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Albert H. Teich
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2. How Society Shapes Technology

ROBERT POOL

Why do we all use VHS cassette recorders instead of Betamax, when most experts (and many nonexperts) agree that Betamax is a better technology? The two formats came on the market around the same time. They are incompatible, however, so consumers had to choose one or the other. When VHS gained a small lead, perhaps because of better marketing, perhaps because it uses six-hour cassettes instead of Betamax's five, or perhaps for other reasons, video rental stores began to stock more VHS tapes. This led people to buy more VHS machines and started a self-reinforcing cycle that, in a few years, made Betamax as obsolete as eight-track audio players.

*This kind of interplay between the developers of technology and the society that uses that technology is characteristic of the way in which technology and society interact. It's not technological determinism and it's not just social construction; it's a combination of the two. Robert Pool examines this fascinating interplay in depth in his book, *Beyond Engineering: How Society Shapes Technology*, from which the following selection is taken. "Modern technology," he writes, "is like a Great Dane in a small apartment. It may be friendly, but you still want to make sure there's nothing breakable within reach." Pool, a freelance writer who has written for *Science* and *Discover* and was news editor at *Nature*, is the author of *Fat: Fighting the Obesity Epidemic* (2001) and *Eve's Rib: The Biological Roots of Sex Differences* (1994).*

Any modern technology is the product of a complex interplay between its designers and the larger society in which it develops.

Consider the automobile. In the early part of this century, gas-powered cars shared the roads with those powered by boilers and steam engines, such as the Stanley Steamer.¹ Eventually, internal combustion captured the market and the old steamers disappeared. Why? The usual assumption is that the two contenders went head to head and the best technology won. Not at all.

Although the internal combustion engine did have some advantages in performance and convenience, steam-powered cars had their own pluses: They had no transmission or shifting of gears, they were simpler to build, and they were smoother and quieter to operate. Experts then and now have called it a draw — the "better" technology was mostly a matter of opinion. Instead, the steamers were killed off by several factors that had little or nothing to do with their engineering merits. For one, the Stanley brothers, builders of the best steam-powered cars of the time, had little interest in mass production. They were content to sell a few cars at high prices to aficionados who could appreciate their superiority. Meanwhile, Henry Ford and other Detroit automakers were flooding the country

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with inexpensive gas-powered cars. Even so, the steamers might well have survived as high-end specialty cars were it not for a series of unlucky breaks. At one point, for example, an outbreak of hoof-and-mouth disease caused public horse troughs to be drained, removing a major source of water for refilling the cars' boilers. It took the Stanley brothers three years to develop a closed-cycle steam engine that didn't need constant refilling, but by then World War I had begun, bringing strict government limits on the number of cars that businesses could build for the consumer market. The Stanley company never recovered, and it folded a few years later. The remnants of the steam automobile industry died during the Depression, when the market for high-priced cars all but disappeared.

Nonengineering factors play a role in the development of all technologies, even the simplest. In *The Pencil*, Henry Petroski tells how pencil designers in the late 1800s, in order to get around a growing shortage of red cedar, devised a pencil with a paper wrapping in place of the normal wood.² It "worked well technically and showed great promise," Petroski writes, "but the product failed for unanticipated psychological reasons." The public, accustomed to sharpening pencils with a knife, wanted something that could be whittled. The paper pencil never caught on.

Today, particularly for such sophisticated creations as computers, genetic engineering, or nuclear power, nontechnical factors have come to exert an influence that is unprecedented in the history of technology. Invention is no longer, as Ralph Waldo Emerson's aphorism had it, simply a matter of "Build a better mousetrap and the world will beat a path to your door." The world is already at your door, and it has a few things to say about that mousetrap.

The reasons for this are several, some grounded in the changing nature of technology itself and others arising from transformations in society. A hundred years ago, people in western nations generally saw technological development as a good thing.³ It brought prosperity and health; it represented "progress." But the past century has seen a dramatic change in western society, with a resulting shift in people's attitudes toward technology.⁴ As countries have become more prosperous and secure, their citizens have become less concerned about increasing their material well-being and more concerned with such aesthetic considerations as maintaining a clean environment. This makes them less likely to accept new technologies uncritically. At the same time, citizens of western democracies have become more politically savvy and more active in challenging the system with lawsuits, special interest groups, campaigns to change public opinion, and other weapons. The result is that the public now exerts a much greater influence on the development of technologies — particularly those seen as risky or otherwise undesirable — than was true one hundred, or even fifty, years ago.

Meanwhile, the developers of technology have also been changing. A century ago, most innovation was done by individuals or small groups. Today, technological development tends to take place inside large, hierarchical organizations. This is particularly true for complex, large-scale technologies, since they demand large investments and extensive, coordinated development efforts. But large organizations inject into the development process a host of considerations that have little or nothing to do with engineering. Any institution has its own goals and concerns, its own set of capabilities and weaknesses, and its own biases about

the best ways to do things. Inevitably, the scientists and engineers inside an institution are influenced — often quite unconsciously — by its culture.

A closely related factor is the institutionalization of science and engineering. With their professional societies, conferences, journals, and other means of communion, scientists and engineers have formed themselves into relatively close-knit — though large — groups that have uniform standards of practice and hold similar ideas. Today, opinions and decisions about a technology tend to reflect a group's thinking more than any given individual's.

The existence of large organizations and the institutionalization of the professions allow a technology to build up a tremendous amount of momentum in a relatively short time.⁵ Once the choice has been made to go a certain way, even if the reasons are not particularly good ones, the institutional machinery gears up and shoves everybody in the same direction. It can be tough to resist.

But the most important changes have come in the nature of technology itself. In the twentieth century, the power of our machines and devices has grown dramatically — along with their unanticipated consequences. When DDT was introduced, it seemed an unalloyed good: a cheap, effective way to kill insect pests and improve crop yields. It took years to understand that the pesticide made its way up the food chain to weaken the shells of birds' eggs and wreak other unintended havoc. Similarly, chlorofluorocarbons, or CFCs, were widely used for decades — as refrigerants, as blowing agents in making foams, and as cleaners for computer chips — before anyone realized they were damaging the ozone layer.

Even normally benign technologies can take on different complexions when multiplied to meet the needs of a world with five billion people. Burning natural gas is an economical, safe, and clean way to heat homes and generate electricity. Its only major waste material is carbon dioxide, the same gas that humans exhale with each breath. But carbon dioxide, in the quantities now being produced worldwide by burning fossil fuels (coal and oil as well as natural gas), is exaggerating the greenhouse effect in the earth's atmosphere and threatening major changes in the global climate.

Modern technology is like a Great Dane in a small apartment. It may be friendly, but you still want to make sure there's nothing breakable within reach. So to protect the china and crystal, government bodies, special interest groups, businesses, and even individuals are demanding an increasing say in how technologies are developed and applied.

Besides its power, modern technology has a second feature — more subtle, but equally important — that makes it qualitatively different from earlier technologies: its complexity. The plow, the cotton gin, even the lightbulb — these are simple devices. No matter how much they are changed and improved, it is still easy to understand their functions and capabilities. But for better or worse, technology has reached the point where no individual can understand completely how, say, a petrochemical plant works, and no team of experts can anticipate every possible outcome once a technology is put to work. Such complexity fundamentally changes our relationship with technology.

Consider the accident that destroyed the space shuttle *Challenger*.⁶ Although the cause was eventually established as the failure of O-rings at low temperatures,

which allowed the escape of hot gases and led to an explosion of a fuel tank, the real culprit was the complexity of the system. Space-shuttle engineers had been concerned about how the O-rings would behave in below-freezing weather, and some even recommended the launch be postponed to a warmer day, but no one could predict with any certainty what might happen. There were too many variables, too many ways in which the components of the system could interact. Management decided to proceed with the launch despite the engineers' disquiet, and it was only months later that experts pieced together the chain of events that led to the explosion.

Complexity creates uncertainty, limiting what can be known or reasonably surmised about a technology ahead of time. Although the shuttle engineers had vague fears, they simply did not — could not — know enough about the system to foresee the looming disaster. And in such cases, when there is not a clear technical answer, people fall back on subjective, often unconscious reasoning — biases and gut feelings, organizational goals, political considerations, the profit motive. In the case of the *Challenger*, NASA was feeling pressure to keep its shuttles going into space on a regular basis, and no one in the organization wanted to postpone a launch unless it was absolutely necessary. In this case, it was, but no one knew.

For all these reasons, modern technology is not simply the rational product of scientists and engineers that it is often advertised to be. Look closely at any technology today, from aircraft to the Internet, and you'll find that it truly makes sense only when seen as part of the society in which it grew up.

The insight is not a particularly new one. Thoughtful engineers have discussed it for some time. As early as the 1960s, Alvin Weinberg, the longtime director of Oak Ridge National Laboratory, was writing on the relationship between technology and society, particularly in regard to nuclear power.⁷ There have been others. But until recently no one had studied the influence of society on technology in any consistent, comprehensive way. Philosophically inclined engineers like Weinberg did not have the time, the temperament, or the training to make careful studies. They reported what they saw and mused about the larger implications, but nothing more. And social scientists, when they noticed technology at all, viewed it primarily in terms of how it shapes society. Sociologists, economists, and others have long seen technology as the driving force behind much of history — a theory usually referred to as “technological determinism”⁸ — and they have happily investigated such things as how the invention of the printing press triggered the Reformation, how the development of the compass ushered in the Age of Exploration and the discovery of the New World, and how the cotton gin created the conditions that led to the Civil War.⁹ But few of these scientists turned the question around and asked how society shapes technology.

In just the past decade or two, however, that has begun to change. Indeed, it has now become almost fashionable for economists, political scientists, and sociologists to bring their analytical tools to bear on various technologies, from nuclear power and commercial aviation to medical instruments, computers, even bicycles.¹⁰ Part of the reason for this is, I suspect, the increasing importance of technology to our world, and another part is the realization by social scientists that science and technology are just as amenable to social analysis as politics or

religion. Whatever the reason, the result has been to put technology in a whole new light. Scholars now talk about the push and pull between technology and society, rather than just the push of technology on society. Engineers have been brought down from the mountain to take their place as one — still very important — cog in the system by which technology is delivered to the world.

Unfortunately, very little of this has filtered down. It remains mostly specialists talking to other specialists in books and journals that few outside their fields ever see. [The book from which this chapter is taken] aims to change that. From its original design as a study of how engineers are creating a new generation of nuclear power, it has metamorphosed into a more general — and more ambitious — look at how nontechnical forces shape modern technologies. In it I collect and synthesize work from a wide variety of disciplines: history, economics, political science, sociology, risk analysis, management science, psychology. At various points, the book touches on personal computers, genetic engineering, jet aircraft, space flight, automobiles, chemical plants, even steam engines and typewriters. Such a book obviously cannot be comprehensive. Instead, my goal is to introduce a different way to think about technology and to show how many things make much more sense when technology is viewed in this way.

* * *

Lurking just beneath the surface . . . is one of the most intriguing and frustrating questions of our time, although it seldom gets much attention outside universities and other scholarly places: How do we know what we know? Or, to put it differently, What is the nature of human knowledge? This may sound like the sort of abstract question that only a philosopher could love, but its answer has practical — and important — ramifications for how we deal with science and technology.

There are two schools of thought on the nature of human knowledge, and they have little common ground. One has its roots in the physical sciences and goes by such names as positivism or objectivism or rationalism. Positivism accepts as knowledge only those things that have been verified by the scientific method of hypothesis formation and testing. It is, of course, impossible to verify anything absolutely — no matter how many times the sun comes up right on schedule, there is no guarantee it won't be a couple of hours late tomorrow — but positivists are generally content with verifying something beyond a reasonable doubt. Karl Popper, the influential philosopher of science, put a slightly different spin on it: Scientific statements, he said, are those that can be put to the test and potentially proven wrong, or falsified. It's not possible to prove a hypothesis is true, but if the hypothesis is tested extensively and never proven false, then one accepts it as provisionally true. If it later turns out to be false in certain situations, it can be modified or replaced. By this method, one hopes to get better and better approximations to the world's underlying physical reality. Absolute knowledge is not attainable. This provisional knowledge is the best we can do.

The strength of positivism — its insistence on verification — is also its weakness, for there is much that people think of as “knowledge” that cannot be verified in the same way that theories in physics or biology can. “The United States is a capitalist country” is a statement most would accept as true, but how does one

prove it? Or how about, "Santa Claus wears a red suit and rides in a sleigh pulled by eight reindeer"? This is clearly knowledge of a sort — everyone in our culture older than two or three "knows" it — and though it may not be in the same intellectual league as, say, the general theory of relativity, it's much more important to most people than anything Einstein came up with. Yet the positivist approach has no place for such folderol.

For many years, social scientists, impressed with the success of the physical sciences, modeled their methods along the same positivist lines. They made observations, formed hypotheses, and tested their theories, attempting to make their research as objective as possible. Many social scientists still do, but in the past few decades an influential new school of thought has appeared, one that offers a different take on human knowledge. This approach, often referred to as "social construction"¹¹ or "interpretation," is designed explicitly to deal with social reality — the web of relationships, institutions, and shared beliefs and meanings that exist in a group of people — instead of physical reality. It sees knowledge not as something gleaned from an underlying physical reality but as the collective product of a society. Social constructionists speak not of objective facts but only of interpretations of the world, and they set out to explain how those interpretations arise. They make no attempt to judge the truth or falsity of socially constructed knowledge. Indeed, they deny that it even makes sense to ask whether such knowledge is true or false.

Thus, positivism and social construction offer diametrically opposed views of knowledge. Positivists see knowledge as arising from nature, social constructionists see it as a product of the human mind. Positivists speak of proof, social constructionists of interpretation. Positivists assume knowledge to be objective, social constructionists believe it to be subjective. In general, positivists have been willing to defer to the social constructionists in the case of social knowledge.

After all, information about Santa Claus or the importance of capitalism is not really what a positivist has in mind when he speaks about "knowledge." But the social constructionists have been unwilling to return the favor and so have triggered a sharp, if so far bloodless, battle.

All human knowledge is social knowledge, the social constructionists say, even science.¹² After all, scientific knowledge is created by groups of people — the scientific community and its various subsets — and so it inevitably has a collective character. There is no such thing as a scientific truth believed by one person and disbelieved by the rest of the scientific community; an idea becomes a truth only when a vast majority of scientists accept it without question. But if this is so, the argument goes, then science is best understood as socially constructed rather than derived in some objective way from nature.

The earliest and best-known example of this approach to science is Thomas Kuhn's *The Structure of Scientific Revolutions*.¹³ In it, Kuhn depicts most science as taking place inside a "paradigm" — a set of beliefs and expectations that guide the research, defining which questions are important and designating the proper ways to go about answering them. Scientific revolutions — such as the shift from the Ptolemaic to the Copernican view of the universe — occur when a paradigm breaks down and the scientific community collectively settles on a new paradigm

in which to work. Kuhn argued that because such a paradigm shift is a change of the rules by which science is done, there can be no objective reasons for making the shift or for deciding on one paradigm over another. The choice is a subjective one. Ironically, much of the positivist scientific community has accepted the general idea of paradigms without understanding the deeper implications of Kuhn's work. It's not unusual to hear a scientist speak of "working within a paradigm" even though that scientist would be appalled by Kuhn's claim that scientific paradigms have no objective basis.

Today, many social scientists agree with Kuhn that the positivist claims for science were a myth. For example, in 1987 the sociologists Trevor Pinch and Wiebe Bijker wrote:

[T]here is widespread agreement that scientific knowledge can be, and indeed has been, shown to be thoroughly socially constructed. . . . The treatment of scientific knowledge as a social construction implies that there is nothing epistemologically special about the nature of scientific knowledge: It is merely one in a whole series of knowledge cultures (including for instance, the knowledge systems pertaining to "primitive" tribes). Of course, the successes and failures of certain knowledge cultures still need to be explained, but this is to be seen as a sociological task, not an epistemological one.¹⁴

Such comments anger many scientists. Physicists especially dispute the conclusions of the social constructionists.¹⁵ Yes, they admit, of course the creation of scientific knowledge is a joint effort, but nonetheless it is epistemologically special. Quantum mechanics, for instance, provides predictions that are consistently accurate to a dozen or more decimal places. This is no accident, they insist, but instead reflects the fact that science is uncovering and explaining some objective reality.

On the whole, the physicists get the better of this particular argument. Social construction theory is useful in explaining social knowledge and belief, but it does little to explain why physicists accept general relativity or quantum mechanics as accurate portrayals of physical reality. Social constructionists like Pinch and Bijker ignore a key difference between science and other knowledge cultures: science's insistence that its statements be falsifiable.¹⁶ As long as science restricts itself in this way and continues testing its theories and discarding those that disagree with experiments, it is indeed epistemologically special. This and nothing else explains why science has been so much more successful than other knowledge cultures. Science may not be as objective as the positivists would like to believe, but the positivist approach comes closer than any other to capturing the essence of science.

This all may seem to be a tempest in an academic teapot, a question of interest to no one besides philosophers and the handful of scientists with an interest in epistemology, but it underlies many of the debates on scientific issues that affect the public. Consider the controversy in the mid-1980s over the use of recombinant bovine growth hormone in dairy cattle. Although the scientific community pronounced it safe, opponents of its use suggested that the researchers were influenced more by the sources of funding for their research and by their own inherent biases than by evidence.¹⁷ This argument depended implicitly upon the assumption that the scientific opinions were not objective

but rather were socially constructed. In general, if science is accepted as objective, people will give a great deal of weight to the conclusions of the scientific community and to the professional opinions of individual scientists. But if science is seen as a social construct, vulnerable to biases and fashion, people will question or even dismiss its conclusions.

Which brings us back to our original subject. At its heart, [the book from which this chapter was taken is] about technological knowledge: What is it? and, How is it formed? Traditionally, engineers have seen their work in positivist terms. Like scientists, they take it for granted that their work is objective, and they believe that to understand a technology, all one needs are the technical details. They see a strict dichotomy between the pure logic of their machines and the subjectivity and the irrationality of the world in which they must operate. On the other hand, a growing school of social scientists sees technology as socially constructed. Its objectivity, they say, is a myth created and propagated by engineers who believe their own press. As with science, this is no mere academic debate. Our attitudes toward technology hinge, in large part, on what we believe about the nature of the knowledge underlying it.

To understand technological knowledge, this book argues, it is necessary to marry the positivist and the social constructionist perspectives. Technology combines the physical world with the social, the objective with the subjective, the machine with the man. If one imagines a spectrum with scientific knowledge on one end and social knowledge on the other, technological knowledge lies somewhere in the middle. It is falsifiable to a certain extent, but not nearly to the same degree as science. Conversely, much of technological knowledge is socially constructed, but there are limits — no matter what a group of people thinks or does, an airplane design that can't fly won't fly. In short, the physical world restricts technology. Some things work better than others, some don't work at all, and this leads to a certain amount of objectivity in technological knowledge. But, unlike scientists, engineers are working with a world of their own creation, and the act of creation cannot be understood in positivist terms.

Ultimately, any understanding of technological knowledge must recognize the composite nature of that knowledge. Our technological creations carry with them the traces of both the engineer and the larger society.

NOTES

1. Charles McLaughlin, "The Stanley Steamer: A Study in Unsuccessful Innovation," *Explorations in Entrepreneurial History* 7 (October 1954), pp. 37–47.
2. Henry Petroski, *The Pencil* (New York: Alfred A. Knopf, 1989), p. 207.
3. Merritt Roe Smith, "Technological Determinism in American Culture," in Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History?* (Cambridge, MA: MIT Press, 1994), pp. 1–35.
4. Ronald Inglehart, *The Silent Revolution: Changing Values and Policy Styles among Western Publics* (Princeton, NJ: Princeton University Press, 1977), p. 3.
5. Thomas P. Hughes, "Technological History and Technical Problems," in Chauncey Starr and Philip C. Ritterbush, eds., *Science, Technology and the Human Prospect* (New York: Pergamon, 1980), p. 141.

6. Maureen Hogan Casamayou, *Bureaucracy in Crisis: Three Mile Island, the Shuttle Challenger and Risk Assessment* (Boulder, CO: Westview, 1993), pp. 57–85.
7. Alvin M. Weinberg, *Nuclear Reactions: Science and Trans-Science* (New York: American Institute of Physics, 1992). See also Alvin M. Weinberg, *The First Nuclear Era: The Life and Times of a Technological Fixer* (New York: American Institute of Physics, 1994).
8. For a critical review of technological determinism, see Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History?* (Cambridge, MA: MIT Press, 1994).
9. Leo Marx and Merritt Rowe Smith, introduction to Marx and Smith, *Does Technology Drive History?* p. x.
10. There have been a number of books published recently that analyze technology from a social science perspective. They include Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 1987); Marcel C. LaFollette and Jeffrey K. Stine, eds., *Technology and Choice: Readings from Technology and Culture* (Chicago: University of Chicago Press, 1991); Meinolf Dierkes and Ute Hoffmann, eds., *New Technology at the Outset: Social Forces in the Shaping of Technological Innovations* (Boulder, CO: Westview, 1992); Wiebe Bijker and John Law, eds., *Shaping Technology/Building Society: Studies in Sociotechnical Change* (Cambridge, MA: MIT Press, 1992); Wiebe E. Bijker, *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Cambridge, MA: MIT Press, 1995). See also various issues of *Technology and Culture*; *Technology in Society*; *Science, Technology & Human Values*; and *Technology Review*.
11. The seminal work here is Peter L. Berger and Thomas Luckmann, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge* (New York: Doubleday, 1966).
12. A good summary of the social constructionist approach to scientific knowledge can be found in Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other," in Bijker, Hughes, and Pinch, *The Social Construction of Technological Systems*, pp. 17–50.
13. Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962).
14. Pinch and Bijker, "The Social Construction of Facts and Artifacts," pp. 18–19.
15. David Mermin, a very thoughtful physicist at Cornell University, offers a careful refutation of the social construction of physics in a two-part article: "What's Wrong with the Sustaining Myth?" *Physics Today* 49 (March 1996), pp. 11, 13; and "The Golemization of Relativity," *Physics Today* 49 (April 1996), pp. 11, 13.
 In spring 1996, the dispute between physicists and social constructionists took an amusing turn — amusing, at least, for the physicists — when Alan Sokal published an article entitled "Transgressing the Boundaries: Toward a Transformative Hermeneutics of Quantum Gravity" in *Social Text*, a "postmodernist" journal devoted to social constructionist analyses. Sokal, a physicist at New York University, later revealed that it was all a hoax. He had cobbled together bad science, even worse logic, and a bunch of catchphrases from postmodernist theorizing and had somehow convinced the editors of *Social Text* that the nonsensical article was a contribution worthy of publication. The editors were understandably not amused but neither were they contrite. They did not seem to see it as a weakness on their part — or even less, on the part of the entire postmodernist movement — that they could not tell the difference between an obvious hoax and what passes for serious work in their field. The original article appeared in *Social Text* 46/47 (Spring/Summer 1996), pp. 217–252. Sokal revealed the hoax in "A Physicist Experiments with Cultural Studies," *Lingua Franca* (May/June 1996), pp. 62–64.
16. This argument is modified from one offered by Thelma Lavine, Clarence J. Robinson Professor of Philosophy at George Mason University in Fairfax, Virginia.
17. W. P. Norton, "Just Say Moo," *The Progressive* (November 1989), pp. 26–29. See also Gina Kolata, "When the Geneticists' Fingers Get in the Food," *New York Times* (February 20, 1994), sec. 4, p. 14.