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Two Questions Concerning Technology

Is Technology Applied Science?

The idea that technology is applied science is now centuries old. In the early seventeenth century, Francis Bacon and René Descartes both promoted scientific research by claiming that it would produce useful technology. In the twentieth century this view was importantly championed by Vannevar Bush, one of the architects of the science policy pursued by the United States after World War II: "Basic research . . . creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. . . . Today, it is truer than ever that basic research is the pacemaker of technological progress." The basic-applied research connection is part of a "linear model" that traces innovation from basic research to applied research to development and finally to production. That linear model developed over the first two-thirds of the twentieth century, as a rhetorical tool used by scientists, management experts, and economists (Godin 2006).

However, accounts of artifacts and technologies show that scientific knowledge plays little direct role in the development of even many state of the art technologies. Historians and other theorists of technology have argued that there are technological knowledge traditions that are independent of science, and that to understand the artifacts one needs to understand them.

Because of its large investment in basic research, in the mid-1960s the US Department of Defense conducted audits to discover how valuable that research was. Project Hindsight was a study of key events leading to the development of 20 weapons systems. It classified 91% of the key events as technological, 8.7% as applied science, and 0.3% as basic science.

Project Hindsight thus suggested that the direct influence of science on technology was very small, even within an institution that invested heavily in science and was at key forefronts of technological development. A subsequent study, TRACES, challenged that picture by looking at prominent civilian technologies and following their origins further back in the historical record.

Among historians of technology it is widely accepted that "science owes more to the steam engine than the steam engine owes to science." Science is applied technology more than technology is applied science. As we saw in the last chapter, scientific work depends crucially on tools for purifying, controlling, and manipulating objects. Meanwhile, technology may be relatively divorced from science. Work on the history of aircraft suggests that aeronautical engineers consult scientific results when they see a need to, but their work is not driven by science or the mere application of science (Vincenti 1990). Similarly, the innovative electrical engineer Charles Steinmetz did not either apply physical theory or derive his own theoretical claims from it (Kline 1992), but instead developed theoretical knowledge in purely engineering contexts. Engineers, then, develop their own mathematics, their own experimental results, and their own techniques.

Technology is so often seen as applied science because technological knowledge is downplayed (Layton 1971, 1974). In the nineteenth century, for example, American engineers developed their own theoretical works on the strength of materials, drawing on but modifying earlier scientific research. When engineers needed results that bore on their practical problems, they looked to engineering research, not pure science. Engineers and inventors participate in knowledge traditions, which shape the work that they do, especially work that fits into technological paradigms (Constant 1984). Science, then, does not have a monopoly on technical knowledge. The development of technologies is a research process, driven by interesting problems: actual and potential functional failure of current technologies, extrapolation from past technological successes, imbalances between related technologies, and, more rarely, external needs demanding a technical solution (Laudan 1984). All but the last of these problem sources stem from within technological knowledge traditions.

For a group of people to have its own tradition of knowledge means that that knowledge is tied to the group's social networks and material circumstances. As we have seen, there is some practical incommensurability between knowledge traditions, seen in the difficulties of translating between traditions. In addition, some knowledge within a tradition is tacit, not fully formalizable, and requires socialization to be passed from person to person (Chapter 10).

So far, we have seen arguments that technological practice is autonomous from science. A separate set of arguments challenge the idea that technology is applied science from almost the opposite direction. Some people working in STS have argued that science and technology are not sufficiently well defined and distinct for there to be any determinate relationship between them. In the context of large technological systems, "persons committed emotionally and intellectually to problem solving associated with system creation and development rarely take note of disciplinary boundaries, unless bureaucracy has taken command" (Hughes 1987). "Scientists" invent, and "inventors" do scientific research – whatever is necessary to move their program forward.

The indistinctness of science and technology can fall out of accounts of science, as well. First, "basic research" turns out to be a flexible and ambiguous concept, having a history and being used in different ways (Calvert 2006): Scientists use the term in order to do boundary work, drawing on the prestige of ideals of purity to gain funding and independence. Second, for the pragmatist, scientific knowledge is about what natural objects can be made to do. Thus laboratory science may be seen to be about what can be constructed, not about what exists independently (Knorr Cetina 1981). For the purposes of this chapter, the pragmatic orientation is relevant in that it draws attention to the ways in which science depends upon and involves technology, both materially and conceptually.

Actor-network theory's term *technoscience* eschews a principled conceptual distinction between science and technology. It also draws attention to the increasing causal interdependence of what is labeled science and technology. We might think it odd that historians are insisting on the autonomy of technological traditions and cultures precisely when there is a new spate of science-based technologies and technologically oriented science – biotechnologies, new materials science, and nanotechnology all cross obvious lines.

Latour's networks and Thomas Hughes's technological systems bundle many different resources together. Thomas Edison freely mixed economic calculations, the properties of materials, and sociological concerns in his designs (Hughes 1985). Technologists need scientific and technical knowledge, but they also need material, financial, social, and rhetorical resources. Even ideology can be an input, in the sense that it might shape decisions and the conditions of success and failure (e.g. Kaiserfeld 1996). For network builders nothing can be reduced to only one dimension. Technology requires heterogeneous engineering of a dramatic diversity of elements (Law 1987; Bucciarelli 1994). A better picture of technology, then, is one that incorporates many different inputs, rather than being particularly dependent upon a single stream. It is possible that no one input is even essential: any input could be worked around, given enough hard work, ingenuity, and other resources.

To sum up, scientific knowledge is a resource on which engineers and inventors can draw, and perhaps on which they are drawing increasingly, but on the whole it is not a driver of technology. Rather, technological development is a complex process that integrates different kinds of knowledge – including its own knowledge traditions – and different kinds of material resources. At the same time, science draws on technology for its instruments, and perhaps also for some of its models of knowledge, just as some engineers may draw on science for their models of engineering knowledge. There are multiple relations of science and technology, rather than a single monolithic relation. "The linear model . . . is dead" (Rosenberg 1994).

Does Technology Drive History?

Technological determinism is the view that material forces, and especially the properties of available technologies, determine social events. The reasoning behind it is usually economistic: available material resources form the environment in which rational economic choices are made. In addition, technological determinism emphasizes "real-world constraints" and "technical logics" that shape technological trajectories (Vincenti 1995). The apparent autonomy of technologies and technological systems provides some evidence of these technical logics: technologies behave differently and enter different social contexts than their inventors predict and desire. If this is right, then social variables ultimately depend upon material ones.

A few of Karl Marx and Friedrich Engels's memorable comments on the influence of technology on economics and society can stand in for the position of the technological determinist, though they are certainly not everything that Marx and Engels had to say about the determinants of social structures. Looking at large-scale structures, Marx famously said "The hand-mill gives you society with the feudal lord, the steam-mill, society with the industrial capitalist." Engels, talking about smaller-scale structures, claimed that "The automatic machinery of a big factory is much more despotic than the small capitalists who employ workers ever have been."

There are a number of different technological determinisms (see Bimber 1994; Wyatt 2007), but the central idea is that technological changes force social adaptations, and consequently constrain the trajectories of history. Robert Heilbroner, supporting Marx, says that

> the hand-mill (if we may take this as referring to late medieval technology in general) required a work force composed of skilled or semiskilled craftsmen, who were free to practice their occupations at home or in a small atelier, at times and seasons that varied considerably. By way of contrast, the steam-mill – that is, the technology of the nineteenth century – required a work force composed of semiskilled or unskilled operatives who could work only at the factory site and only at [a] strict time schedule. (Heilbroner 1994 [1967])

Because economic actors make rational choices, class structure is determined by the dominant technologies. This reasoning applies to both the largest scales and much more local decisions. Technology, then, shapes economic choices, and through them shapes history.

Some technologies appear compatible with particular political and social arrangements. In a well-known essay, Langdon Winner (1986a) asks "do artifacts have politics?" Following Engels, he argues that some complex technological decisions lend themselves to more hierarchical organization than others, in the name of efficiency – the complexity of modern industrial production does not sit well with consensus decision-making. In addition, Winner argues, some technologies, such as nuclear power, are dangerous enough that they may bring their own demands for policing, and other forms of state power. And finally, individual artifacts may be constructed to achieve political goals. For example, the history of industrial automation reveals many choices made to empower and disempower different key groups (Noble 1984): Numerical control automation, the dominant form, was developed to eliminate machinist skill altogether from the factory floor, and therefore to eliminate the power of key unions. While also intended to reduce factories' dependence on skilled labor, record-playback automation, a technology not developed nearly as much, would have required the maintenance of machinist skill to reproduce it in machine form (for some related issues see Wood 1982). In general, technologies are deskilling. In replacing labor they also replace the skills that are part of that labor. Even a technology like a seed can have that effect. Before hybrid corn was introduced in the 1930s, American farmers were skilled at breeding their own corn, for high yield and disease resistance (Fitzgerald 1993). Lines of hybrid seed, though, could not be continued on the farm, since they were first-generation crosses of inbred lines; this ensured that seed producers could sell seed every year, which was an explicit goal. When American farmers bought high-yield hybrid seed, which they did willingly, they were delegating their breeding work to the seed companies, and setting their breeding skills aside.

Even for non-determinists, the effects of technologies are important. As we saw in Chapter 1, a key part of the pre-STS constellation of ideas on science and technology was the study of the positive and negative effects of technologies, and the attempt to think systematically about these effects. That type of work continues. At the same time, as we see below, some STS researchers have challenged a seemingly unchallengeable assumption, the assumption that technologies have any systematic effects at all! In fact, they challenge something slightly deeper, the idea that technologies have essential features (Pinch and Bijker 1987; Grint and Woolgar 1997). If technologies have no essential features, then they should not have systematic effects, and if they do not have any systematic effects then they cannot determine structures of the social world.

No technology – and in fact no object – has only one potential use. Even something as apparently purposeful as a watch can be simultaneously constructed to tell time, to be attractive, to make profits, to refer to a well-known style of clock, to make a statement about its wearer, etc. Even the apparently simple goal of telling time might be seen a multitude of different goals: within a day one might use a watch to keep on schedule, to find out how long a bicycle ride took, to regulate the cooking of a pastry, to notice when the sun set, and so on. Given this diversity, there is no essence to a watch. And if the watch has no essence, then we can say that it has systematic effects only within a specific human environment.

In their work on "Social Construction of Technology" (SCOT), Trevor Pinch and Wiebe Bijker (1987) develop this point into a framework for thinking about the development of technologies. In their central example, the development of the safety bicycle, the basic design of most twentieth-century bicycles, there is an appearance of inevitability about the outcome. The standard modern bicycle is stable, safe, efficient, and fast, and therefore we might see its predecessors as important, but ultimately doomed, steps toward the safety bicycle. On Pinch and Bijker's analysis, though, the safety bicycle did not triumph because of an intrinsically superior design. Some users felt that other early bicycle variants represented superior designs, at least superior to the early versions of the safety bicycle with which they competed. For many young male riders, the safety bicycle sacrificed style for a claim to stability, even though new riders did not find it very stable. Young male riders formed one *relevant social group* that was not appeased by the new design. Their goals were not met by the safety bicycle, as its meaning (to them) did not correspond well to their understanding of a quality bicycle. There is, then, *interpretive flexibility* in the understanding of technologies and in their designs. We should see trajectories of technologies as the result of rhetorical operations, defining the users of artifacts, their uses, and the problems that particular designs solve. The Luddites of early-nineteenth-century Britain adopted a variety of interpretations of the factory machines that they did and did not smash (Grint and Woolgar 1997). Although some saw the factory machines as upsetting their preferred modes of work, others saw the problem in the masters of the factories. Resistance to the new technologies diminished when new left-wing political theories articulated the machines as saviors of the working classes. The machines, then, did not have a single consistent set of effects.

Interpretive flexibility can create quite unexpected results. For example, the use of "safer sex" technologies by prostitutes shows how users can give technologies novel meanings, even in the service of the ends for which it is made (Moore 1997). In order to fit the contexts and culture in which prostitutes use it, an apparently clinical latex rubber glove can become sexy by being snapped onto hands in the right way, or can be put to new uses by being cut and reconfigured. Very high numbers of users modify products for their own use, in some cases giving very new meanings to those products (von Hippel 2005).

On a SCOT analysis, the success of an artifact depends upon the strength and size of the group that takes it up and promotes it. Its definition depends upon the associations that different actors make. Interpretive flexibility is a necessary feature of artifacts, because what an artifact does and how well it performs are the results of a competition of different groups' claims. Thus the good design of an artifact cannot be an independent cause of its success; what is considered good design is instead the result of its success.

Attention to users reveals the variety of relations that users and technologies have (Oudshoorn and Pinch 2003). Among other things, users contribute to technological change, not just by adapting objects to their local needs, but also by feeding back into the design and production processes. In its early days the automobile was put to novel uses by farmers, for example, who turned it into a mobile source of power for running various pieces of farm machinery; their innovations contributed to the features that became common on tractors (Kline and Pinch 1996). In general, *lead users*, those who are early adopters of a new technology that goes on to have wide use, and who gain considerable benefits from innovating, tend to make substantial innovations that can be picked up by producers of that technology (von Hippel 2005). This poses another problem for the linear model of innovation.

A different kind of novel use of technology is the use of different *ideologies* of technology. The "electromechanical vibrator" was widely sold, and advertised in catalogues, between 1900 and 1930, despite the fact that masturbation was socially prohibited in this period, and was even thought to be a cause of hysteria (Maines 2001). The vibrator could be acceptable for sale because of its association with professional instruments, because of the high value attached to electric appliances in general, and because electricity

Box 9.1 Digital rights management

With the advent of digital culture, debates about copyright became louder and acquired new dimensions. Digital cultural objects such as CDs, DVDs, and MP3s can in principle be copied indefinitely many times without any degradation. That worries many people, most importantly people in the powerful US music and film industries. One result has been Digital Rights Management (DRM), explored by Tarleton Gillespie in his book *Wired Shut* (2007). DRM is ostensibly an attempt by copyright holders to directly prevent illegal, and some legal, copying, by encrypting files so that they may only be copied in authorized ways.

By itself DRM cannot work. The history of encryption is a history of struggles between coders and decoders. Moreover, for DRM to work for the cultural industries, the decryption codes must be very widely shared, or else sales will be very limited. "The real story, the real power behind DRM, is . . . the institutional negotiations to get technology manufacturers to build their devices to chaperone in the same way, the legitimation to get consumers to agree to this arrangement . . . and the legal wrangling to make it criminal to circumvent" (Gillespie 2007: 254). And the cultural industries in the United States have successfully convinced the US government to try to spread protection of DRM to the rest of the world through intellectual property negotiations.

But in this social context, DRM has real effects. It prevents some copying, both legal and illegal. It gives content providers more control over the uses of their products, which may allow them to find new business models on which they can charge per use, for different types of uses, and can charge differently in different markets.

was seen as a healing agent. The modernity of technology, then, could be used to revalue objects and practices.

To give technologies reasonably determinate meanings requires work. In one study, at a point well into the development process, a computer firm needed to test prototypes of their package, to see how easy it was for unskilled users to figure out how to perform some standard tasks (Grint and Woolgar 1997). On the one hand these tests could be seen as revealing what needed to be done to the computers in order for them to be more user-friendly. On the other hand they could be seen as revealing what needed to be done to the users – how they needed to be defined, educated, controlled – to make them more computer-friendly: successful technologies require what Steve Woolgar calls *configuring the user*. The computer, then, does what it does only in the context of an appropriate set of users.

Surely, though, some features of technologies are autonomous and defy interpretation. We might, for example, ask with Rob Kling (1992) "What's so social about being shot?" Everything, say Grint and Woolgar. In a tour-de-force of anti-essentialist argumentation, Grint and Woolgar argue that a gun being shot is not nearly as simple a thing as it might seem. It is clear that the act of shooting a gun is intensely meaningful – some guns are, for example, more manly than others. But more than that, even injuries by gun-shot can take on different meanings. When female Israeli soldiers were shot in 1948, "men who might have found the wounding of a male colleague comparatively tolerable were shocked by the injury of a woman, and the mission tended to get forgotten in a general scramble to ensure that she received medical aid" (Holmes, quoted in Grint and Woolgar 1997). Even death is not so certain. Leaving aside common uncertainties about causes of death and the timing of death, there are cross-cultural differences about death and what happens following it. No matter how unmalleable a technology might look, there are always situations, some of them highly hypothetical, in which the technology can take on unusual uses or interpretations. In addition, technologies are not as autonomous as they often appear. Some of the appearance of autonomy in a technology stems from of our lack of knowledge. As we gain knowledge of the historical paths of particular trajectories, we see more human roles in those paths (Hong 1998).

To accept that technologies do not have essences is to pull the rug out from under technological determinism. If they do nothing outside of the social and material contexts in which they are developed and used, technologies cannot be the real drivers of history. Rather these contexts are in the drivers' seats. This recognition is potentially useful in enabling political analyses, because particular technologies can be *used* to affect social relations (Hård 1993), such as labor relations (e.g. Noble 1984) and gender relations (e.g. Cockburn 1985; Cowan 1983; Oudshoorn 2003).

There should, then, be no debate about technological determinism. However, in practice nobody holds a determinism that is strict enough to be completely overturned by these arguments. Even the strictest of determinists admit that social forces play a variety of important roles in producing and shaping technology's effects. Such a "soft" determinism is an interpretive and heuristic stance that directs us to look first to technological change to understand economic change (Heilbroner 1994 [1967]). Choices are made in relation to material resources and opportunities. To the extent that we can see social choices as economic choices, technology will play a key role.

Anti-essentialists show us that even soft determinism must be understood within a social framework, in that the properties of technologies can determine social structures and events only once the social world has established what the properties of technologies are. Anti-essentialism directs us to look to the social world to understand technological change and its effects. This is perhaps most valuable for its constant reminder that things could be different.

On the other hand, we study technology because artifacts appear to do things, or at least are made to do things. Thus a limited determinism is right, given a particular set of actions within a particular social and material arrangement. "Our guilty secret in STS is that really we are all technological determinists. If we were not, we would have no object of analysis" (Wyatt 2007).

Bijker's theory of *sociotechnological ensembles* is an attempt to understand the thorough intertwining of the social and technical (Bijker 1995). Bijker draws heavily on work on technology as heterogeneous engineering, and on his earlier work with Pinch on SCOT. A key concept in the theory is that of the *technological frame*, the set of practices and the material and social infrastructure built up around an artifact or collection of similar artifacts – a bit like Kuhn's *paradigm*. Another, similar concept is the notion of a technological *script*, developed from within actor-network theory (Akrich 1992). As the frame is developed, it guides future actions. A technological frame, then, may reflect engineers' understandings of the key problems of the artifact, and the directions in which solutions should be sought. Technological frames also reproduce themselves, when enough physical infrastructure is built around and with them. The "system of automobility" (Urry 2004), for example, has been and continues to be very durable, given the enormous physical, political, and social infrastructure, on both local and global scales, based on cars made of steel that use petroleum.

A technological frame may also reflect understandings of the potential users of the artifact, and users' understanding of its functions. If a strong technological frame has developed, it will cramp interpretative flexibility. The concept is therefore useful in helping to understand how technologies and their development can appear deterministic, while only appearing so in particular contexts. For example, in recent decades research on contraception has concentrated on female contraception. This gender asymmetry and the assumptions behind it are constituted by negotiations, choices, and contingencies. As a result, new male forms of contraception depend on alternative sociotechnical ensembles. Ultimately, their success will depend on cultural work to reshape the features of gender that contribute to the asymmetry, and to which the available technologies contribute (Oudshoorn 2003).

Stretching the concept a little, we might see how technological frames can highlight some features of technologies and hide others. In the nineteenth century governments and banks went to extensive efforts to protect paper currency from forgery. Exquisite engravings, high-quality paper and ink, and consistent printing processes gave users of paper money more confidence that it was genuine. In principle those features of paper money could not serve to answer doubts about the solidity of paper currency – in comparison to coins containing precious metals – even if the banknote as a work of art had the effect of distracting from those doubts (Robertson 2005).

Architecture provides a good example of the ways in which technologies have effects and embody social structure. A building is a piece of technology, one that shapes the activities, interactions, and flows of people. For example, a study of the design and use of a university biotechnology building showed some of the negotiations incorporated into the building: it will have space for visiting industrial scientists, but not for undergraduate students; it will integrate molecular biology, genetics, and biochemistry, but separate molecular biology from microbiology (Gieryn 2002). Once these decisions are made, the (literally) concrete structure forms a concrete social structure. Yet, there is more flexibility than designers intended: the unused labs for visiting industrial scientists eventually become academics' labs; and some teaching of undergraduate students takes place in research labs. The building becomes reinterpreted.

Even if technologies do not have truly essential forms – properties independent of their interpretations, or functions independent of what they are made to do – essences can return, in muted form. Artifacts do nothing by themselves, though they can be said to have effects in particular circumstances. To the extent that we can specify the relevant features of their material and social contexts, we might say that technological artifacts have dispositions or affordances. Particular pieces of technology can be said to have definitive properties, though they change depending upon how and why they are used. Material reductionism, then, only makes sense in a given social context, just as social reductionism only makes sense in a given material context.

Does technology drive history, then? History could be almost nothing without it. As Bijker puts it, "purely social relations are to be found only in the imaginations of sociologists or among baboons." But equally, technology could be almost nothing without history. He continues, "and purely technical relations are to be found only in the wilder reaches of science fiction". (Bijker 1995).

Box 9.2 Were electric automobiles doomed to fail?

David Kirsch's history of the electric vehicle illustrates both the difficulty and power of deterministic thinking (Kirsch 2000). The standard history of the internal combustion automobile portrays the electric vehicle as doomed to failure. Compared with the gasoline-powered vehicle, the electric vehicle suffered from lack of power and range, and so could never be the all-purpose vehicle that consumers wanted. However, "technological superiority was ultimately located in the hearts and minds of engineers, consumers, and drivers, not programmed inexorably into the chemical bonds of refined petroleum" (Kirsch 2000: 4).

Until about 1915 electric cars and trucks could compete with gasoline-powered cars and trucks in a number of market niches. In many ways electric cars and trucks were successors to horse-drawn carriages: Gasoline-powered trucks were faster than electric trucks, but for the owners of delivery companies speed was more likely to damage goods, to damage the vehicles themselves, and in any case was effectively limited in cities. Because they were easy to restart, electric trucks were better suited to making deliveries than early gasoline-powered trucks; this was especially true given the horse-paced rhythm of existing delivery service, which demanded interaction between driver and customer. Electric taxis were fashionable, comfortable, and quiet, and for a time were successful in a number of American cities, so much so that in 1900 the Electric Vehicle Company was the largest manufacturer of automobiles in the United States.

As innovators, electric taxi services were burdened with early equipment. Some happened to suffer from poor management, and were hit by expensive strikes. They failed to participate in an integrated urban transit system that linked rail and road, to create a niche they could dominate and in which they could innovate. Meanwhile, Henry Ford's grand experiment in producing low-cost vehicles on assembly lines helped to spell the end of the electric vehicle. World War I created a huge demand for gasoline-powered vehicles, better suited to war conditions than were electric ones. Increasing suburbanization of US cities meant that electric cars and trucks were restricted to a smaller and smaller segment of the market. Of course, that suburbanization was helped along by the successes of gasoline, and thus the demands of consumers not only shaped, but were shaped by automobile technologies.

In 1900 the fate of the electric vehicle was not sealed. Does this failure of technological determinism mean that electric cars could be rehabilitated?

According to Kirsch, writing in the late 1990s, that seemed unlikely. Material and social contexts have been shaped around the internal combustion engine, and it seemed unlikely that electric cars could compete directly with gasoline cars in these new contexts. Yet, only a few years later, it appears that there may be niches for electric cars, created by governments' and individuals' commitment to reducing greenhouse gases.