with that marker.

It also may be argued that a logical, detached, and dispassionate approach to the world is suffused with a "masculine" approach to understanding and interacting with the world. Some technologies have largely been a male domain, but throughout history women have also made significant contributions to technological advance.[19] The complex relationship of gender and technology is illustrated by the history of the technological artifact most strongly associated with the present era, the digital computer. Its development has generally been viewed as the product of hyperrational male engineers, mathematicians, scientists, and technicians. In reality, many of the programmers of first-generation computers were women whose accomplishments have often been passed over in standard histories.[20] More recently, the development of computer technology has depended on thought processes that are relentlessly rational, objective, and logical, but at the same time has required an intuitive, interactive, and generally less structured approach.[21] This is not to say that either style is the exclusive province of men or women, only that technological advance often requires both approaches. Equally important, although these modes of thinking may be described in gender terms, they need not reflect the cognitive approaches of individual men and women.

Technological Determinism

Nothing worthwhile in life comes without some costs attached. So it is with technology; while it has expanded human power and made our lives materially richer, the advance of technology has created many problems—environmental degradation, alienation, and the threat of nuclear annihilation, to name only the most obvious ones. And, most bothersome of all, there looms the possibility that technology is out of control. If this is so, what began more than a million years ago as a human creation has taken on a life of its own, with technology advancing according to its own inner dynamic, unrestrained by social arrangements, systems of governance, culture, and thought.[22] The belief that technology acts as an independent force in our life, unaffected by social forces, is known as "technological determinism," and if it is true, we have become the servant of technology instead of its master.

There can be little question that technology exerts a great influence on social, political, and economic relationships. Everything from antibiotics to zippers has affected our lives to some degree; many of these influences will be explored in subsequent portions of this book. But that is not the end of the story. As will be explored at greater length in Chapter 3, students of technology have given extensive consideration to the opposite possibility, that instead of operating as an independent force, technology is shaped by social arrangements. According to social constructivists (adherents of the Social Construction of Technology approach), the emergence of particular technologies, choices between competing technologies, and the way these technologies are actually used owe a great deal to socially grounded forces such as political power, social class, gender, and organizational dynamics.

Asserting the supremacy of either technological determinism or social constructivism is not a very useful activity. Such straightforward cause-and-effect relationships can be found in some realms—Newtonian physics, for example—but technological and social change is better understood in terms of probabilities, reciprocal interactions, and feedback loops. Even William F. Ogburn, a sociologist who is often characterized as a technological determinist, on occasion took a more nuanced view of the subject: "The more that one studies the relationships between mechanical and social invention, the more interrelated they seem…. The whole interconnected mass [i.e., social institutions, customs, technology, and science] is in motion. When each part is in motion and banging up against some other part, the question of origins seems artificial and unrealistic. If one pushes the question to the extreme, origins are lost in a maze of causative factors."[23]

The wondrously complicated interactions of technology and society often result in unimagined consequences when new technologies emerge. To take one example, when the first digital computers appeared in the mid-1940s, they elicited modest expectations about their future applications. Today, the world as we know it is almost unimaginable without computers, as everything from air travel to the mapping of genomes is totally dependent on the storage, retrieval, and manipulation of information performed by computers. Accordingly, the history of the computer would seem to lend credence to technological determinism. Nobody saw it coming in the 1940s, but within a few decades the computer had become a universal and essential part of contemporary life.

This is the story from a technological determinist standpoint, but social constructivists would challenge it by noting that the technical development of the computer in the 1950s and 1960s was heavily supported by military expenditures, just as one of today's major computer applications, the internet, was initially a creation of the U.S. Department of Defense. Someone taking a social constructivist approach might also point out that the expansion of the market for computers was also powerfully stimulated by commercial enterprises like banks and insurance companies, and that this huge market supported the research and development that rapidly advanced computer technology.

A similar story could be repeated for most successful technologies. New technologies bring changes to many aspects of society, while at the same time social forces do much to stimulate and shape these technologies. To try to assign primacy to one or the other is to ignore a crucial feature of technological and social change. Both are dynamic processes characterized by the reciprocal interaction of a host of factors, some of them narrowly technical in nature, others not. No reasonable person could deny that technology has been a major force in making the world we live in, but it is important to always keep in mind that technology has not operated as an agent independent of the society in which it is imbedded.

Social constructivism therefore offers the possibility for more human agency than technological determinism, but it is not likely that the ability to influence the course of technological change will be evenly distributed among the population as a whole. To the contrary, social constructivist analyses have often shown how differences in power and access to resources have shaped technological change. Particular technologies may be devised, selected, and disseminated because they serve the interests of a particular group, possibly in opposition to the interests of other groups. Technology confers power, but this power is not wielded over only the nonhuman universe. As C. S. Lewis has reminded us, “Man’s power over nature is really the power of some men over others with nature as their instrument.”[24]

Living in a Technological Society

The development and application of technologies that are suited to our needs requires the informed participation of a wide range of people. Unfortunately, the very nature of modern technology places severe limits on popular understanding. The sophistication and complexity of contemporary technologies preclude direct involvement by all but those immediately concerned with them. The rest of us are passive consumers, content to reap the benefits of rationally derived knowledge but woefully ignorant of it. This creates the fundamental paradox of modern society: technology has generated massive powers available to human society, while as individuals we exert very little of that power. We have access to a wide range of powerful technologies, yet our inability to understand them often leaves us with feelings of impotence and frustration, as anyone who has experienced a computer crash will attest.

As has been noted, the application of rationality for the solution of human problems is both the consequence and the cause of optimism and a willingness to accept constant change. Yet one cannot help but wonder if these characteristics can be sustained in an environment that sharply limits participation and inculcates widespread feelings of having little or no power over the process of technological change.

Strange notions can emerge when feelings of powerlessness are coupled with an extravagant faith in technology. The consequences of this combination are sometimes exhibited by fervent believers in alien spacecraft or UFOs (unidentified flying objects). Although convincing evidence of UFOs is lacking, a belief in their existence does not necessarily make one a crackpot. In some cases, however, a strident belief in the existence of UFOs takes on the characteristics of membership in a religious cult where the deities are superior beings who have produced an advanced technology. Alien spaceships represent a level of technical sophistication not attained on Earth, and some UFO enthusiasts entertain the hope that the aliens that created them will take over this planet and solve its problems. Faith in a higher technology may be combined with a mistrust of the “establishment,” as a fair number of

UFO adherents claim that their government is engaged in a massive conspiracy to prevent the general public from being aware of the existence of UFOs. There is no denying that on occasion governments lie to their citizens, but a cover-up of the required magnitude would be impossible for even the most well-organized government to pull off. Still, conspiracy theories strike a resonant chord with people who feel that they have been excluded from decision making, both political and technological. A quasi-religious belief in UFOs may therefore combine an excessive confidence in technology in general with a distrust of the people and organizations that control it in actual practice.

Distrust flourishes when people have no ability to participate in decisions that shape their lives, and the inability to affect the course of technological change can produce a mixture of naive hope and paranoid reaction. A realistic sense of control, including a sense of having some control over technology, is essential for an individual’s mental health. No less important, widespread participation in the shaping of technology is essential for democracy. Technology’s benefits cannot be separated from its costs, and thus it becomes necessary to determine if the former justify the latter. If a society is truly democratic, such decisions will be made with as much citizen participation as possible. Moreover, the benefits and costs of technology are not shared equally, and once again the apportioning of costs and benefits should be done in as participatory a manner as possible. We will return to these themes in Chapter 17, but first, we will take a closer look at how technology can affect people and groups in different ways.

QUESTIONS FOR DISCUSSION

1. In your opinion, which recent technology has produced the greatest benefit? Which has produced the most harm? Are there any harmful elements to the beneficial technology, and has anything good come from the harmful one?
2. You have probably heard the old saying that "necessity is the mother of invention." Are new technologies usually a response to an existing need of some sort? Can you think of any technologies that created a need before most people were aware of it?
3. Are technologies "gendered"? Are some technologies identified with women and others with men? On what bases do we make these distinctions? Will this situation necessarily continue in the years to come?
4. Can you think of any technologies that were developed simply because of the technical challenges involved? How can these "impractical" technologies be justified?
5. How do you feel when a technological device upon which you depend malfunctions? What do these feelings tell you about your attitude toward technology in general?
6. It is sometimes asserted that the development and use of birth control pills were responsible for the sexual revolution that began in the 1960s. Is there a simple cause-and-effect relationship of the two? Have there been any other forces that contributed to changing sexual mores?

Do all rechnologies require material artifacts of some sort? Does it make any sense to speak of bureauracy as a kind of technology?

CHAPTER TWO

Winners and Losers: The Differential Effects of Technological Change

The last chapter may have seemed a bit negative in its assessment of technology and the culture that supports it. In one regard, however, there is no denying technology's positive consequences: technological advance has been the greatest single source of economic growth. If our material lives are better than those of our grandparents, it is largely because technological development has boosted the production of goods and services. Equally important, it has created entirely new products while at the same time improving the quality of existing ones.

Curiously, economists were slow to grasp this seemingly obvious fact. Conventional economic analysis identifies three basic "factors of production": land (which includes natural resources), labor, and capital. Any increase in production was therefore taken to be the result of an increase of these factors. This view began to change in the 1950s when the historical course of economic development in the United States was analyzed through the use of sophisticated statistical techniques. It then became apparent that increases in the traditional factors of production did not adequately explain the actual record of economic growth. The amount of land had remained constant, and capital accumulation and increases in the labor force accounted for only 10 to 20 percent of economic growth during the first half of the twentieth century.[1] Accordingly, the major source of economic growth was a "residual" factor of overwhelming importance. Most economists agree that technological advance is the main element of this residual, although organizational development and improved worker skills, along with economies of scale, are also key components. Still, as we have already seen, organization and skill are integral parts of technology, so it is reasonable to view technological change as the major source of economic growth, a conclusion that is widely supported by economists today.[2]

While technological development has been the primary source of economic advance, it has not been cost-free. One of the most pleasant myths about technology is that it can work its wonders without altering existing social arrangements. Americans in particular have often seen technological progress as the surest basis for progress in general, and have tended to believe that technological solutions to problems are less painful than solutions that require political or social changes.[3] These beliefs are not easily sustained after an examination of the actual pattern of technological advance.

It is a truism that a particular technology can be used for either good or evil purposes; a construction team employs explosives to build a road, while a terrorist uses them for roadside bombs. But there is less appreciation for a more subtle point: technological change is often a subversive process that results in the modification or destruction of established social roles, relationships, and values. Even a technology that is used exclusively for benign purposes will cause disruptions by altering existing social structures and relationships. There are many technological changes that are small in scope, the effects of which are felt by only a few. A few technological changes are massive and they lead to vast social restructuring. In either case, technology does not yield its benefits without exacting a cost.

Technology as a Subversive Force

The disruptive effects of technological change can readily be seen in the economic realm, where new technologies can lead to the destruction of obsolete firms, as when the fabled Pony Express rapidly lost its customers after telegraph wires had been strung across the West. Of course, sometimes the disruption is less apparent when technological innovation results in the creation of entirely new industries that are not in direct competition with existing ones. Many new industries and individual firms owe their existence to the emergence of a new technology. Witness, for example, the rapid growth of personal computer manufacturing, peripheral equipment production, software publishing, and app development that followed the invention of the integrated circuit. Even so, lurking behind these successes were a number of failures, most notably the manufacturers of vacuum tubes and individual transistors, who faced a diminished market for their products.

Concerns about the disruptive effects of technological change are not new, as can be seen in an English magazine editor's fulminations against the first railroads in 1835: "Railroads, if they succeed, will give an unnatural impetus to society, destroy all the relations that exist between man and man, overthrow all mercantile regulations, and create, at the peril of life, all sorts of confusion and distress."[4]

Anyone convinced of the virtues of technological change could easily criticize this reactionary view by noting how the railroad stimulated economic development and produced many social benefits. Even so, there is more than a grain of truth in the concerns expressed by the agitated magazine editor. Technological changes, both major and minor, often lead to a restructuring of power relations, the redistribution of wealth and income, and alterations to human relationships.

One recent and much-debated instance of a disruptive new technology is the rise of ride-sharing services like Uber and Lyft. The use of private automobiles for the paid transportation of individuals is nothing new; a century ago, privately owned cars known as "jitneys" regularly picked up and delivered paying passengers.[5] Although it can be argued that they performed a useful service, jitneys were quickly banned by municipal governments due to safety concerns, but also because they were deemed unfair competition for public trolley and bus lines. The resurgence of ride-sharing services today has come as a result of the ubiquity of smartphones. After downloading an appropriate app, individuals can easily request a car and driver to pick them up and take them to their destination.

Boston Globe/Getty Images

Technological change may contribute to the decline of many established products and organizations, as exemplified here by the closure of a Borders bookstore.

Ride-sharing services are convenient for their users, and they allow drivers to work as much or as little as they prefer with no immediate supervision. The convenience and generally lower fares offered by these services has led to their spectacular growth. Uber, the largest, began in San Francisco in 2010; a mere five years later, it was operating in 58 countries and was valued at $50 billion.[6]

At the same time, however, ride-sharing services and especially Uber have generated a storm of protest. Drivers of established taxi firms and their supporters have mounted vociferous and sometimes violent protests against

Uber in New York, France, Brazil, Australia, and elsewhere.[7] Critics of Uber and similar services point to the iniquities that result from treating drivers as contractors rather than employees. As such, they are not eligible for pension and health care benefits, and ride-sharing firms avoid making contributions to Social Security payroll taxes. Issues have also been raised concerning the screening of drivers, vehicle safety, and insurance coverage.

In addition to energizing a considerable amount of mass protest, ride-sharing firms have met with government opposition. In California, the birthplace of so many new technologies, government agencies have challenged some of the practices of ride-sharing firms. In 2015, the California Labor Commission ruled that Uber drivers were employees, and not contractors, which would make them eligible for the benefits noted above. In the same year, New York taxi-enforcement officials seized nearly 500 cars over a six-week period, citing illegal street pickups by Uber drivers.[8] But government agencies elsewhere have been less decisive. In 2015, the Florida state agency charged with resolving unemployment compensation issues overturned an earlier decision that had labeled Uber drivers employees and not contractors.[9] In both California and Florida, the cases centered on single individuals and the overall applicability of either of these legal rulings is debatable. All that can be confidently said at this point is that it will likely take several years for the governments and the law to sort out the status of ride-sharing services and their drivers.

LUIS ROBAYO/Getty Images

Taxi drivers in Cali, Colombia protest the presence of Uber in their city.

On occasion, technological advance has fatally disrupted entire communities and the people living in them. One such place was Caliente, Nevada.[10] Caliente was a small town with a variety of civic amenities—schools, churches, a hospital, a theater, a park, and many prosperous small retail businesses. Many of its inhabitants were proud members of civic organizations such as the Chamber of Commerce, Rotary, the Masons, and the American Legion. It was a typical American small town, with typical American small-town values.

The life of the town was supported by a single industry: the servicing of steam locomotives. Caliente was an important division point on a transcontinental railroad, and many of the town's people worked as machinists, boilermakers, and repairmen. Their incomes in turn supported Caliente's commercial and civic establishments. Then, in the late 1940s, the diesel-electric locomotive rapidly replaced the steam locomotive. Diesels had many advantages; they were more fuel-efficient, hauled longer trains, and did less damage to the rails and roadbed. They also required less frequent servicing. When servicing was required, it took place in large centralized shops. As a result, service facilities were eliminated at many division points, and Caliente was one of them. The town lost its economic base, and within a few years, it had become a shell of its former self. People moved out, homes were abandoned, and shops were boarded up. The local newspaper sadly noted, “Employees who have given the best years of their lives to this railroad are cut off without anything to which they can turn, many of them with homes in which they have taken much pride; while others, similarly with nice homes, are told to move elsewhere.”[11]

Jack Delano/Farm Security Administration-Office of War Information Photography Collection (Library of Congress)

By providing many jobs, the servicing of steam locomotives formed the economic base of towns like Caliente, Nevada.

The tragedy of this small town has been repeated in many other communities affected by technological change. Many places of employment have closed down as new products and processes have replaced old ones, leaving communities and their inhabitants in desperate straits. The technological advances that produced these dislocations may have benefited society as a whole, but at great cost to the people who were immediately affected.

Technological changes do not always result in the disruption or modification of an existing social order; sometimes they may help to preserve it, as happened when pneumatic molding machines were adopted by the McCormick reaper manufacturing plant in the 1880s.[12] These machines were not installed, as conventional analysis would lead us to think, in order to reduce costs or to produce a better product; in fact, they were deficient on both counts. They were installed for the sole purpose of eliminating the skilled workers who formed the backbone of the National Union of Iron Molders, an organization that was challenging the entrenched authority of McCormick’s management. The molding machines allowed the replacement of skilled workers by unskilled ones, and three years later, having served their purpose, they were discarded by McCormick’s management.

Groups that are threatened by a technological innovation are not always as helpless as the iron molders apparently were. Many affected parties have been able to defend themselves against changes in the way of doing things. To take one example, prefabricated buildings were vigorously resisted by many local construction workers’ unions because they threatened their members’ jobs. One sad tale is narrated by Peter Blake:[13]

> Shortly after the end of World War II, an enterprising manufacturer decided to mass-produce a so-called service core: a complete “package” containing kitchen, bathroom, and utility room, with all fixtures, pipes, ducts, and wires in place, ready to be plonked down in any typical suburban house.
>
> The first twenty of these beautifully designed and beautifully made “packages” arrived on a site near Detroit; local union plumbers and electricians promptly refused to install them. Finally, after nine months of heated debate (during which the units, parked on a sidewalk, were exposed to weather and vandalism), the local unions agreed to handle the “packages”—by disassembling them on the sidewalk and then reassembling them, piece by piece, in each of the houses. The manufacturer, needless to say, thereupon went out of business.

The Luddites

In the cases previously described, the successful resistance to a new technology entailed some disruptive, even violent, acts. A resort to violence was also a feature of the case of the most famous example of resistance to technological change, the outbreaks of machine-smashing that occurred in early nineteenth-century England.[14] These attacks were the work of different groups who were collectively known as Luddites, a name that was derived from one Ned Ludlum, an apprentice stocking maker who, as legend had it, answered his master's reprimand by smashing his stocking frames with a hammer. There was really nothing new about these attacks; the breaking of machines by disgruntled workers had a long history in England, the earliest recorded episode taking place in 1663. But the Luddite disturbances that began in 1811 did represent a substantial increase in the scale of these attacks; by the following year, the government had to deploy 12,000 troops to restore order to the parts of England affected by the movement.

Since these attacks coincided with an era of rapid technological change, it is easy to draw the conclusion that they were motivated by the fear of many workers that their jobs would be lost to new machinery. The actual story is a bit more complicated. Luddite attacks occurred in a number of separate branches of the textile industry, and each was characterized by a distinctive set of motivations and responses. The Luddite movement began in the hosiery trades, where there had long been opposition to the use of wider stocking frames, which allowed the employment of poorly paid unskilled labor for the manufacture of an inferior product. The situation might have been resolved in a peaceful manner had it not been for the dire conditions encountered by many of England's working people at the time. The Napoleonic wars had resulted in the closure of many export markets, leading to a general trade depression. To make matters worse, a series of bad harvests led to sharp increases in the cost of food, and many workers found that their wages were insufficient to meet their basic needs. These conditions produced a fertile ground for the spread of "collective bargaining by riot," and Luddite attacks were soon fomented by shearers in the textile industry. Another occupational group, the handloom weavers, viewed the advance of steam-powered weaving machinery with understandable apprehension, and, following the example of workers in the hosiery trade, some of them attacked the factories housing mechanized looms, as well as the houses of their owners. Only in a few instances was the machinery itself directly attacked.

Luddite disturbances were expressly oriented toward blocking technological change in the cropping trade. Wool cloth was traditionally finished by raising the nap and then leveling the surface through the use of a heavy set of shears. The growing use of the gig mill, a device for raising the nap, along with the employment of a crude device for the mechanized cropping of cloth, threatened the livelihood of the traditional handworkers. They responded with some of the most severe attacks of the Luddite epoch. Although the machinery had been used for many years in many textile establishments, the severe economic conditions of the time brought matters to a head. More than the other instances of Luddite revolt, the attacks on cropping equipment were motivated by a deep fear of unemployment induced by technological change.

Within a few years, the Luddite assaults came to an end due to the deployment of government troops; the execution, imprisonment, and exile to Australia of a number of the participants; and the general improvement in living conditions after the defeat of Napoleon. The succeeding decades of the nineteenth century also saw the replacement of the small manufacturing establishment by the large factory. Machine-smashing by riotous crowds was a likely form of labor protest when workers were scattered and lacking in permanent organizational linkages. In contrast, the factory served as a fertile ground for the development of labor unions and other organizational vehicles for pressing the interests of workers. Industrial sabotage did not come to an end, but it was generally superseded by unionization and more effective forms of worker protest.

Neo-Luddism

These early episodes of machine-smashing have led to the application of the "Luddite" label to anyone opposed to modern technology. But it is perhaps unfair to impute to the original Luddites a hostility to technology per se. As we have seen, most instances of Luddism were not motivated by a fear and hatred of new machinery; their grievances were those of people suffering from the low wages and unemployment caused by a generally depressed economy. The machines were seen as convenient targets of their ire rather than the sources of it.

In recent times, technology itself has been attacked by individuals and groups who have been labeled as "neo-Luddites." In 1995, the *New York Times* and the *Washington Post* published a lengthy critique of modern society and the pivotal role of technology in creating and maintaining it. According to its author, a society based on modern technology brings some material comforts, but "all these technical advances taken together have created a world in which the average man's fate is no longer in his own hands or in the hands of his neighbors and friends, but in those of politicians, corporation executives and remote, anonymous technicians and bureaucrats whom he as an individual has no power to influence."[15] Regaining human freedom therefore required the total destruction of industrial society and the technologies that made it possible. This would not be a peaceful revolution, but one that required the destruction of factories, the burning of technical books, and the eradication of all of the components of an industrial civilization. This creed might have been dismissed as the agitated musings of a late twentieth-century Luddite, but its author was not just a misguided critic of the modern world. Shortly after the publication of the manifesto, it was discovered that its author was a brilliant mathematician named Theodore Kaczynski, dubbed by the media as "The Unabomber," an elusive figure who from 1978 to 1995 had been responsible for 16 bombings that killed three people and wounded 23 others.

Kaczynski was an extreme example; most expressions of neo-Luddism are aimed at excessive involvement in particular kinds of technology, especially those of the digital variety. A much milder criticism has come from a number of writers who have advocated “digital detox.” Few of them suggest jettisoning computers, tablets, and smartphones. Rather, they prescribe occasional respites from social media, Twitter feeds, email, and blogs. Occasional separation from digital devices, it is claimed, will lead to lower levels of stress, improved concentration, higher productivity, and more face-to-face human interaction.[16]

Whose Technology?

We have just seen how specific technologies have been used and resisted by particular groups in accordance with their own needs and concerns. These examples should help us to realize that technology does not proceed solely through its own momentum, as implied by technological determinism; its development is strongly influenced by existing social and political arrangements. Technological changes may take place because they advance the interests of a particular group. Conversely, some technologies may meet with stiff resistance because they threaten a group’s interests. Technologies do not stand or fall solely on their intrinsic merits; the decision to develop and deploy a new technology is often shaped by the distribution of power in a society.

Social, economic, and political arrangements affect the course of technological change by influencing the kinds of investments that are made, the research projects that are funded, and the general priorities that are established. Large organizations, such as corporations and government agencies, often wield disproportionate influence over the process of technological change. As we will see in Chapter 17, the federal government is a major source of financial support for research and development, with the Department of Defense, the National Aeronautics and Space Administration (NASA), and the Department of Energy (primarily for nuclear research and development) accounting for a large share of these expenditures. Although we can only speculate about alternative outcomes, it seems likely that American technology would have diverged markedly from its historic path if financial resources had been distributed differently.

Perhaps with a different set of sponsors, technological development might have made greater contributions to the solution of a number of pressing social problems, such as poverty and crime. At the same time, however, it can be argued that certain kinds of problems are simply not amenable to technological solutions. Even with significant changes in the funding of research, technological solutions to many social problems will not be forthcoming. This is an important objection, and we will examine it in the next section.

What Technology Can Do—And What It Cannot Do

The growth of technology has brought dazzling changes to our lives. At the same time, we seem to be mired in problems for which there seem to be no solution. The continued existence of these problems is all the more frustrating when contrasted with the rapid progress of technology. For example, we can use all kinds of sophisticated medical equipment and techniques to preserve the lives of sickly infants who have been born many weeks premature, but we cannot seem to conquer the poverty that often results in sick infants. Why, it is often asked, is there such a gulf between technological progress and social progress? Why can technology not be applied as a solution for more, if not all, of our problems? If we can put a man on the moon, why can we not …?

The Technological Fix

These are troubling paradoxes, and in recent years we have searched for ways of finding technological solutions to a host of problems. The drug methadone has been widely used to eliminate addicts' cravings for heroin. As highway accidents continue to result in tens of thousands of deaths and hundreds of thousands of injuries each year, efforts have been mounted to develop and manufacture cars capable of protecting their occupants from the consequences of incompetent driving. Cities befouled by graffiti have turned to the use of new paints and cleaning solutions that resist the endeavors of spray-can artists. Overweight men and women spend billions of dollars annually on medications and exercise apparatus in the hope of shedding excess pounds. College professors worried about plagiarized papers use computer programs to detect possible cheating.

The list of technologies that have been or could be applied to the alleviation of social problems is an extensive one, and examples could be endlessly supplied. What they have in common is that they are "technological fixes," for they seek to use the power of technology in order to solve problems that are nontechnical in nature. In this section, we will briefly examine a few of these technologies and consider the extent to which technology can alleviate these pressing problems.

Many technological fixes have been employed over time, although not always with the conscious understanding that technology was being used in lieu of some other method of achieving a desired end. To take one example, at the beginning of the twentieth century the United States was undergoing severe growing pains; the urban population was expanding at a rapid rate, accompanied by congestion, pollution, and a host of other urban ills. In a nation steeped in the Jeffersonian belief that cities were inherently evil and that the countryside was the best location for virtuous living, the conversion of the American populace into a race of unhealthy and disaffected city dwellers was viewed with alarm. A number of technologies did make urban life more tolerable, most notably those concerned with public health and sanitation, but these only served to ameliorate living conditions without addressing the real issue: the desire of many Americans to escape the city and return to a vaguely perceived rural idyll.

The pursuit of this goal gave a great impetus to the development of transportation technologies that would allow the solution of urban problems by eliminating the need for cities, at least as places of residence. Instead of comprehensively addressing urban ills through planning and the development of social programs, Americans pinned their hopes on new transportation technologies. The first of these was the electric trolley. Through the construction of extensive networks of interurban electric lines, it was hoped, America's urban problems could be literally left behind as a new generation of workers could commute from their places of work to their rural or suburban homes.[17]

In many American cities, the trolley was displaced by the automobile, as a great deal of automobile ownership was motivated by similar sentiments. Widespread automobile ownership promised an escape from the harsh realities of America's cities through individual commuting. As Henry Ford neatly summed things up, "We shall solve the city problem by leaving the city."[18] Ford's sentiments were taken to rhapsodical levels by one early twentieth-century journalist:[19]

> Imagine a healthier race of workingmen, toiling in cheerful and sanitary factories, with mechanical skill and tradecraft developed to the highest, as the machinery grows more delicate and perfect, who, in late afternoon, glide away in their own comfortable vehicles to their little farms or houses in the country or by the sea twenty or thirty miles distant! They will be healthier, happier, more intelligent and self-respecting citizens because of the chance to live among the meadows and flowers of the country instead of in crowded city streets.

It is hardly necessary to note that these hopes were not realized. The mushrooming growth of suburbs spawned by trolleys and automobiles did not create a harmonious social order based on rural values. All too often the legacy has been suburban sprawl, the deterioration of city centers, visual blight, air pollution, traffic fatalities, and many other ills. This is not to say that the automobile has been an unmixed curse; the benefits of personal mobility, privacy, and a sense of power have been too eagerly accepted to allow such a judgment. But the automobile, just like its predecessor the trolley, was hardly the technological panacea that was envisioned. The examples of the trolley and the automobile remind us that while some specific problems may be amenable to technological solutions, larger issues rarely admit of easy solutions through the application of technological fixes.

Archive Photos/Getty Images

The trolley held out the promise of an escape from the noise, dirt, and congestion of the early twentieth-century city.

Why Technology Cannot Always Fix It

The main difficulty underlying the use of technology to solve social problems is that these problems are fundamentally different from technical problems. In the first place, social and technical problems differ in their specificity. If you intend to design an air conditioner, you at least know what your goal is: to keep a space cool. In many ways, this problem is similar to the far more grandiose objective of landing a man on the moon; although there may be daunting technical problems to overcome, at least the goal is clear and unambiguous. But what if your goal is to reduce crime? Crime, unlike air temperature, is a very diffuse concept, encompassing everything from forgery to murder. Even when a particular crime is singled out for treatment, its causes are likely to be manifold and not easily addressed by a single technology.

To make matters even more difficult, social problems are directly concerned with human motivations and behaviors. It is one thing to change the temperature of the air by inventing and installing an air conditioning system; it is quite another to attempt to change human behavior through the same kind of technological intervention. Human beings are wondrously intricate creatures whose actions are governed by extremely complex motivations. Trying to understand, let alone change, human actions is an exceedingly difficult task. And humans are likely to resist when attempts are made to change their behavior. Consequently, successful technological fixes tend to be those that get the job done without challenging the existing values and interests of the population.[20]

It is also apparent that technological solutions work best when they operate within closed systems—that is, when the issue to be addressed is sealed off from outside influences. Of course, no technology exists in isolation from the surrounding society. A transportation system based on private automobiles, for example, is the result of choices exercised within the economic and political realm, such as a government's decision to build a highway network. But within a given technology there are many specific matters that can be treated as purely technical problems. In these cases, it is possible to approach the problem directly and not worry about the influence of other factors. If your car fails to start one morning, you can be sure that the problem lies only with its components; you need not concern yourself with sunspot activity or a recent presidential election in Peru.

When a problem is not so easily isolated, a technological solution is much less likely. Today, nearly one out of six boys under the age of 10 in the United States is diagnosed with attention deficit hyperactive disorder (ADHD).[21] This behavioral problem undoubtedly has a neurological basis, at least for some children, and amphetamine-like stimulants such as Ritalin are routinely prescribed to alleviate the symptoms of ADHD. It is likely, however, that many children afflicted with the disorder have problems that go beyond the neurological. Dysfunctional relationships and actions within a family can create stresses that produce ADHD. Under these circumstances, the administration of a drug will be insufficient. As the ADHD website of the National Institute of Mental Health notes, “Sometimes, the whole family may need therapy.”[22]

As a final point, it should be noted that no problem, technical or otherwise, is ever really “solved.” Not only are most solutions incomplete, they also generate new (and sometimes very different) problems. These unintended and often unforeseen problems may be even more difficult to solve than the original problem. This process has been dramatically illustrated by the rapid development of modern medical technologies, a topic that will be explored in greater depth in Chapter 7. Technical solutions such as the development of lifesaving drugs, organ transplants, and sophisticated diagnostic techniques have proliferated, but at the same time they have created a host of new dilemmas. Given the expense of many of these new technologies, it may be necessary either to spend more on medical care or to attempt to ration it. If these technologies are to be rationed, will this take place through the price mechanism, or will it be done according to some formalized procedure? In either case, serious ethical issues will have to be faced. Life-extending technologies have also raised vexing questions about the morality of prolonging a life under conditions that seem dismal indeed. Moreover, a longer individual life span leads to an aging population and the necessity for a wide range of adjustments to the society, the economy, and even the culture. Without belaboring the point, it should be apparent that no set of technologies will make our lives better without requiring the enactment of other changes, which may generate problems of their own.

The Appeal of Technocracy

These inherent limitations have not deterred a number of individuals and groups from trying to convert social problems into technical problems. There have been numerous flirtations with technocracy—the governance of society by engineers and other people with technical expertise, who attempt to develop policies based on technical and "scientific" principles. There is no denying that the technocratic vision is at first glance an appealing one. In a world too often governed by venal and incompetent politicians, there is something very attractive about a system of governance that supposedly bases itself on logic and the use of expertise. Moreover, where conventional political systems of all types seem endlessly involved with apportioning pieces of a small pie, adherents of some form of technocracy often promise a social and economic order that produces an ever-expanding pie through the application of the methods that have served technological development so well.

The promises and pitfalls of a technocratic approach to the solution of social problems are well illustrated by the theories of Scientific Management, as developed by Frederick W. Taylor (1856–1915) and his followers during the early decades of the twentieth century.[23] Scientific Management arose in an era marked by a profound paradox: industrial production was increasing at a rapid pace, but at the same time American society was racked by large-scale and potentially explosive conflicts between workers and management. Many cures for labor unrest had been proposed, but for Taylor, all of them missed the mark. Taylor had earned an international reputation as a metallurgical engineer, and his systematic studies on the cutting tools used for machining metal had resulted in major technological advances. If obdurate metals could be better controlled and shaped through the application of new technologies guided by scientific principles, why could the same thing not be done with workers?

To achieve this goal, Taylor and his colleagues developed a "scientific" regimen for studying work. The main technique used for this task was the time-and-motion study through which workers were systematically observed and their work motions precisely timed. Through an analysis of these observations and measurements Taylor came up with a supposedly optimum set of motions for a given job, all of them subject to rigid time constraints. Equally important, the development and administration of these motions were the business of management exclusively, and any attempt by workers to go about their tasks independently would necessarily result in wasted motions and general inefficiency. A basic tenet of Scientific Management was that the planning and organization of work had to be separated from its actual execution. Only specially trained managers had the time and expertise necessary for the devising of optimal methods of production. The prime obligation of the workers was to do what they were told to do.

Although they had no power to plan and manage their own work, workers were supposed to benefit from the system. Because their work activities were now optimized, production would supposedly increase significantly. Workers would necessarily share in these higher returns, for Taylor also advocated that workers be paid according to piece rates rather than straight wages; the more they produced, the more they earned.

THE MIDVALE STEEL CO.

Form D—124. Machine Shop.......................18..........

ESTIMATES FOR WORK ON LATHES

OPERATIONS CONNECTED WITH PREPARING TO MACHINE WORK ON LATHES AND WITH REMOVING WORK TO FLOOR AFTER IT HAS BEEN MACHINED	
OPERATIONS	TIME IN MINUTES
Putting chain on, Work on Floor	
Putting chain on, Work on Centers	
Taking off chain, Work on Floor	
Taking off chain, Work on Centers	
Putting on Carrier	
Taking off "	
Lifting Work to Shears	
Getting Work on Centers	
Lifting Work from Centers to Floor	
Turning Work, end for end	
Adjusting Soda Water	
Stamping	
Center-punching	
Trying Trueness with Chalk	
" with Calipers	
" with Gauge	
Putting in Mandrel	
Taking out "	
Putting in Plug Centers	
Taking out " "	
Putting in False Centers	
Taking out " "	
Putting on Spiders	
Taking off "	
Putting on Follow Rest	
Taking off " "	
Putting on Face Plate	
Taking off " "	
Putting on Chuck	
Taking off "	
Laying out	
Changing Tools	
Putting in Packing	
Cut to Cut	
Learning what is to be done	
Considering how to Clamp	
Oiling up	
Cleaning Machine	
Changing Time Notes	
Changing Tools at Tool Room	
Shifting Work	
Putting on Former	
Taking off "	
Adjusting Feed	
" Speed	
" Poppet Head	
" Screw Cutting Gear	
SIGNED TOTAL	

NAME ....
Sketch .... Number............
Order.............. Weight............
Metal.............. Heat No. ....
Tensile Strength.... Chem. Comp.......
Per cent. of Stretch ....
HARDNESS. Class...................

OPERATIONS CONNECTED WITH MACHINING WORK ON LATHES						
OPERATIONS	Speed	Feed	Cut	Tool	Inches	Minutes
Turning Feed In						
" " "						
" Hand Feed						
" " "						
Boring Feed In						
" " "						
" Hand Feed						
" " "						
Starting Cut						
" "						
Finishing Cut						
" "						
Fillet						
"						
"						
Collar						
"						
Facing						
"						
Slicing						
"						
"						
Nicking						
"						
Centering						
"						
Filling						
"						
Using Emery Cloth						
" " "						
TOTAL						

Machining—Two Heads Used
" —One Head Used
Hand Work
Additional Allowance

TOTAL TIME
HIGH RATE
LOW RATE

Remarks

Time actually taken

INSTRUCTION CARD FOR LATHE WORK

Frederick Taylor believed that all kinds of work could be reduced to rationally derived actions, much as machining operations could be precisely timed through the use of this worksheet.

The technocratic spirit of Scientific Management is thus evident: the tasks and prerogatives of management rested not upon the exercise of raw power but on management's technical superiority in guiding the production process. At the same time, Scientific Management promised relief from continual squabbling over relative shares of the fruits of production; an optimal system of organization would result in more of everything for everybody. Taylor was not content with using Scientific Management as a solution for the problems of the workplace; its principles, he claimed, "can be applied with equal force to all social activities: to the management of our homes; the management of our farms; the management of the business of our tradesmen large and small; of our churches, our philanthropic organizations, our universities; and our governmental departments."[24]

The appeal of Scientific Management was not confined to the United States, or even to the capitalist world. Vladimir Lenin, the leader of the Bolshevik Revolution in Russia, expressed a deep admiration for American technology and American forms of industrial organization, and for Taylor's ideas in particular. Although he duly noted that Scientific Management embodied "the refined cruelty of bourgeois exploitation," Lenin made it clear that its basic principles and procedures could contribute to the realization of Soviet economic goals: "The possibility of building Socialism will be determined precisely by our success in combining Soviet government and the Soviet organization of administration with the modern achievements of capitalism. We must organize in Russia the study and teaching of the Taylor System and systematically try it out and adopt it to our ends."[25]

The Technocrat's Delusion

Although some of its elements, such as the use of time-and-motion studies, can still be found in contemporary managerial practices, Scientific Management in its pure form never took hold in the United States, the Soviet Union, or anywhere else. A number of technical problems impeded its use. Considerable skill was required for the administration of time-and-motion studies, and they were especially difficult to conduct in work settings not characterized by repetitious actions. But of equal or greater importance, both management and labor realized that the implementation of Taylor's system posed fundamental threats to their own interests. Most managers were highly reluctant to delegate their authority to the dictates of "scientific" procedures.[26] Workers, on the other hand, resented the loss of what little autonomy they had, and they widely believed—with considerable justification—that higher levels of productivity would result in the downward adjustment of piece rates, leaving them no better off than before the program had been enacted.

Scientific Management, like all technocratically inspired systems, ignored the distinction between technical and sociopolitical problems. Even if Scientific Management had generated the productive increases it promised—which is unlikely—it would still have been strongly resisted by those who had to submit to it. Scientific Management promised a conflict-free method of administration where no such thing was possible. Workers and managers had their separate interests, and each group was unwilling to entrust its fate to Taylor and his disciples.

The basic fallacy of Scientific Management, one shared by all other variants of technocracy, is that *administration* can replace *politics*. Administration is based on the application of rules that allow the realization of given ends. It is thus a manifestation of the rational spirit of applying the best means for the achievement of a particular goal. It does not, however, determine these ends. The Internal Revenue Service (IRS) officials who administer the tax system are not the authors of the tax code. Around April 15, we may get angry about the perceived unfairness of the tax code, but it is pointless to blame the officials at the local IRS office, who are only executing a set of policies that they did not create.

Tax codes and other policies are formulated through choices made in the political arena. Neither technology nor administration can supply the values that form the basis of these choices. They cannot tell us what we should do with our lives, nor can they help us to resolve the fundamental issue that all societies confront: how to distribute fairly life's necessities and luxuries. The resolution of these issues will always be marked by sizable differences of opinion and a good deal of conflict. The technocrat's hope that society can be run on the basis of engineering principles will always remain an illusion.

To summarize, technological changes inevitably produce social changes. These changes, in turn, do not affect everyone equally. Although many technologies produce widespread benefits, not everyone benefits to the same degree, and there are instances where particular individuals and groups lose out completely. A choice of technology is often a determination of who wins and who loses; it is therefore proper that affected parties have the opportunity to participate in the process. This issue will be taken up in greater depth in the last three chapters. At this point, it can at least be hoped that without deflating the very real achievements of technology, some sense of its inherent limitations has been conveyed. Technology and the procedures underlying its development have been immensely powerful in their own realm; outside this realm, however, they are less likely to be effective. Equally important, the methods that have been so successful in developing and applying new technologies cannot be transferred to the governance of society. Technological development may make some aspects of our lives better, but it can never substitute for a just and effective political and social system.

QUESTIONS FOR DISCUSSION

1. Technological advance has often undermined established businesses. Most recently, the growth of internet-based e-commerce has posed a threat to conventional brick-and-mortar retail firms. Can you think of other business enterprises that the internet may damage or even destroy? Should anything be done to prevent this from happening?
2. Were the Luddites justified in mounting their attacks on machinery? How else might they have expressed their grievances? Would other kinds of actions have been more successful?
3. What examples of technological "fixes" can you think of? Have they been successful or not? What are your criteria for judging success and failure?
4. Political leaders at home and abroad are occasionally described as "technocrats." What are the implications of this description? Would you be more or less likely to vote for somebody who was described in this way?

CHAPTER FOUR

Scientific Knowledge and Technological Advance

One of the most common beliefs about technology is that it is simply "applied science." There are certainly many examples that can be cited in support of this view. Modern medical practices have been strongly influenced by fundamental discoveries in biology. The development of the transistor depended on a thorough understanding of quantum mechanics. Synthetic materials have been made possible by research into polymer chemistry. But one should not be content to rest with these examples. When the full spectrum of technological advance is considered, it becomes evident that science does not always play the decisive role in the development of technology. Indeed, many are the times when technological advances have taken place without the benefit of scientific knowledge. Conversely, on some occasions scientific advance has depended on prior technological achievements. In this chapter, we will look at the complex and shifting relationships between science and technology to come to a better understanding of how they differ, as well as the ways in which they have influenced each other.

The Historical Separation of Science and Technology

The definition of technology that was offered in the first chapter stressed that technology is based above all on the application of knowledge. But not all knowledge need be derived from scientific research. It is certainly true that today much of the knowledge required for technological advance is derived from scientific inquiries. Still, when the full history of technology is surveyed, it is apparent that most technologies have been developed and applied with little scientific input. The ancient Greeks made important contributions to many sciences—most notably astronomy, optics, and acoustics—as well as producing major advances in mathematics. Greek technology also progressed through innovations in agriculture, building construction, mining, the refining of metals, and military equipment. Yet none of these innovations drew to any significant degree on Greek science. Moreover, the Greeks' technological achievements were far less impressive than their scientific achievements, again indicating the lack of connection between the two. This lopsided pattern of development continued with the Romans, although in reverse. Roman engineering, manifest in the construction of great aqueducts and roads that are still in use today, reached a high level of development through the use of established principles.

Image Source/Getty Images

The Pont du Gard, an aqueduct near Nîmes, France, stands today as one of the triumphs of Roman civil engineering.

The European Middle Ages were a time of slow but significant technological advance. Improved agricultural practices were introduced, and the power of wind and falling water was used for everything from grinding grain to polishing metal. An effective horse collar allowed the literal harnessing of another important source of power. Soaring cathedrals were built in many parts of Europe, where they continue to be a source of awe and inspiration. Again, these achievements owed nothing to the scientific inquiries of the time. In fact, the designers and builders of the cathedrals apparently did not even have knowledge of multiplication tables. Then, too, there was little that technology could have drawn on, for medieval science exhibited little of the dynamism of medieval technology.

At about the same time, blacksmiths in parts of the Middle East were using steel superior to anything made in Europe. The swords and other edge weapons that they made from the steel first produced in Damascus (the capital of present-day Syria) combined a hard cutting edge with the flexibility necessary for an effective weapon. Yet it was only late in the twentieth century that the metallurgical principles underlying Damascus steel were discovered. Although it was unknown to the swordsmiths of the time, minute quantities of impurities, vanadium especially, made an essential contribution to the unseen processes that gave the steel its desired qualities. Consequently, when the composition of imported iron ore changed, the steel made from it lacked the desired characteristics. Unable to draw on modern metallurgical knowledge, traditional swordsmiths could not make the necessary adjustments, and the "secret" of Damascus steel was lost for centuries.[1]

The disconnect between scientific and technological development continued through the succeeding centuries, but there were some points of tangency. During the fifteenth and sixteenth centuries, the working methods of some "natural philosophers" (as scientists were so labeled in those days) benefited from an exposure to the practices of skilled artisans. In particular, the latter's commitment to careful observation, accurate measurement, hands-on practice, and an empirical approach to seeking the truth eventually were assimilated into the process of scientific inquiry.[2]

From the seventeenth century onward, scientific knowledge expanded at an unprecedented rate, but technological practices remained stagnant, largely unaided by these advances. This disconnect between scientific and technological progress is evident when France and England, two of the wealthiest and most powerful countries in Europe, are compared. By the early decades of the nineteenth century, France led the world in the generation of scientific advances, yet it lagged behind England in the practical use of steam power and the application of mechanical principles.[3] All in all, this historical record led one historian of science, Thomas Kuhn, to speculate that for the bulk of human history, technology has flourished in societies where science has remained undeveloped, and vice versa.[4] It is possible that our era is unique in its apparent ability to simultaneously support scientific and technological advance, all the while forging strong connections between them.

Studies of Contemporary Science–Technology Relationships

Even today, when the connection between science and technology is much stronger than it was in the past, a great deal of technological change takes place without substantial inputs from science. The relative unimportance of science for many technological developments was highlighted by a study that was conducted by the U.S. Defense Department in the mid-1960s. Dubbed Project Hindsight, this study assessed the extent to which pure scientific research had been essential to the development of 20 major weapons systems. In conducting their study, the Hindsight researchers began with a weapon system and traced its history backward in order to determine the key "events" that produced the knowledge that had been essential to its creation and development. The results of the study gave little credence to the commonly accepted view that scientific knowledge is the primary basis of technological development. Of the 710 events surveyed, only 2 were the result of basic scientific research, a minuscule 0.3 percent of the total.[5] Scientific research that was specifically directed toward a particular military project was of greater importance, accounting for 6.7 percent of events, while 2 percent were the result of scientific research directed toward commercial or nondefense needs. The greatest portion of events, the remaining 92 percent, owed little to concurrent scientific research, and relied almost entirely on established scientific concepts and principles.

Nearly 40 years later, a group of researchers conducted a similar study, dubbed Project Hindsight Revisited, in which they surveyed the processes involved in the design of the Apache helicopter, the Abrams battle tank, the Stinger antiaircraft missile, and the Javelin antitank missile. Although the researchers did not attempt to determine the role of basic scientific research in the design of these weapons, their report noted that most of the relevant research had been done well before these projects were initiated, and that very little basic research had been done in order to address specific design issues.[6]

Although it showed that technology's connection to science had not been as straightforward as is often assumed, one should not draw sweeping generalizations from this study. The authors of the original Hindsight project, as well as a number of its critics, were quick to note that the long-term influences of scientific research were not captured by the study's methodology. Project Hindsight considered only the effects of scientific research conducted for the most part after 1945, thereby removing from consideration the immense body of scientific knowledge that had accumulated before that time. The study's researchers found that a median delay of nine years separated the completion of a scientific research project from its technological application, even when research efforts targeted at specific missions were included. It was therefore not surprising that basic scientific research had few technological consequences during the 20-year span covered by the study.[7]

By taking a longer chronological view, another study, entitled Technology in Retrospect and Critical Events in Science (TRACES), contradicted Project Hindsight by determining that a number of innovations, ranging from oral contraceptives to videocassette recorders, had been directly tied to prior scientific research.[8] But even here, the researchers were obliged to point out that the sequence from scientific discovery to technological innovation is not linear, and that "a better understanding needs to be achieved concerning the two-way influence between science and technology."[9]

How Technology Differs from Science

If nothing else, these studies show that the connection between science and technology is not adequately captured by the common belief that technology is simply applied science, and that scientific discoveries quickly and easily give rise to technological applications. Some technologies draw directly on scientific research, while others make little use of it. This is rather obvious. Of greater significance is the fact that science and technology are quite different in their basic natures. This makes the translation of scientific knowledge into technological application a difficult and complex process.

The Pure versus the Practical

Whereas science is directed at the discovery of knowledge for its own sake, technology develops and employs knowledge in order to get something done. The content of the knowledge may be rather similar, but different motivations underlie its pursuit and application. Here, of course, we are on slippery ground; it is often extremely difficult to discern the motivations underlying a person's activities, and it may well be the case that a particular engineer may be driven by the same desire to understand something for its own sake that animates the work of a pure scientist. Motives are often mixed and complex.[10]

Much of the prestige accorded to science is the result of its supposed purity; science is thought to be an intellectual venture free from political, organizational, and economic constraints. The insulation of scientists from the demands of their patrons confers a sense of higher ethical standards; scientists are beholden to nothing but the internal demands of science. A great deal of recent scholarship has sharply questioned this assumption. As has been the case with some current studies of the history of technology, science has been described and analyzed as a social construction. From this standpoint, scientific inquiry is not a disinterested, fact-driven search for truth, but a human creation that has been shaped by cultural patterns, economic and political interests, and gender-based ways of seeing the world.[11] For uncompromising social constructivists, successful scientific outcomes may have more to do with negotiation, the support of designated authorities, and resonance with prevailing attitudes than theoretical elegance or experimental evidence. Under these circumstances, the idea that science is a "pure" intellectual endeavor cannot be supported.

The social construction of a science approach remains controversial, and, in any event, few social constructivists believe that scientific facts and theories are purely social creations that have nothing to do with underlying realities. Moreover, social constructivism is a largely academic enterprise, and most laypeople still believe in the objectivity of science and the purity of scientific motives. These qualities give individual scientists a claim to autonomy not enjoyed by other employees. Scientists are thus in a particularly favorable situation. The assumption that scientific progress leads to material progress confers an aura of practicality on their work, while at the same time they are in a good position to resist the overt control of their work by their sponsors.

In contrast, most engineers work under tighter constraints. Their employers expect results that have immediate applications and fall within a narrowly defined range of possibilities. A scientist may abandon a theory or an experiment in order to pursue a line of inquiry that unexpectedly arises during the course of his or her research. An engineer, however, rarely has this opportunity; there may be some room for serendipity, but the bridge has to be built within a given time frame and under definite budget constraints. For this reason, what separates scientific and technological inquiries may not be the motivations of individual practitioners but the motivations of their employers and patrons.[12]

Scientific Knowledge and Technological Knowledge

AFP/Getty Images

Superconductive magnets kept at extremely low temperatures are essential components of magnetic levitation, which is demonstrated by this high-tech skateboard. Although there are several other technological applications of low-temperature superconductivity, the underlying physics of the phenomenon is not well understood.

Technology differs from science in the type and depth of knowledge it employs. The ultimate question asked of scientific knowledge is “Is it true?” For technological knowledge, the key issue is “Will it work?” Technological problems can often be solved with no understanding of what is going on. As we have seen, throughout history many technologies were effectively applied even though the basic principles underlying their operation were poorly understood, if they were understood at all. A similar situation can be found today; high-temperature (which, in this case, means 130 K or minus 418°F) superconducting materials are beginning to be used in motors and other devices, even though the physics of the process remains something of a mystery. It is also instructive to consider the story of the great scientist Johannes Kepler (1571–1630), who developed and employed the calculus of variation in order to derive optimum dimensions of wine barrels—only to discover that these dimensions were already being employed by the coopers who actually built the barrels![13]

Many other technological innovations seem to fall into this pattern. Although scientifically derived principles may emerge after the fact, many technologies have been guided almost exclusively by trial and error, with the successful ones informed by an intuitive sense of the right solution, and not by scientific truths.[14] As Eugene Ferguson has observed, at the end of the nineteenth century there were no scientific principles that could be invoked during the design of the first motorcycles; the placement of the engine, fuel tank, and other major components could be determined only through the actual construction and operation of motorcycles, without the benefit of scientific principles or other forms of existing knowledge. Ferguson therefore makes the point that “there is often no a priori reason to do one thing rather than another, particularly if neither had been done before. No bell rings when the optimum design comes to mind.”[15]

How Technology Facilitates Scientific Discovery

Although we tend to think of science as the leading factor in technological advance, the reverse often occurs: scientific knowledge and discovery may be a by-product of technological achievements. The most obvious examples of technological developments playing a vital role in fostering scientific advance can be found in the provision of devices and instruments. From early telescopes and galvanometers to today's electron microscopes and computers, the products of technology have steadily increased our ability to observe and analyze the phenomena that science presents as objects of inquiry. To take only a few recent examples, the scanning tunneling microscope has allowed a much better imaging of plant and animal cells; the Hubble Space Telescope has given us new insights into the age and size of the universe and how it was created; particle accelerators have enabled physicists to obtain a better understanding of the basic constituents of matter; and magnetic resonance imaging, complemented by powerful computers, has played a key role in the rapid development of neuroscience, the study of the brain and how it functions. All in all, it is thus no exaggeration to claim that scientific "instruments shape research, determine what discoveries are made, and perhaps even select the types of individuals likely to succeed as scientists."[16]

Less obvious are instances where scientific advance was stimulated by a technology already in operation that defied accepted scientific explanations and theories. This process is exemplified by the story of how the steam injector contributed to the abandonment of a popular scientific theory regarding the nature of heat.[17] In the mid-nineteenth century, many scientists believed that heat was the result of the presence of a substance known as "caloric." According to this theory, when caloric combined with other materials those materials became hot. Also, caloric particles were supposedly self-repellent; thus, when sufficient quantities of these particles came into contact with water, their repulsive quality resulted in water turning into steam.

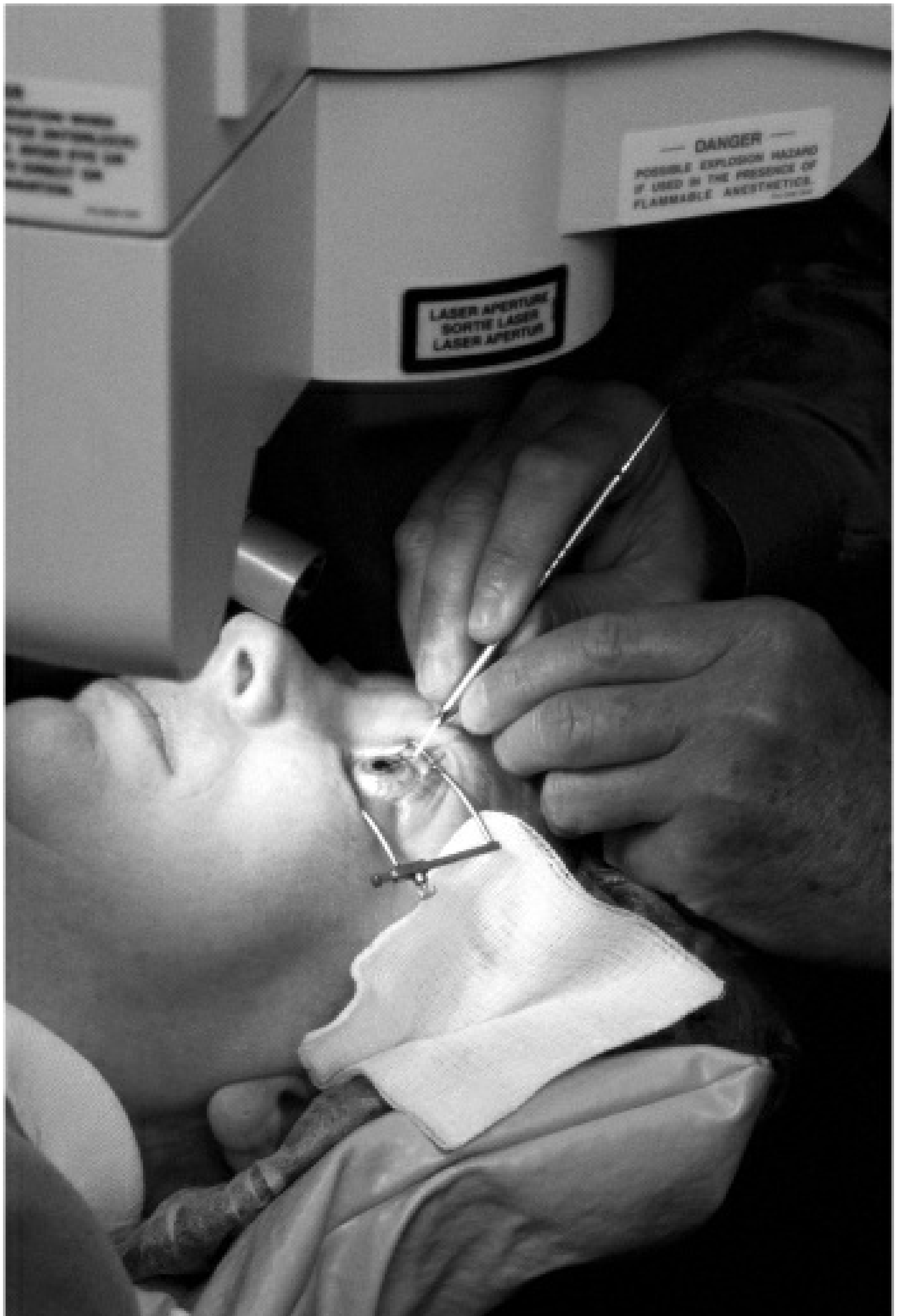
While this theory had its uses, it could not explain the operation of the steam injector that was patented by Henri Giffard in 1858. The injector used steam from the boiler to lift water into it, an operation that seemed to mimic perpetual motion for those who subscribed to the caloric theory. In fact, Giffard, who was well trained in academic science, based his injector on the Bernoulli principle, which postulated that the pressure of a fluid (in this case, steam) drops as its velocity increases. The operation of the injector was therefore the result of expanding steam producing a partial vacuum that sucked water into the boiler.

Giffard's injector was no perpetual motion machine; it used a quantity of heat that was equal to the quantity of work expended in raising water into the boiler, plus the losses due to radiation and contact with surrounding surfaces. Its operation therefore made sense only when the interconvertability of heat and work was understood. This idea rested on the kinetic theory of heat, and it followed the first law of thermodynamics (which stipulates that, quantitatively, energy cannot be created or destroyed). The kinetic theory of heat was formulated several years before Giffard's invention but had been slow in winning acceptance. The rival caloric theory had many adherents in the scientific community, and it took the apparent anomaly of the injector to convert many of them to the now universally accepted kinetic theory of heat.

The steam injector illustrates the often subtle interactions between science and technology. The operation of the injector provided a strong stimulus for the acceptance of one scientific theory and the rejection of another. At the same time, another scientific theory had been essential to the invention of the injector. But scientific theories by themselves were not enough; the design and effective use of the injector still depended on the experiments and modifications performed by practicing engineers, for no set of theories was powerful enough to guide its design. Again, we have an example of a technology that worked even though existing scientific principles did not completely explain its operation.

This example and many others that could be cited indicate that science and engineering are still separate enterprises, although there are certainly linkages between them. Scientific knowledge can result in technological advances, while at the same time new and extant technologies can create opportunities and motivations for new scientific inquiries. Many technological developments reach a plateau due to a lack of scientific knowledge, thereby generating a clearly perceived need for fundamental scientific research. The knowledge obtained through technological practices and applications is thus the raw material of many scientists, whose work centers on explaining technological practices at a deeper level.[18]

One example of this process is the invention of the laser. During World War II, the United States and other countries were engaged in a major effort to develop radar as a means of detecting enemy ships and aircraft. While participating in the development of radar technology, scientists used the knowledge that they had gained to make significant advances in microwave spectroscopy, which allowed a more accurate determination of molecular structures. One of the main developers of microwave spectroscopy, Charles Townes, although nominally a physicist, continued to work on technologies for the generation of microwaves. In 1954, he and his co-workers created a device they called the “maser” (for “microwave amplification by stimulated emission of radiation”). In 1958, he and a former student published a paper that outlined how the principle of the maser could be extended into the region of infrared, visible, and ultraviolet light. These ideas were the foundation for the laser (the acronym for “light amplification by stimulated emission of radiation”). At first, the laser was the classic example of an invention looking for an application. But in succeeding years, the laser became the basis for a host of technologies ranging from scanners used at checkout counters to devices used for the surgical rejoining of detached retinas. In short, the development of one technology (radar) gave rise to scientific advance (the determination of molecular structures through microwave spectroscopy) and at the same time provided a scientific foundation for an entirely new technology (the laser).[19]



O. LOUIS MAZZATENTA/National Geographic Creative

One of the unanticipated uses of the laser is its use as a surgical instrument for the correction of faulty vision.

As this example indicates, the relationship between science and technology, far from being linear, may be one characterized by considerable back-and-forth movement. This feedback between science and technology may be a fundamental source of their dynamism.[20] This complex reciprocal relationship can be seen in the highest accolade for scientific achievement, the Nobel Prize. Although there is no prize for technology per se, a large portion of the prizes for chemistry, physics, and medicine have in fact been awarded for the invention of new devices and techniques. Some of them eventually resulted in commercially viable products, while others were used for further scientific inquiries.[21] In sum, when science and technology have gone their separate ways, as has been the case for most of human history, they develop more slowly than when they interact with each other, as they have done to an increasing degree during the present era.

Legitimating Science through Technology

There is a final and less immediately evident contribution that technology has made to scientific progress. Although an effort has been made here to demonstrate that science has not always been decisive in the development of new technologies, the opposite is widely believed. To a significant degree, this faith in the practical consequences of scientific research has given science the immense prestige and legitimacy that it enjoys today. Many areas of scientific inquiry have become increasingly expensive propositions. To take two admittedly extreme examples, the James Webb Space Telescope, which is slated to replace the Hubble Space Telescope in 2018, is expected to cost $8.7 billion over a 5-year period, while Europe's Large Hadron Collider carried an initial price tag of $4.9 billion. Expensive programs need sponsors with deep pockets. Although neither project is expected to generate technological spinoffs, many other high-priced research programs would die for lack of funding without the promise of some practical paybacks. Over the years, quite a lot of sophisticated and expensive biological research has been justified on the grounds of its potential contribution to curing cancer—a hope that has yet to be realized. Biological research is hardly unique in this aspect, as scientists have become quite proficient in writing grant applications that stress the potential useful outcomes of their abstract inquiries.

Financial support, however important it is to the maintenance of scientific inquiry, is only part of the picture. The willingness of government agencies to grant money for scientific research and of citizens to have their taxes used in this manner is indicative of a widespread belief in the legitimacy of scientific research. This legitimacy is in large measure the product of the presumed ability of science to ultimately produce practical results. These ascribed powers of science have been analyzed by Langdon Winner:[22]

> [The ultimate success of science] must be accounted to its fulfillment of Baconian ambitions—the delivery of power. Other modes of knowing have been able to give an intelligible, systematic, aesthetically pleasing picture of reality. If science had only been able to accomplish this and

> nothing more, it is likely that it would have been supplanted by yet another philosophy of inquiry. But in the West at least, the test is not so much what do you know? or how elegant is your interpretation of worldly phenomena? but rather, what can you actually do? This is the conclusive factor, the reason that, for instance, social science has never fully established its credentials in the halls of science.
>
> Science succeeds over rival ways of knowing—poetry, religion, art, philosophy, and the occult—not by its ability to illuminate, not even by its ability to organize knowledge, but by its ability to produce solid results…. In the last analysis, the popular proof of science is technology.

This expected ability of science to “deliver the goods” is somewhat paradoxical, for science as a system unto itself responds rather poorly to economic needs. This has even been made into a virtue by many scientists who pride themselves on their insulation from the crass demands of the marketplace. As we have seen, the autonomy of scientists has been legitimized by the conception of science as a detached exercise in free inquiry. But it is also the case that the unpredictable nature of scientific discovery often precludes the possibility of useful discoveries being produced to order.

Scientific research, especially when directed at the discovery of basic principles, is an uncertain endeavor that cannot be guided by schedules and routinized procedures. This is illustrated by the response of one researcher who was offered more research funds by an officer of his company in the hope that the conclusion of a particular project could thereby be hastened. The researcher replied that it would be just as logical to expect that eggs could be made to hatch in half the normal time if twice as many hens were recruited to sit on them. Not only are the paths of scientific discovery full of twists and turns, but many of them terminate in dead ends. Of course, technology may also be incapable of solving the problems presented to it. If it were otherwise, we would have a cure for cancer by now. But most technology is directed toward the solution of specific problems, which narrows its scope and makes it a more predictable enterprise than science.

Scientific knowledge often ends up being extremely useful to technology, but in most instances that is not why it was produced. Scientists typically create knowledge for other scientists. Their efforts are focused on the testing of theories and the solution of problems that have been generated by previous scientific inquiries. If scientific knowledge is used for technological applications, it is because engineers and other technologists have appropriated it for their own use. In most places where science and technology meet, engineers and technicians "pull" knowledge out of science. Only in rare instances is knowledge directly relevant to technological application "pushed" by science itself.[23]

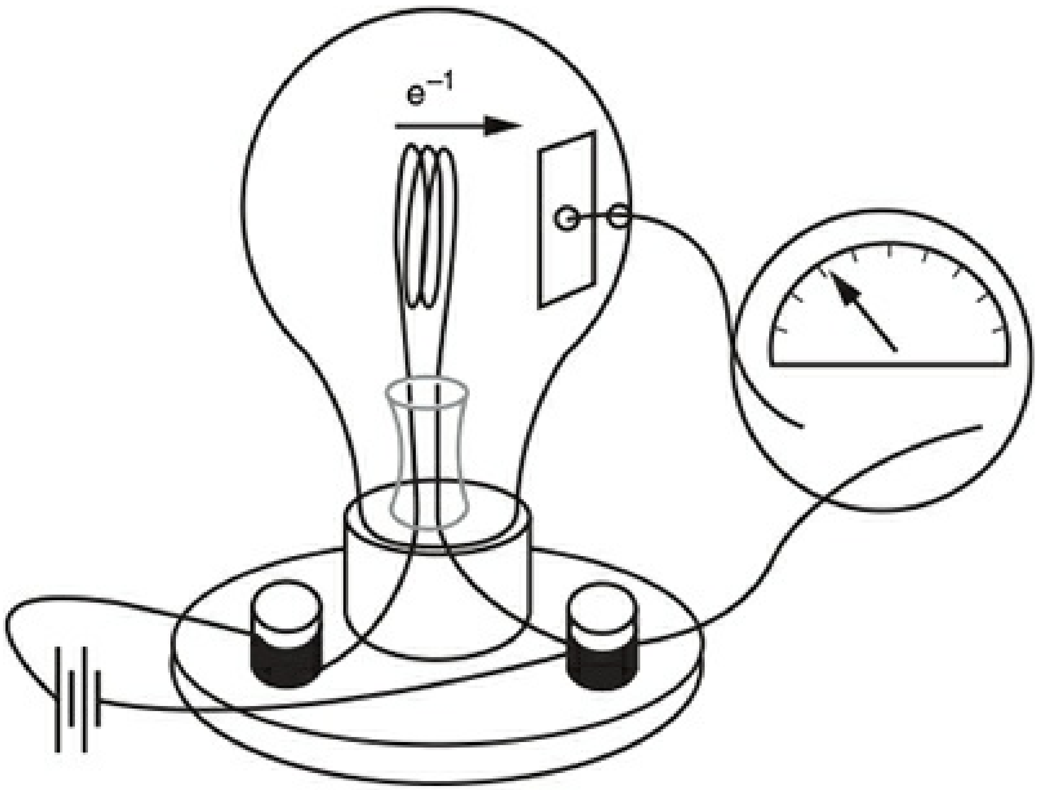
When knowledge is "pushed" from science into technology, it often happens indirectly. The transfer of knowledge from science to technology can be a subtle process, with scientific research motivating technological change by pointing out unseen problems and at the same time suggesting new opportunities. This happened in the 1930s when the evolving science of aerodynamics showed how the behavior of aircraft changed dramatically at high speeds. This research clearly indicated that conventional propeller-driven airplanes would encounter an insurmountable velocity barrier as they approached the speed of sound. At the same time, aerodynamic research indicated that proper streamlining could greatly increase the speed at which airplanes could fly, provided they had a different method of propulsion. In making these discoveries, aerodynamic researchers generated a powerful impetus for the development of jet engines that produced more power and did not have the inherent limitations of existing power systems.[24]

The Translation of Science into Technology

Today, many technologies make heavy use of the products of scientific inquiry. Much of this use, however, is indirect. A great deal of scientific information finds its way into technological practice through the education of engineers.[25] The findings of basic scientific research eventually appear in handbooks, university courses, and textbooks. Much of the scientific knowledge presented in these ways is eventually drawn on during the course of technological development.[26]

Even here there can be problems. It has been argued that a significant amount of engineering education has been distorted by overreliance on science-based instruction. This has led to a devaluation of nonverbal thought, an excessive stress on mathematics, and an unwillingness to tackle problems that do not have a single unique solution.[27] Scientific thinking converges toward a single (if temporary) set of theories, while the history of technology is replete with examples of the old saying that there’s more than one way to skin a cat. An excessive focus on the principles and methods of science may therefore restrict creativity and lead to an overly rigid approach to the solving of technological problems.

There is no getting around the fact that despite all that they have in common, science and technology usually operate in different worlds. If the two are to share in a productive symbiosis, they must be sustained by continual efforts to span the differences that separate them. In many cases, technological development has been stimulated by the presence of individuals and organizations that simultaneously participate in scientific and technological communities. Their primary role is to serve as translators, “decoding information generated in one system and transforming it into information usable in another.”[28]



The Edison effect: Thomas Edison inserted a metal plate into a bulb and noted that when the power was turned on, a meter attached to the plate indicated that current was flowing through the air between the glowing filament and the plate.

This process can be seen in the events that culminated in the invention of the vacuum tube, which in the pre-transistor era was an essential part of radio and television technology. The story began with Edison's invention of the light bulb.[29] While trying to determine why dark deposits were forming on the interior walls of the bulbs, Edison found that the needle of a galvanometer deflected when a wire probe was placed in a circuit between the galvanometer and the bulb's glowing filament. Edison did not understand what was producing the flow of electrical current through thin air, although he patented the modified bulb for use as a voltage indicator. (Many years later, the realization came that the current was produced by the migration of electrons from the negatively charged filament to the positively charged probe.)

Nothing practical came of Edison's discovery until John Ambrose Fleming renewed his acquaintance with the modified bulbs. During the 1880s and 1890s, Fleming had conducted a number of experiments using them; his sporadic efforts produced useful scientific knowledge, but no technological applications. Things began to change in 1899 when he became technical adviser to Guglielmo Marconi's Wireless Telegraphy Company. At that time, the chief need of the infant radio industry was for a detector that could efficiently convert the weak oscillatory current of radio waves into direct current. After a few years' work with other devices, in 1904, Fleming came to the sudden realization that the specially equipped light bulbs with which he had previously worked might be used for this purpose. His hunch proved to be correct, and the "oscillation valve," as he named the device, began to be commercially used for the detection of radio signals a short time later.

Fleming had not been the only one to experiment with modified light bulbs, but he had been uniquely situated to act as a "translator" between science and technology. He was not an inventor like Edison or a full-fledged scientist like other experimenters. Rather, he was a scientifically trained engineer and teacher who was closely associated with the electrical industry and with engineering-training institutions. These separate but interrelated roles gave him the knowledge and the motivation to convert a scientific curiosity into a practical technology.

Corbis

John Ambrose Fleming with a vacuum tube diode.

The Commonalities of Science and Technology

Up to now, this chapter has stressed the differences between science and technology, but they also share common characteristics. Both science and technology are based on the gathering of knowledge, and they both advance through the cumulative development of that knowledge. Isaac Newton is reputed to have said that he could see farther because he stood on the shoulders of giants. That is, his scientific discoveries were based on knowledge produced by earlier scientists. The same holds true for modern technology. Just as the scientific achievements of an individual chemist owe a great deal to the past research efforts of other chemists, the work of an aerospace engineer draws upon the accomplishments of other aerospace engineers.

More generally, science and technology have been nourished by a supportive culture at least since the days of the early Industrial Revolution. Although science provided few direct inputs into early industrialization, the values and attitudes of engineers and mechanics had much in common with those of scientists. As Peter Mathias has described this era:[30]

> Together, both science and technology give evidence of a society increasingly curious, questioning, on the move, on the make, having a go; increasingly seeking to experiment, wanting to improve. So, much of the significance [of the cultural climate] impinges at a more diffused level, affecting motivations, values, general assumptions, the mode of approach to problem-solving, and the intellectual milieu rather than a direct transfer of knowledge.

A key component of the shared culture of modern science and modern technology is their reliance on the rational thought processes described in Chapter 1. Although the development of both science and technology requires intuitive and other nonrational modes of thought, rationality is essential to the general methodology of science and technology. In general, a rational approach includes a propensity to challenge traditional intellectual authorities; a willingness to settle questions through observation, testing, and experimentation; and a desire to develop exact methods of measurement.[31]

Some of the basic elements of this mode of inquiry are described by Robert Pirsig in *Zen and the Art of Motorcycle Maintenance,* where he explains how even a clearly technological task like determining why a motorcycle won't start is addressed through the use of procedures that have much in common with scientific inquiry.[32] As a first step, a mechanic might formulate the hypothesis that the battery is dead; he or she will then try to honk the horn to see if the battery is working. If the horn honks, the mechanic concludes that the problem doesn't lie with the battery and proceeds to other parts of the electrical system. Should tests performed on these components show them to be in good shape, the mechanic may hypothesize that the problem lies with the fuel system and conduct tests (experiments) to check them out. And so it goes, with the formulation of a series of hypotheses and the conducting of experiments to test them. In the end the problem is isolated and perhaps fixed; if nothing else, you know what is wrong as you push your motorcycle along the side of the road.

Of course, one shouldn't take this analysis too far. Although both science and technology make heavy use of rational modes of thought, neither can be properly characterized as the embodiment of rationality. Scientific theories must be logically consistent and rationally articulated, but their ultimate source is human creativity and imagination—qualities often at a considerable distance from rational thought processes. At the other end of the scientific enterprise, the testing of these theories, there are no perfectly rational means of determining the criteria through which theories can be validated or disproved. Even empirically derived "facts" can be subject to interpretation, and general worldviews can strongly affect what is acceptable as "proof."[33] In similar fashion, a great deal of technological advance is also the product of nonrational thought. And, as was noted earlier, the benefit or harm of a particular technology cannot always be adjudged according to criteria based on rationally determined principles; a great deal hinges on values and ethical standards that have been derived through other means.

Other commonalities between science and technology can be noted. Mathematics is important to both as a kind of language and as an analytical tool. The practice of both science and technology requires university-based training that can stretch out for many years. Also, engineers and other technological practitioners employ organized knowledge that is presented and diffused through journals, books, blogs, and professional meetings that have many similarities to those found in the realm of science. And although engineers usually work for firms that try to retain exclusive use of innovative products and processes that were developed in-house, there can be a surprising willingness on the part of engineers to share their knowledge with engineers employed elsewhere, just as occurs between scientists.[34]

Although the sharing of information has long been a characteristic of science, in recent years an increasing number of scientific discoveries have come to be treated as proprietary information. This tendency has been particularly evident in biotechnology, where basic research is often essential for the rapid development of biological and medical technologies. Under these circumstances, the usual distinction between basic science and technological application no longer has much meaning.[35] In this field, and in a growing number of others, the distinction between science and technology has become so blurred that both can be subsumed under a single rubric, “technoscience.” Since innovative, biologically based technologies can generate very large profits for the firms that develop them, these firms are likely to be reluctant to share their discoveries with the scientific community as a whole. It is not just for-profit private firms that have a reason for keeping scientific knowledge under wraps; universities are major players in industries based on cutting-edge technologies. Consequently, the research conducted in their laboratories may eventually generate substantial revenues. For universities and private firms alike, the lucrative coupling of basic research with technological application may seriously inhibit the sharing of new information, substances, and devices. These restrictions violate a basic canon of scientific culture—the free distribution of ideas and research findings—and, in the long run, they may result in a slower rate of progress for both science and technology.

Finally, at the core of the common culture of science and technology is a sense of optimism and progress within their own realms. Science and technology are dynamic enterprises that build on past successes, but they also make profitable use of their failures. An inadequate scientific theory may lead to the formulation of a better one, and a collapsed bridge is likely to provide valuable lessons that help to prevent future failures.[36] Above all, science is predicated on the belief that the world is knowable, while technology is animated by a conviction that it will always be possible to do something better. Both of these beliefs contribute to the dynamic, essentially optimistic spirits of science and technology.

Although there are broad similarities between science and technology today, their coexistence is problematic, much as it has been in the past. For Melvin Kranzberg, their coexistence has been marked by the same kind of tensions and attractions that characterize the marriage of a man and a woman. In Kranzberg's words:[37]

> History suggests that science and technology, though wedded today, went through a long, indifferent courtship. They grew up independently, either oblivious to each other's existence or taking scornful note of the other's presence. When they reached the age of puberty—the scientific revolution in the case of science and the Industrial Revolution in the case of technology—a mild flirtation ensued.
>
> The marriage, when it came at last, was a marriage of convenience and necessity, certainly no love match. Insofar as military needs helped to bring about many a daring and secretive meeting, the ceremonies when finally reached, could be called a shotgun wedding; and the couple, predictably, has not lived happily ever after.
>
> Each partner has retained a good deal of independence, though lately both have been having identity problems. There are constant bickerings about who is contributing more to the marriage. They quarrel over mutual responsibilities, the education of their offspring, and, as might be expected, the household budget.
>
> It is a very modern marriage. Science and technology live independently, yet coordinately, as if they had but one joint bank account and one car. Divorce is frequently discussed. It is invariably rejected, however, because the scandal would surely deface the public image of the parties, and because, I suspect, of the indisputable pleasures and the learned frivolities of the bed.

This chapter began with the assertion that technology is not simply applied science, and went on to provide some evidence for this statement. It is undeniable that technology today makes extensive use of scientific knowledge. But as we have seen, scientific knowledge often makes its way into technological practice in a very roundabout way. At the same time, a considerable amount of scientific advance stems from prior achievements in technology. Science and technology have evolved along separate paths that often intersect. At these points of intersection, each has often contributed to the other’s development. Both science and technology seem to do best when they remain in close contact, but this should not obscure the fact that in most instances they remain very different enterprises.

QUESTIONS FOR DISCUSSION

1. In 1993, the U.S. Congress canceled one of the most ambitious scientific research projects of all time, the superconducting supercollider for high-energy physics. One of the major reasons for canceling the project was its cost, which was estimated to be at least $8.5 billion. In the years that followed, the U.S. government continued to support the International Space Station, a project that will end up costing more than $100 billion by the time it is completed. Why has one project received financial support while the other was killed? Was the perceived scientific value of the projects the paramount concern of congressional decision makers?
2. Why have science and technology been so closely associated in popular thought? How does each of them gain from this association?
3. Monetary considerations aside, which would you find more personally satisfying: making a scientific discovery or inventing a useful technology? Why?
4. Quite a few research projects in chemistry, physics, and biology receive grants for millions of dollars, whereas most researchers in the social sciences and humanities consider themselves lucky to receive a few thousand dollars in grant aid. Why is this so? Does it represent a proper distribution of research funds?
5. Students in engineering programs typically take a substantial number of science and mathematics courses. Should some of these courses be eliminated and replaced with different kinds of courses? If so, which courses should be taken instead?