Technology Matters

Questions to Live With

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Edwin P. Nye (1920–2004), Halden Professor of Engineering, Trinity College, Hartford, 1959–1983

4 How Do Historians Understand Technology?

The previous two chapters suggest that one must reject technological determinism and admit that the invention and the diffusion of technologies are not predictable. What is the alternative? Historians in the field give roughly equal weight to technical, social, economic, and political factors. Their case studies suggest that artifacts emerge as the expressions of social forces, personal needs, technical limits, markets, and political considerations. They often find that both the meanings and the design of an artifact are flexible, varying from one culture to another, and from one time period to another. Indeed, Henry Petroski, one of the most widely read experts on design, argues that there is no such thing as perfect form: "Designing anything, from a fence to a factory, involves satisfying constraints, making choices, containing costs, and accepting compromises."[1] Technologies are social constructions. Historians of technology have also generally agreed that after initial invention comes an equally important stage of "development." Indeed, since the late 1960s the study of development has been at the center of much work in the field, for example in studies of Nicholas Otto's internal-combustion engine or the development of the diesel engine.[2] Nathan Rosenberg, a leading economic historian, emphasizes that for every new product or production technique "there is a long adjustment process during which the invention is improved, bugs ironed out, the technique modified to suit the specific needs of users, and the 'tooling up' and numerous adaptations made so that the new product (process) can not only be produced but can be produced at low cost." Indeed, during this "shakedown period" of early production some feasible inventions are abandoned as unprofitable.[3] As the study of development has increased, the heroic "lone inventor" has largely disappeared from scholarship. Anthony F. C. Wallace, a senior historian in the field, declared: "We shall view technology as a social product and shall not be over much interested in the priority claims of individual inventors, for the actual course of work that leads to the conception and use of new technology *always* involves a group that has worked for a considerable period of time on the basic idea before success is achieved."[4]

Variation in design continues during early stages of development, until one design meets with wide approval. Once a particular design is widely accepted, however, variation in form gives way to innovation in production. Take the bicycle as an example. The earliest bicycles (high-wheelers) were handmade and cost an ordinary worker a year's wages. Only the well-to-do could afford them. Most riders were young and male. The danger of toppling from a high-wheeler gave bicycling a macho aura. For more than a generation, low-wheel bikes were for women, clergymen, and old people. Tremendous experimentation took place as inventors changed the size of the wheels, made three-wheelers, moved the larger wheel from the front to the back, and tried out various materials, including wood and steel frames. They developed different drive and braking systems, tried various shapes and positions for the handlebars, and created accessories such as lights and panniers. Dunlop developed air-filled rubber tires that together with a padded seat reduced discomfort from bumps and vibrations. At first, professional racers derided these "balloon" tires as being for sissies. However, bicycle design reached closure in the 1890s, when low-wheel models with front and back wheels of equal size and fitted with Dunlop tires proved to be the fastest on the racetrack.

Once the low-wheel "safety bicycle" had become accepted as the standard, manufacturing changed. The leading producers of high-wheelers, such as the Pope Company, had prided themselves on durable construction by skilled artisans, who adjusted the wheel size of each cycle to match the length of a customer' legs. In the 1880s such bicycles cost $300 or more, well beyond the reach of the average consumer. In the 1890s, however, mass producers such as Schwinn made bicycles with stamped and welded frames. They were of lesser quality, but priced as low as $50. By 1910 a used bicycle in working order could be had for $15, and ownership had spread to all segments of society. The bicycle had ceased to be a toy for the wealthy and had become a common form of transportation and recreation for millions. The military had adapted it to troop transport, delivery services had thousands of bicycle messenger boys, and bicycle racing had emerged as a professional sport.

The social significance and use of the bicycle was not technologically determined. For example, from the beginning some women adopted the bicycle, and during the era of the high-wheeler some joined the popular bicycle clubs. In 1888, eighteen women were members of a Philadelphia club, and one of them won the "Captain's Cup," awarded annually to the member who covered the most miles (in this case, 3,304¼). However, women on wheels met opposition. Some physicians declared that the bicycle promoted immodesty in women and harmed their reproductive organs. Moralists thought women on bicycles were indecent because they wore shorter skirts to ride them, and worried that women would find straddling the seat sexually stimulating. The bicycle craze helped kill the bustle and the corset and encouraged "common-sense dressing." Many in the women's suffrage movement adopted bicycles. In 1896, Susan B. Anthony declared: "Bicycling . . . has done more to emancipate women than anything else in the world. I stand and rejoice every time I see a woman ride by on a wheel. It gives women a feeling of freedom and self-reliance."[5] The women's movement embraced the bicycle, and its democratization became part of their drive for social equality.

Outside the United States, the bicycle persisted much longer as an important form of transportation. In the Netherlands and in Denmark, bicycles were more common than automobiles were until the early 1960s. In those countries, major roads have special lanes and special traffic signals for bicyclists, and government programs encourage citizens to use bicycles instead of automobiles. But most Western societies have chosen the automobile as the primary mode of transportation instead, and even in Denmark and the Netherlands bicyclists are not as numerous as they were a generation ago. Despite the bicycle's head start on the automobile, in most societies only the automobile seemed to achieve what Thomas Hughes calls "technological momentum."

Hughes argues that technical systems are not infinitely malleable. If technologies such as the bicycle or the automobile are not independent forces shaping history, they can still exercise a "soft determinism" once they are in place. "Technological momentum" is a particularly useful concept for understanding large-scale systems, such as the electric grid, the railway, or the automobile. In *Networks of Power,* Hughes examines five stages of system development for the electrical grid, and these stages can apply to other inventions as well. In the case of electrification, the sequence began in the 1870s with invention and early development in a few locations (1875–1882). That was followed by technology transfer to other regions (1882–1890). With successful transfer came growth (1890–) and the development of subsidiary infrastructures of production, education, and consumption, leading to technological momentum (after c. 1900) as electricity became a standard source of light, heat, and power. In the mature stage (after. c. 1910), the problems faced by management required financiers and consulting engineers.[6]

"Technological momentum" is not inherent in any technological system when first deployed. It arises as a consequence of early development and successful entrepreneurship, and it emerges at the culmination of a period of growth. The bicycle had such momentum in Denmark and the Netherlands from 1920 until the 1960s, with the result that a system of paved trails and cycling lanes were embedded in the infrastructure before the automobile achieved momentum. In the United States, the automobile became the center of a socio-technical system more quickly and achieved momentum a generation earlier. Only some systems achieve "technological momentum," which Hughes has also applied to analysis of nitrogen fixation systems and atomic energy.[7] The concept seems particularly useful for understanding large systems. These have some flexibility when being defined in their initial phases. But as technical specifications are established and widely adopted, and as a system comes to employ a bureaucracy and thousands of workers, it becomes less responsive to outside pressures. Hughes provided an example in *American Genesis:* ". . . the inertia of the system producing explosives for nuclear weapons arises from the involvement of numerous military, industrial, university, and other organizations, as well as from the commitment of hundreds of thousands of persons whose skills and employment are dependent on the system."[8] Similarly, at the end of the nineteenth century, once the width of railway tracks had been made uniform and several thousand miles were laid out, once bridges and grade crossings were designed with rail cars of certain dimensions in mind, it was expensive and impractical to reconfigure a railway system.

Hughes makes clear when discussing "inertia" that the concept is not only technical but also cultural and institutional. A society may choose to adopt either direct current or alternating current, or to use 110 volts, or 220 volts, or some other voltage, but a generation after these choices have been made it is costly and difficult to undo such a decision. Hundreds of appliance makers, thousands of electricians, and millions of homeowners have made a financial commitment to these technical standards. Furthermore, people become accustomed to particular standards and soon begin to regard them as natural. Once built, an electrical grid is "less shaped by and more the shaper of its environment."[9] This may sound deterministic, but it is not entirely so, for people decided to build the grid and selected its specifications and components. To later generations, however, such technical systems seem to be deterministic.[10]

The US electrical system achieved technological momentum around 1900. By that time, it was "reinforced with a cultural context, and interacting in a systematic way with the elements of that context," and "like high momentum matter [it] tended in time to resist changes in the direction of its development."[11] From 1900 on, growth was relentless and not easily deflected by contingencies. The electrical system was far more than machines themselves; it included utility companies, research laboratories, regulatory agencies, and educational institutions, constituting what Hughes calls a "sociotechnical system." It had high momentum, force, and direction because of its "institutionally structured nature, heavy capital investments, supportive legislation, and the commitment of know-how and experience."[12] Similarly, the automobile achieved technological momentum not as an isolated machine, but as part of a system that included road building, driver education programs, gas stations, repair shops, manufacturers of spare parts, and new forms of land use that spread out the population into suburbs that, practically speaking, were accessible only to cars and trucks.

The concept of technological momentum provides a way to understand how large systems exercise a "soft determinism" once they are in place. Once a society chooses the automobile (rather than the bicycle supplemented by mass transit) as its preferred system of urban transportation, it is difficult to undo such a decision. The technological momentum of a system is not simply a matter of expense, although the cost of building highways, bicycle lanes, or railroad tracks is important. Ultimately, the momentum of a society's transport system is embodied in the different kinds of cities and suburbs fostered by each form of transportation. Relying on bicycles and streetcars has kept Amsterdam densely populated, which in turn means that relatively few kilometers of streetcar line can efficiently serve the population. If the Dutch were to decide to rely more on the automobile, they would have to rip apart a tightly woven urban fabric of row houses, canals, and small businesses. In contrast, cities such as Houston, Phoenix, and Los Angeles sprawl over larger areas, with more than half the land area devoted to roads, parking lots, garages, gas stations, and other spaces for automobiles. Such a commitment to the automobile has resulted in massive infrastructure investments that make it impractically expensive to shift to mass transit, not least because the houses are so far apart. In the United States the automobile now is "less shaped by and more the shaper of its environment."[13] Hughes's idea of "technological momentum" is far less deterministic than externalist theories, and provides a useful way to think about how large socio-technical systems operate in society.

Most historians of technology are either contextualists or internalists.[14] These are not so much opposed schools of thought as different emphases. Internalists reconstruct the history of machines and processes focusing on the role of the inventor, laboratory practices, and the state of scientific knowledge at a particular time. They chart the sequence that leads from one physical object to the next. The internalist approach has some affinities with art history,[15] but it grew out of the history of science. A five-volume *History of Technology* published in the 1950s detailed the histories of industrial chemicals, textile machinery, steelmaking, electric lighting and generating systems, and so forth.[16] Internalists establish a bedrock of facts about individual inventors, their competition, their technical difficulties, and their solutions to particular problems.

An internalist may be a feminist working on Madame Curie or a railroad historian interested in how different kinds of boxcars developed. Tracy Kidder's best-selling book *The Soul of a New Machine* is an example.[17] Kidder spent months observing a team that was inventing a new computer, charting the work process, the pressures from management for rapid results, the continual advances in electronics that made it hard to know when to freeze the design of the machine, and the step-by-step developments that led to a final product. The book ends shortly after the company presents the new computer to the public at a press

conference. It does not examine the consumer's response to the computer or tell the reader much about its sales success. The internalist writes from the point of view of an insider who looks over an inventor's shoulder. Such studies, whether of the light bulb, the computer, or the atom bomb, culminate at the moment when the new device is ready for use.

If many non-specialists believe that necessity is the mother of invention, internalists usually find that creativity is by no means assured or automatic. A machine that society fervently desires cannot be ordered like a pizza. Edison spent years trying to invent a lightweight battery for electric automobiles that could be recharged quickly and could hold a charge for a long time. He made some progress, but 100 years later the problem still eludes complete solution.[18] Money and talent can speed refinements along, but they cannot always call an invention into being.

The internalist approach also emphasizes alternative solutions to problems. For example, late in the nineteenth century the need for flexible power transmission over a distance was solved by a variety of devices. In different places one could buy power in the form of compressed air, pressurized water, moving cables, steam, and electricity. These were not merely invented: by 1880 all were in commercial use. In Paris, compressed air drove machines in some small businesses. It was easy to use and far less trouble than installing and maintaining a steam engine. In New York and other nearby cities, the hot-air engine enjoyed a brief vogue. In Boston, from 1880 until as late as 1962 many small businesses in a single block had steam power delivered to them by overhead driveshafts. In hilly San Francisco, cable cars were superior to streetcars driven by electric motors.[19] The research of internalist historians explains the precise characteristics of these power systems, helps us to understand their relative merits, and shows us how they were used and why they were eventually abandoned.

The internalist can compare the technical merits of early steam-powered, electric-powered, and gasoline-powered automobiles, all of which were successfully produced and marketed between 1900 and 1920. This is necessary (but not sufficient) knowledge to understand why Americans preferred gasoline automobiles, even though initially they were more familiar with the steam engine. Only in retrospect was the gasoline engine the obvious winner. In 1900 the majority of the roughly 8,000 automobiles in the United States were steam-powered; gasoline autos were the least common type.[20] The electric car was the quietest and least polluting of the three, but it lacked the range of the others. Steam automobiles took the longest to start, as it took time to get cold water up to a boil. The Stanley Steamer overcame this objection by heating water in small amounts as it was needed. The steam auto was reliable, and people understood its technology.

Internal-combustion engines were noisy and polluting. Furthermore, there were few filling stations or mechanics to service them in 1900, while steamers burned kerosene, which was available in any hardware store. In addition, the early gasoline autos had to be cranked, which was inconvenient, physically demanding, and somewhat dangerous—the crank could kick back and hurt one's wrist or arm. On the other hand, because the steam auto was the heaviest of the three types, it was hard on driveways and road surfaces, and, at a time when most roads were unpaved, it easily got stuck in the mud. The batteries for electric cars were heavy and took a long time to recharge, making long trips inconvenient. The internal-combustion engine delivered the most power for its weight because its fuel had a high energy density. The internalist approach thus can identify the strengths and

weaknesses of competing technologies. Clearly, the gasoline auto's longer range, lighter construction, and greater power gave it decided advantages. Yet such factors alone did not give it what Hughes would call technological momentum. By c. 1905 all three forms of automobile had been invented, had begun to spread into the society, and had experienced growth in demand. But none had gained a decisive lead, and all still competed with streetcars and bicycles.

To tell the story beyond this point requires the contextualist approach, which focuses on how the larger society shapes and chooses machines.[21] It is impossible to separate technical and cultural factors when accounting for which technology wins the largest market share. The Stanley brothers made fine steam cars, but, like most automakers, they built them by hand and in limited numbers. This meant that they were priced high. Electrics were manufactured in much the same way, so they had no price advantage. Some electrics were marketed as ideal for women, however. A sales strategy that "feminized" their ease in starting, lower speed, and limited range made such cars unappealing to men without attracting many female buyers.[22] Only the gasoline auto had an entrepreneur of the caliber of Henry Ford, who realized that the way forward was mass production of a standard design at the lowest possible price. As his managers invented and installed the assembly line, they brought the price of a new car down from more than $850 in 1908 to $360 in 1916.[23] Ford also benefited from geographical factors. The gasoline auto was best suited to use in the countryside, where the heavier steam cars sank into the mud and electrics could seldom be recharged. (Only one farmer in 15 had electricity.) In 1910 more than half the population of the United States remained on the land, and the gasoline auto had that market virtually to itself. Furthermore, rural people could better afford the Model T than its hand-assembled and more expensive competition. By 1926 an astonishing 90 percent of the farmers in Iowa owned automobiles,[24] and Ford had sold almost 15 million Model Ts. Ford's success spurred subsidiary investment in service stations, the training of thousands of mechanics, and the creation of a national network of companies selling tires, batteries, spare parts and the automobiles themselves. By the end of the 1920s, an auto industry overwhelmingly devoted to the internal-combustion engine consumed 20 percent of the nation's steel, 80 percent of its rubber, and 75 percent of its plate glass. Embedded in this extensive socio-technical system, the gasoline auto had achieved a technological momentum in the United States that it would not attain in Europe until the 1950s. In 1926, 78 percent of the world's automobiles were in North America. There was one for every six Americans, but only one for every 102 Germans.[25]

The success of the gasoline automobile can thus be attributed to a variety of interlinked factors. The lack of an electrical grid in large parts of the country and the unresolved problem of the heavy, slow-charging battery counted against the electric car, as did its extensive marketing as a woman's vehicle. The steam car had none of these problems, and the steam engine was familiar. Yet the steam car was the heaviest, it was not manufactured as cheaply or marketed as aggressively as the gasoline car, and gasoline was abundant and inexpensive. Thus, a wide range of factors were involved, including economics, entrepreneurship, and social norms as well as technology. In thinking about why AT&T's picture phone failed in the 1970s, Kenneth Lepartito concluded that any technology should be understood not as an isolated thing in itself, but as part of a complex system "in which machines have ramifications for other machines, for the plans of contending actors, and for politics and culture." Therefore, "all

technological change becomes problematic. This indeterminacy flows from the fact that technology is not a stable artifact but a system in evolution, one whose features and functions are up for grabs."[26] But if a technology is widely adopted, this indeterminacy gives way to momentum.

In the contextual approach, every technology is deeply embedded in a continual (re)construction of the world. A contextualist eschews the Olympian perspective and tries to understand technologies from the point of view of those who encountered them in a particular time and place. This approach immediately implies that machines and technical processes are parts of cultural practices that may develop in more than one way. For example, the contextualist sees the computer not as an implacable force moving through history (an externalist argument), but as a system of machines and social practices that varies from one time period to another and from one culture to another. In the United States, the computer was not a "thing" that came from outside society and had an "impact"; rather, it was shaped by its social context. In this perspective, each technology is an extension of human lives.

The same generalizations apply to the Internet. Civilians under contract with the Department of Defense developed the Internet to facilitate communication among scientists using the large computers located at universities around the United States. The military funded it and understood its possible use in transmitting vital defense information in case of atomic attack. But the first working system connected universities, and when it was put into operation there was not a great deal of traffic.[27] No one had anticipated the most popular application: what we now call e-mail. In its early years, the system was funded by the Advanced Research Project Agency, out of the Pentagon, and was called ARPANET. In the 1970s, once it was up and running, the military tried to sell the system to AT&T, but AT&T refused the offer. For the next 15 years, scientists and grassroots organizations developed e-mail, user groups, and databases on the net.[28] In the 1990s came the World Wide Web, web browsers, and e-commerce. Then in a great rush the Internet became an integral part of advertising, marketing, politics, news, and entertainment. People used the Internet in unexpected and sometimes illegal ways. For some, "surfing" became a kind of tourism and an entertainment that partly replaced television. For others, the Internet offered ways to share music (often pirated), or to publish their thoughts and ideas in "blogs" (short for "weblogs") addressed to the world. The popular acceptance of the Internet raised political issues. Who should own and control it? Did it threaten to destroy jobs by eliminating middlemen, or was it the basis of a new prosperity? Did it democratize access to information, or did it create a "digital divide" between those who could afford it and those who could not? Like every technology, the Internet implied new businesses, opened new social agendas, and raised political questions. It was not a thing in isolation.

If one takes this approach, then it appears fundamentally mistaken to think of "the home" or "the factory" or "the city" as a passive, solid object that undergoes an involuntary transformation when a new technology appears. Rather, every institution is a social space that incorporates or doesn't incorporate the Internet at a certain historical juncture as part of its ongoing development. The Internet offers a series of choices based only partly on technical considerations. Its meaning must be looked for in the many contexts in which people decide how to use it. For example, in the 1990s many chose to buy books, videos, and CDs on the Internet, but not all were ready for the online purchase of groceries. By 2004 British supermarkets had wooed many customers to shop online for food, but the same idea had little success in Denmark, even though a higher percentage of Danes were online. People in many countries preferred the Internet to the fax machine, but use of the telephone continued to expand. People adapted the Internet to a wide range of social, political, economic, and aesthetic contexts, weaving it into the fabric of experience. It facilitated social transformations, but different societies incorporated it into the structures of daily life in somewhat different ways. Every culture continues to make choices about what to do with this new technology.

The history of electrification offers a suggestive parallel to the Internet. Between c. 1880 and 1920, when the electrical system was being built into American society, a lively debate took place among engineers, progressive reformers, businessmen, and the general public. This debate about the cultural meaning and uses of electricity was necessary because Americans of c. 1900 had to choose whether to construct many small generating stations or a centralized system, whether to adopt alternating or direct current, whether to rely on public or private ownership of the system, and whether to give control primarily to technicians, to capitalists, or to politicians. Similarly, the debate about the Internet (after c. 1992) was necessary because people had to decide whether to construct a decentralized or a centralized system. They debated to what extent it should be monitored or controlled by individuals, corporations, or the government, and they questioned to what degree the Internet and its many individual sites and homepages should become commercialized. Finally, they wrestled with the issue of proprietary software, shareware, and freeware, and with related issues of copyright and intellectual property.

Like the collaborative building of the Internet, electrification was not a "natural process" but a social construction that varied from country to country. For example, electrical light and power were embraced readily by the working class in Sweden, where the first educational publication of the Social Democrats (1897) was titled *Mere Ljus* (meaning "more light").[29] In contrast, South African mining towns used electricity almost exclusively to improve the extraction of gold, diamonds, and coal, and seldom to enhance the lives of black workers.[30] Yet not all consumers immediately embraced electricity. The majority of British workers long retained a familiar gas system. As late as 1936, only one-third of the dwellings in the industrial city of Manchester had electricity.[31] In the United States electrification proceeded much more rapidly, and more than 90 percent of urban homes had electricity in 1936.[32] Just as in the 1990s a divide opened between those who had computers and Internet connections and those who did not, during the 1930s there were equally worrisome divisions between those who had electricity and those who did not. The construction of the Internet opened up political issues, legal problems, entertainment possibilities, and business opportunities. As with electricity, the public found the Internet to be suddenly ubiquitous and yet inscrutable, and it often seemed to be an irresistible natural force. And as with electricity in 1910, so much was attributed to the Internet in the 1990s that it became a universal icon of the age.

The histories of the bicycle, the automobile, electrification, and the Internet all suggest, once again, that there is little basis for a belief in technological determinism. Sweeping externalist histories about machines that shape society remain popular, but they clash with the research of most professional historians of technology (both internalists and contextualists). The more one knows

about a particular device, the less inevitable it seems. Yet a thousand habits of thought, repeated in the press and in popular speech, encourage us in the delusion that technology has a will of its own and shapes us to its ends.

As we become accustomed to new things, they are woven into the fabric of daily life. Gradually, every new technology seems to become "natural," and therefore somehow "inevitable" because it is hard to imagine a world without it. Through most of history flush toilets did not exist, but after 100 years of widespread use they seem normal and natural; the once-familiar outhouse now seems disgusting and unacceptable. Likewise, Western societies have naturalized the radio, the mobile phone, and the television, and most people do not think of them as social constructions.

The novelist Richard Powers noted that the naturalization of technology involves the continual transformation of human desires "until in a short time consumers cannot do without a good that did not exist a few years before." As a contrast, Powers describes a character who has escaped from this continual process of naturalizing the new. She does not transform her apartment to accord with changing fashions, but keeps whatever she likes, regardless or style or age: ". . . Mrs. Shrenck's thing-hoard implied that she had bypassed this assimilation altogether, simply by making no distinction in value between a pine-cone picked up on yesterday's walk and a rare, ancient floor-cabinet radio. . . ."[33] Few consumers are so indifferent to style, however. And once one sees that technologies are shaped by consumption, it becomes apparent that, though devices change often, they do not necessarily improve. One of mankind's oldest technologies, clothing, offers a fine example, for stylistic considerations have often proved more important than comfort or durability. Judith McGaw examined the enormous variety of brassieres and found not only that there is "no convincing evidence that the breasts need support" but also that brassieres never quite fit. Women do not come in standard sizes, and furthermore "the size and shape of any woman's breasts change continuously—as she ages, as she gains or loses weight, as she goes through pregnancies, as she experiences her monthly hormonal cycles."[34] In selecting bras and other clothing, women continuously compromise between style, comfort, and self-expression. As this example suggests, the human relationship to technology is not a matter of determinism; it is unavoidably bound up with consumption.

5 Cultural Uniformity, or Diversity?

In the excitement of the early Internet boom of the 1990s, a group of cyber-libertarians released a manifesto titled "Cyberspace and the American Dream: A Magna Carta for the Knowledge Age." Among their many claims was this assertion: "Turning the economics of mass-production inside out, new information technologies are driving the financial costs of diversity—both product and personal—down toward zero, 'demassifying' our institutions and our culture. Accelerating demassification creates the potential for vastly increased human freedom."[1] For decades, critics of industrialization had asserted just the opposite, arguing that mass production of goods and improved communications together annihilated cultural differences. Are advanced technologies being used to homogenize the world, dissolving distinctive cultures into a global system? Or are advanced technologies being used to create more social differences?

The preceding chapters established that technologies are neither deterministic nor predictable and that they are best understood as social constructions. These conclusions suggest that machines might be used to create choices and possibilities. A highly technological culture might become more diverse, and not, as many

Chapter 4

1. Petroski 2003, p. 13.

2. For an elegant discussion, see Staudenmaier 1985.

3. Cited on pp. 57–58 of Staudenmaier 1985.

4. Wallace 2003, p. 3.

5. Susan B. Anthony, *New York World* interview, 1896, cited on p. 130 of Dodge 1996.

6. Hughes 1983, pp. 14–17.

7. Hughes 1969; Hughes 1994, p. 111.

8. Hughes 1989, p. 460.

9. Hughes 1994, p. 108.

10. Individual machines can achieve a shorter-term technological momentum, but only a few technologies achieve the lasting technological momentum of the railway network or the electrical system.

11. Hughes 1983, p. 140.

12. Ibid., p. 465.

13. Hughes 1994, p. 108.

14. Staudenmaier 1994, pp. 260–273.

15. See Kubler 1962.

16. Singer et al. 1951–1958.

17. Kidder 1995.

18. Israel 1998, pp. 410–421.

19. Hunter and Bryant 1991, pp. 61–68, 115–238.

20. Dukert 1980, p. 50.

21. Contextualists are the largest group of authors in Society for the History of Technology's journal *Technology and Culture.*

22. Scharff 1991, pp. 35–50.

23. Nye 1979, p. 23.

24. Ling 1990, p. 30.

25. Yergin 1992, pp. 208–209.

26. Lepartito 2003, p. 76.

27. Abbate 1999, pp. 43–81.

28. Ibid., pp. 83–144.

29. Furuland 1984, p. 38.

30. Renfrew 1984.

31. Luckin 1990, pp. 61, 68.

32. Nye 1990, p. 299. Electrification of farms was uneven, with 61% electrified in California in 1935 but less than 5% in most of the South. (Williams 1997, p. 223).

33. Powers 1992, p. 298.

34. McGaw 2003, p. 18.

Chapter 5

1. Dyson et al. 1994.

2. Cited on p. 196 of Winner 1997.

3. Huizinga 1972, pp. 234, 237.

4. On the Frankfurt School, see Jay 1973.

5. Quoted on p. 214 of Jay 1973.

6. Riesman 1950.

7. Grant 1969, p. 26.

8. Henry 1963, p. 15.

9. The often-reprinted speech can be found at www.narhist.ewu.edu.