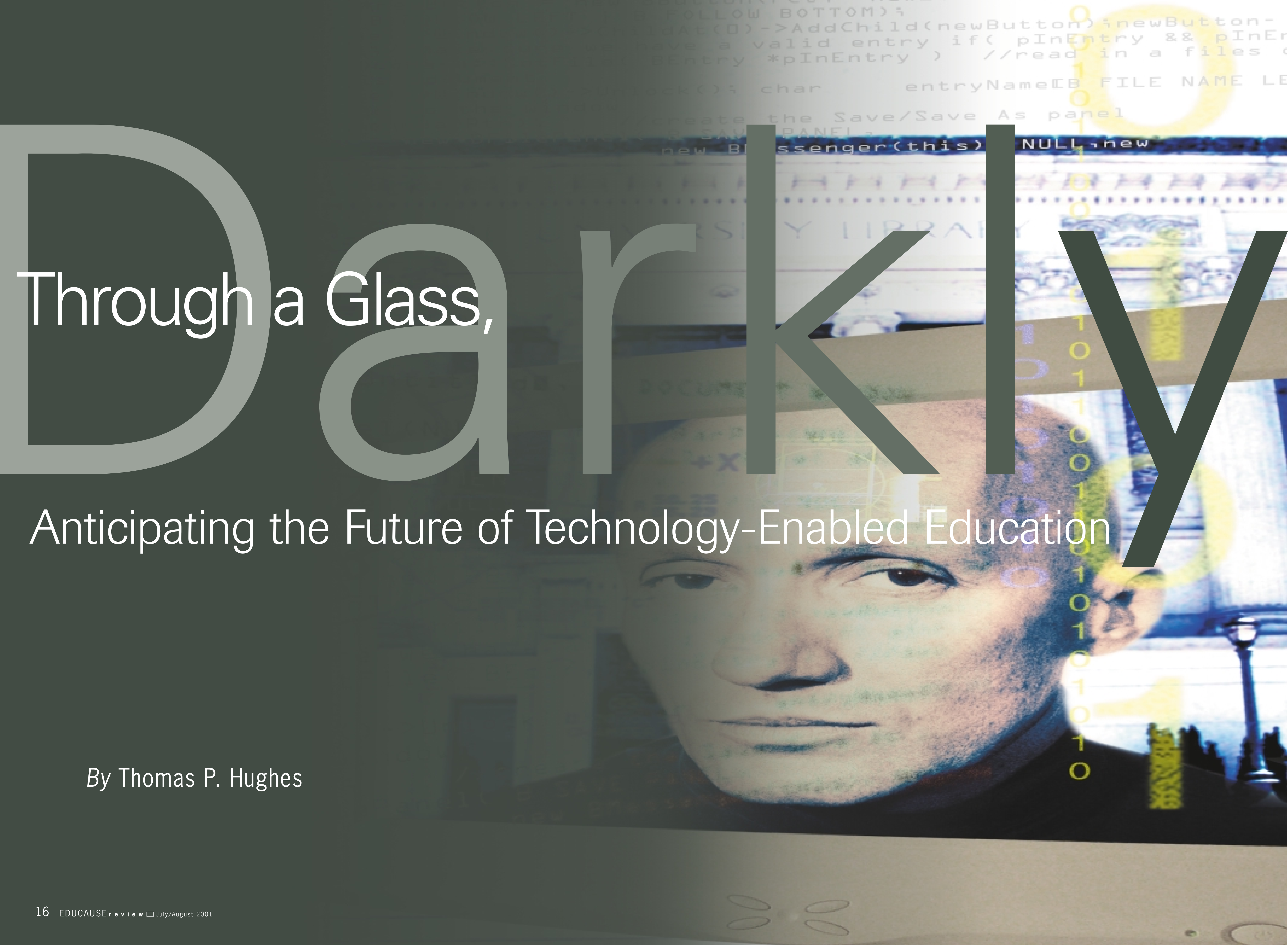
Through a Glass, Darkly

Anticipating the Future of Technology-Enabled Education

By Thomas P. Hughes



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An ever-increasing number of academic administrators, as well as businesspeople, associate technology-enabled education with the information revolution. They speak enthusiastically of distance learning and of "edtech" firms. Talk about virtual universities has increased. Individualized, active learning is seen as displacing passive learning. Lifelong learning is a common commitment. Rapid and radical change in higher education gathers momentum. Enthusiasm waxes. Many in higher education look forward to being swept along by what they perceive as a mounting technological tide. They expect technology, especially computers and the Internet, to drive changes in the educational system. Based on

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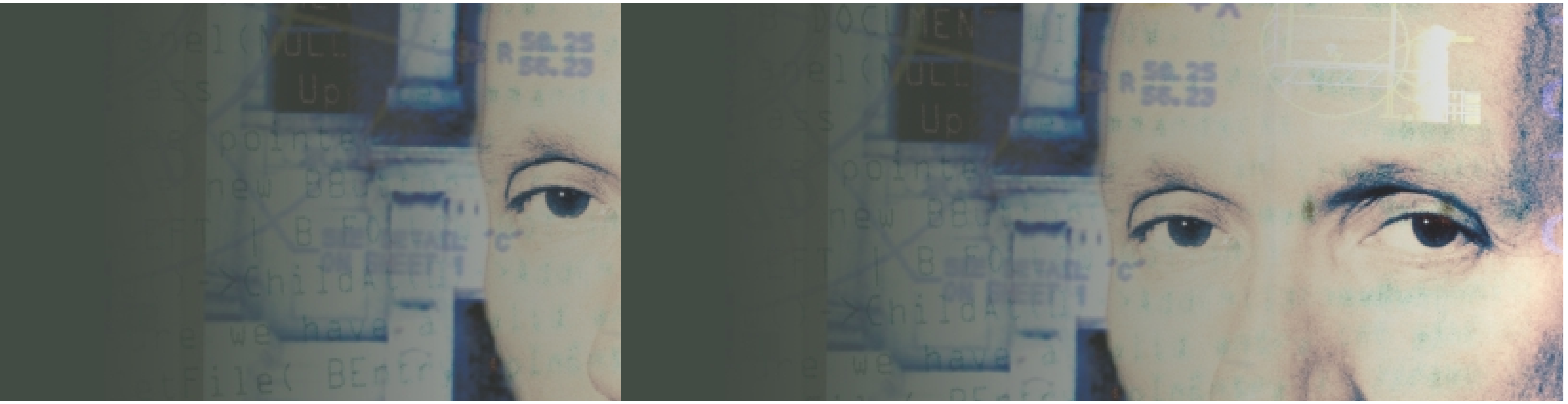
this expectation, they make confident predictions about the future of higher education.

History, however, advises caution, even skepticism. In the novel *Waterland* (1983), Graham Swift wrote: "History is that impossible thing: the attempt to give an account, with incomplete knowledge, of actions themselves undertaken with incomplete knowledge. . . . Yes, yes, the past gets in the way; it trips us up, bogs us down; it complicates, makes difficult. But to ignore this is folly, because, above all, what history teaches us is to avoid illusion and make-believe, to lay aside dreams, moonshine, cure-alls, wonder-workings, pie-in-the-sky—to be realistic."[1] Future changes in higher education will involve actions undertaken based on incomplete knowledge. Furthermore, those making predictions about the future of higher education are doing so with incomplete knowledge. As we shall see, history can help both those making predictions and those presiding over changes in higher education to be more realistic.



The history of technology shows that sociotechnological systems, rather than technical systems, will determine the future of higher education. Technical systems consist of hardware and software components. Sociotechnological systems have technical and organizational systems as components. The Internet and technology-enabled education are sociotechnological systems. Higher education is a large sociotechnological system in which the Internet and technology-enabled education are two of many subsystems. The future of higher education is thus as difficult to fathom and to predict as changes in political and social systems. It will not be simply technologically determined.

We should reject predictions based on the assumption that technology-enabled education is a technical system, and we should not simply extrapolate from the present state of technology-enabled education into the future. For example, we should not assume that an expanding system will continue to expand at its present rate, because the contexts that shape a system change over time. Instead of extrapolation, we should use historical analogies to peer into the future of a sociotechnological system.

By examining the history of various sociotechnological systems, we can suggest, by analogy, the likely future of technology-enabled education. The historian's task is to choose appropriate analogies, to identify appropriate episodes that anticipate the behavior of the system about which predictions are being made. In this connection, we should recall Aristotle's statement that metaphor, or analogy, requires the difficult act of perceiving similarity in the seemingly dissimilar. Even with analogy, we should realize that we are looking through a glass, darkly.

In the following essay, I draw my analogies from case histories that reveal the problematic nature of predictions about technological change, that demonstrate the role of human agency, and that also suggest the deterministic forces at play. These episodes reveal patterns that seem likely to repeat as a system of technology-enabled education evolves.

Is the Information Revolution Changing Everything?

Before discussing these patterns, I will examine the argument that the information revolution, specifically the Internet, will "change everything," including higher education.[2] This seems likely if the Internet system fosters a sociotechnical revolution comparable to industrial revolutions of the past. They "changed everything," including education.

The Internet is likely to generate a sociotechnical revolution in much the same way that electric power and the internal combustion engine first brought a technical revolution and then initiated a sociotechnical revolution generally known as the Second Industrial Revolution (1870–1940). The move from a technical to a sociotechnical revolution occurred when system builders coordinated technical and organizational systems.

The insertion of a new source of energy into an existing sociotechnological system usually requires redesigning many components in the system. For example, the application of electric power in factories substantially altered factory layout and labor processes. A new energy source can also become the core of a new sociotechnological system, even of a sociotechnical revolution, as was the case with electric power.

Information, like energy, is omnipresent in the human-built environment. A new form of information, like a new form of energy, is likely to generate cascading effects when introduced into existing sociotechnological systems. The Internet is analogous to electric power because both are means of transmission and distribution—in one case energy and, in the other, information. The potential applications of the new information technology are as numerous as those of electric power and the internal combustion engine. When variously applied by inventors and engineers, digital information is likely to bring a technical revolution. Later, system builders will foster a sociotechnical revolution.

Pattern 1: Everything Changes but Not as Anticipated

It is reasonable to predict that the Internet is changing everything in a way that recalls the industrial revolutions of the past. Yet history suggests that everything will change in unanticipated ways.

In the 1920s, for example, a number of social scientists, public intellectuals, and industrialists believed that they were experiencing a sociotechnical revolution. Labeled the Second Industrial Revolution, it involved electricity, automobiles, telephones, and radio, as well as organizational, social, political, and demographic changes. But although these observers correctly anticipated momentous changes, they frequently erred in anticipating the nature of those changes. As we shall discover, even though they thought their anticipations were value–free, they unwittingly imposed their values on the technological future. They believed that the new technical systems would predictably drive social changes; thus they knowingly or unconsciously embraced technological determinism.

The predictions of Lewis Mumford, an informed and wise public intellectual, offer an excellent indication of the difficulty of forecasting large-scale sociotechnical change. In two early books, he developed a concept of nineteenth-century New England regionalism that, he believed, would be brought about by the Second Industrial Revolution. Mumford portrayed his ideal twentieth-century regionalism as having moderately sized, culture-cultivating cities, comparable to the historic New England towns, surrounded by a sustaining food-growing country pocketed with small industrial villages where industrial workers also farm. A system of roads links the population centers. Industry draws on waterpower sources and from electricity transmission lines. Thermal power plants situated at coal-mining sites are major suppliers of energy. Coal is not burned but is distilled to draw off valuable by-products. The residual coke is fired. Transmission lines hundreds of miles in length distribute energy throughout the region. Industry is no longer limited to the lowlands, where the coal-carrying railroad networks spread. It moves to the highlands, where hydroelectric plants flourish. People living in the countryside have the radio to enrich their lives, the telephone to involve them in social networks, and the automobile to provide mobility. Electrical motors and internal combustion engines free farmers from the heavy labor of their past.

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Although Mumford rightly recognized that the country was experiencing an industrial revolution, he wrongly believed that it would inexorably bring the regionalism he so ardently desired. Mumford made the same mistake frequently made by technological-change enthusiasts and forecasters. He envisioned a scenario involving a logical sequence of social, political, and cultural changes following in the wake of technological change. Mumford failed to recognize that technology is malleable, that it is shaped by values. He embraced (though did not acknowledge) value-free technological determinism, when in fact his values shaped his predictions.[3] He ignored the aspirations and predictions of those with a different agenda for the new technology. Some of them had a personal stake in maintaining the urban status quo and opposing Mumford's regionalism. While Mumford foresaw a network of roads linking small cities and rural communities, others laid out highways that moved traffic into large cities. Foes of regionalism supported the construction of subways and streets that allowed more commuters to reach and move within the large cities. High-rise buildings accommodated more professionals and workers in inner cities. Instead of mine-mouth power plants, urban power plants receiving coal by rail from distant mines continued to function. Mumford anticipated that electric power, automobiles, radio, and telephone would make rural living so attractive that young people would remain on the farms, but instead they fled the countryside. Mumford envisioned small garden cities surrounded by greenbelts, but suburbia attached itself to the large cities.

Pattern 1 Analogy: Visions and Vested Interests

Many college and university administrators and some faculty envisage a technology-enabled education that reinforces their visions and vested interests. Like Mumford, they unknowingly or knowingly tend toward self-serving technological determinism. They imagine that computers and the Internet inexorably bring change. Their optimism sustains their enthusiastic commitment to technology-enabled education.

Already there is an anticipation canon. Because of the glittering status of the new-economy corporate world, supporters imagine that technology-enabled education will take on a corporate style. Academic administrators are encouraged to use a Silicon Valley management style: campus-corporate joint ventures, mergers, and acquisitions are in vogue; patent law policy is applied to faculty-generated courses, now called "courseware"; entrepreneurial activities are thrust upon the faculty; and college and university presidents are urged to learn from corporate CEOs and reengineer their institutions.

The attraction of the corporate management style in academia today is reminiscent of the widespread envy of the natural sciences—especially physics—among higher education institutions in the 1950s. Even historians tried to transform their art into a quantitative science. Engineering schools became schools of "applied science." The great center of engineering, MIT, characterized itself as an institution polarized—some said paralyzed—around science. Today this era has passed.

We should remember that appealing visions have often proved to be chimerical. In recent decades, the high hopes for atomic energy in the United States were not fulfilled. Cold fusion and superconductivity were short-lived enthusiasms.

Pattern 2: Unanticipated Applications

The history of the internal combustion engine provides a memorable example of unanticipated applications of technical systems. It is highly unlikely that anyone predicted that the internal combustion engine would culminate in the Second Industrial Revolution.

Initially, the internal combustion engine was intended for craftspeople and small manufacturers. Its original inventors did not intend for the engine to be used for transportation systems; others saw this possibility. Even they, however, could not have anticipated the far-reaching consequences of the new engine. In 1883, Gottlieb Daimler, a German engineer, adapted the engine for vehicles by decreasing the weight-to-horsepower ratio, greatly increasing the revolutions per minute, and by substituting liquid petrol for a gaseous fuel.[4] As is often the case with a new artifact, Daimler placed his invention on familiar platforms—bicycles and former horse-drawn carriages.

By 1891, however, the Frenchman Emile Levassor and his partner, René Panhard, were building integrated automobiles according to their *système.* Vehicle components, such as the engine, transmission, and frame, were designed to function harmoniously as a motorcar. As one historian has noted, "The genius of Levassor lay in assembling these [and other components] in a system which comprised a motorcar, in embryo, as distinct from a horseless carriage."[5] In the hands of Americans such as Henry Ford, the motorcar became the core technology in the automobile production and use system that continues to transform the U.S. landscape.

Other inventors maintained the sequence of unanticipated applications. At about the turn of the century, a German, Ferdinand Graf Zeppelin, used the light engine to provide propulsion for a navigable balloon. Orville and Wilbur Wright adapted the petrol engine to a heavier-than-air craft, an innovative process that culminated in their historic flight of 1903. The Wright brothers anticipated that their aircraft would be used by the military, but they did not foresee the dramatic transformation in military and commercial aviation that would transpire during the twentieth century.

Pattern 2 Analogy: Unanticipated Applications in Technology-Enabled Education

The future of technology-enabled education will involve computer and Internet applications not anticipated by present-day inventors and developers. Predictions of future developments in technology-enabled education are mostly projections of contemporary developments. Richard Larson and Glenn Strehle point out that some putative innovations in technology-enabled education are essentially slight improvements in existing educational practices. For example, distance learning is usually a carryover from traditional classroom teaching. They compare this projection of the past into the future to the early railway coaches, which were simply traditional horse-drawn coaches put on rails.[6] The technology-enabled innovations that may transform education are likely to be radical breakthrough inventions bringing a sharp break with past practice.

Creators of ARPANET, the forerunner of the Internet, did not forecast the rapid spread of e-mail. Nor did early predictions about the future of computer networks foresee the Internet. The developers of the World Wide Web did not forecast its tremendous impact on libraries. Failures to envision make a long list.

Awareness that many technology-enabled education innovations cannot now be anticipated should caution enthusiasts not to lock into innovations presently available. Early lock-in will bring the constraints of path dependency, the classic example being the present use of the QUERTY keyboard.

Pattern 3: Independent Inventors

It was not technological determinism, but instead chance, contingency, and confluence, as well as people and values, that shaped the course of the Second Industrial Revolution. Among those bringing change, the independent inventors stand tallest. As we have seen, they presided over critically important internal combustion engine innovations. They also invented and developed other large technical systems at the core of the Second Industrial Revolution

Elmer Ambrose Sperry's activities offer an example of an independent inventor's style. Flourishing in the early twentieth century, Sperry is remembered as the American father of complex feedback controls. A gyrocompass, a naval gunfire-control system, a ship stabilizer, an automatic airplane, and an automatic ship pilot are among his major feedback-control devices. Typically, he presided over radical breakthrough inventions. Sperry avoided working for a company other than one that he founded and controlled. In this way, he maintained his freedom of "problem choice." When engaged in the invention and development process, he headed a small group of inventors and craftsmen.

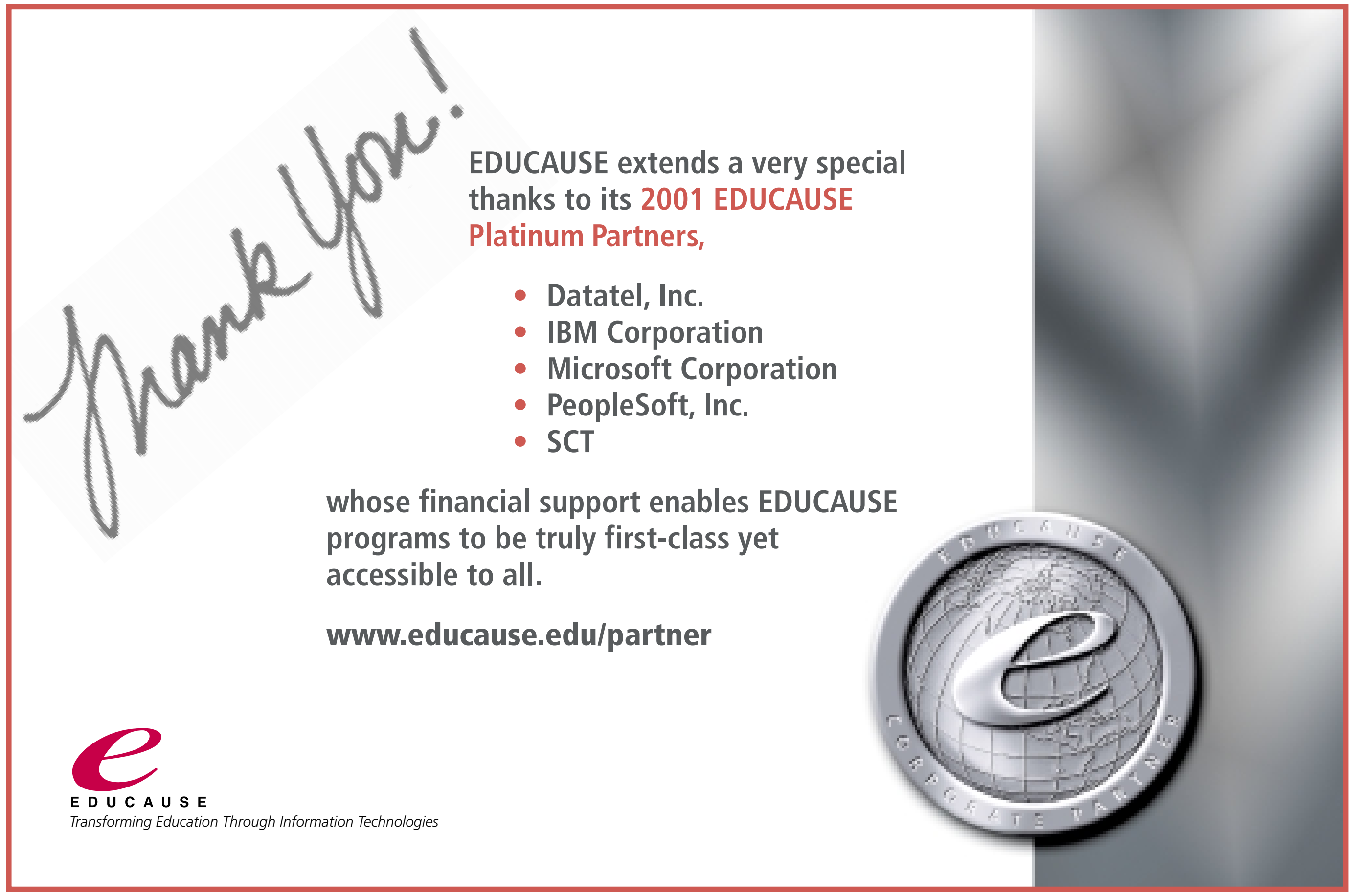
While still young, Sperry mastered the art of patenting and learned how to trade off patent rights for venture capital. He often chose his problems by studying the way in which patents clustered. From observing patents regularly listed in the *U.S. Patent Office Gazette,* Sperry found that they clustered around problems that a number of inventors judged ripe for solution. Sperry concentrated his inventive efforts where patents clustered in technology areas with which he was familiar. For example, he found that independent inventors in the United States and abroad were focusing on problems for which gyro devices could provide solutions.

Pattern 3 Analogy: The Independent Inventor Today

Today's university researchers are analogous to the independent inventors of the past. University researchers are responsible for a disproportionate number of the breakthrough computer hardware and software inventions. Like Sperry, many of them freely choose their research and development problems. In so doing, they differ from researchers in industrial research laboratories. Like Sperry, university researchers tend to concentrate where inventive activity is clustering. They learn of the clusters from a network of peers and from technical and scientific journals.

Breakthrough innovations in a university or academic context include the following: the digital ENIAC computer at the University of Pennsylvania; John von Neumann's computer architecture at the Princeton Institute for Advanced Study; time-sharing introduced at MIT; graphics at the University of Utah; ARPANET at several universities, including the University of California–Los Angeles; minicomputer workstations at Stanford University; the UNIX operating system at the University of California–Berkeley; reduced instruction set computing (RISC) at the University of California–Berkeley; and the Web browser at the University of Illinois–Urbana.

Independent inventors who will create major technical systems for technology-enabled education may well be research associates working in university-related, computer and Internet research laboratories rather than academics working in a departmental context.[7] They may form a project group of five or six people who will draw up a proposal and seek funds from a government or philanthropic organization. The group will likely be interdisciplinary and entrepreneurial, which means that it, like Sperry, will pursue the innovation process from invention, through development, and into use.



Pattern 4: System Builders

After inventor-entrepreneurs introduced technical systems during the Second Industrial Revolution, system builders presided over the growth of the sociotechnological systems that increasingly structured the industrialized world. Transportation, communication, and energy systems—composed of both technical and organizational components—superimposed grids and networks upon the landscape and shaped where humans live, work, and play.

System builders are a special breed of managers who have a holistic ability to coordinate the inventive activities of research laboratories, to solve the personnel and organizational problems that arise as companies grow larger, to raise the funds that are needed for expansion, and to respond to the political problems that often accompany government regulation.

Consulting engineering and management firms provide an example of system building culminating in a sociotechnological system. They proliferated in the electrical supply industry in the 1920s. Electric Bond and Share Company (EBASCO) and Stone & Webster, both consulting engineering and management firms, dominated the field. Their holistic, integrative approach characterizes system building.

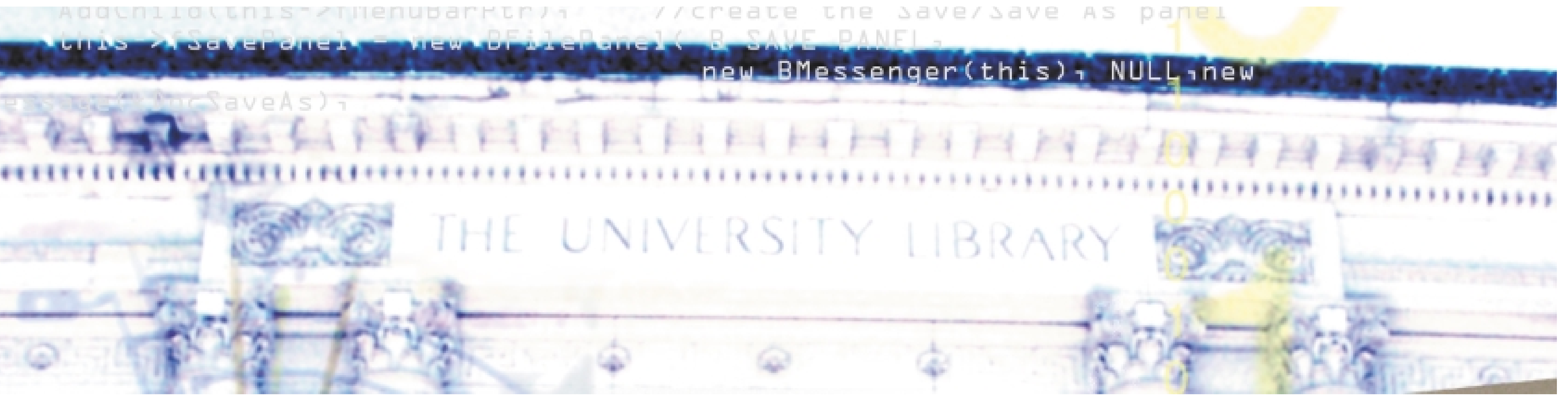
Established in 1905 by the General Electric Company, EBASCO controlled a number of electric utility companies and, through them, a number of technical subsystems—namely electric light and power networks, or grids.[8] EBASCO provided financial, management, and engineering construction services for the utility companies. The system builders of EBASCO saw to it that the services related synergistically. EBASCO management recommended the construction that EBASCO engineering carried out and for which EBASCO arranged financing through the sale of stocks or bonds. If the utilities lay in geographical proximity, then EBASCO often physically interconnected them through high-voltage power grids. EBASCO interacted also with electrical engineering departments in engineering colleges, whose faculty and graduate students conducted research or consulted for EBASCO.

Pattern 4 Analogy: System Builders for Technology-Enabled Education

System builders of sociotechnological systems for technology-enabled education may be individuals, groups, or organizations such as the consulting engineers who built regional electric power systems. The common characteristic shared by system builders is a genius for integrating heterogeneous components—physical, human, and organizational—in a goal-oriented system.

A technology-enabled education system may incorporate a research-and-development organization, a college or university department, a for-profit software developer, computer Web sites, portals, and a funding organization. The system builder should be capable not only of creating this heterogeneous mix but also of presiding over, or managing, it. In addition, system builders should be capable of negotiating with the political authorities that have the power to influence the sociotechnological system.

During the interwar years, the heads of EBASCO, who had begun as engineers, moved into the management of a heterogeneous system. Conceivably, the system builders in technology-enabled education will begin in a college or university setting but will then move into the management of a system that includes a higher education component.



Pattern 5: Research and Development

The manufacturers of electrical, automobile, telephone, and other Second Industrial Revolution technical systems would have improved their products slowly, at best, had they not institutionalized research and development (R&D) by establishing industrial research laboratories. These laboratories are hallmark organizations of the Second Industrial Revolution. The Bell telephone laboratories and the General Electric Research Laboratory are the best remembered of the labs, but hundreds of manufacturing companies established laboratories after the turn of the century. The founders expected the research scientists and engineers to make cumulative improvements in the company's products and services. The General Electric Research Laboratory, for instance, invested heavily in the improvement of the incandescent lamp filament. (Edison, an independent inventor, invented an entire system of electric lighting.)

Researchers in leading industrial research laboratories used theory when applicable but usually forged ahead empirically. Ingenious hypotheses often formulated by analogy, and tireless testing of these hypotheses by experimentation, characterized their style. Over time, the research changed from a hypothesis-driven wild-goose chase to a theory-related scientific foxhunt. The engineer Thomas Midgley Jr., an outstanding General Motors research lab leader, attributed successful research "in part to luck and religion, as well as to the application of science."[9]

Pattern 5 Analogy: R&D for Technology-Enabled Education

The relative freedom of problem choice enjoyed by university researchers and developers, as compared with the situation of engineers and scientists in large industrial research laboratories, partially explains the radical, breakthrough nature of the university researchers' highly innovative inventive activity. Engineers and scientists who are able to choose their problems freely often create new technical systems. In contrast, engineers and scientists who conduct R&D for large firms usually make conservative inventions resulting in improvements in the product line in which the firms are heavily invested.[10] They work within a highly structured organizational environment. Some large firms today counter these shaping influences by funding start-up ventures outside the firm or by distancing, physically and administratively, a small group of their own researchers.

After independent inventors and system builders bring new technology-enabled education into use, R&D laboratories analogous to those supported by large manufacturing companies will be needed to improve the technology or to adapt it to changing circumstances. The need for improvements will arise like reverse salients as technology-enabled educational systems expand and find new users. The staff of the research labs should monitor the enlarging and spreading systems in order to identify the reverse salients.

It is important to note that R&D often proceeds as a combination of empirical testing and science application. The notion that all research and development is simply the application of science is a myth.

Pattern 6: Resistance to Change

People and their values shape technology. They can effectively delay or even prevent technological change. Massive sociotechnological systems, such as educational systems, have characteristics analogous to the physical inertia of motion. Involving a mass of human, technical, organizational, and attitudinal components, higher education systems tend to maintain steady growth and direction. The extremely large investment of physical and human resources in education militates against disruptive changes that threaten to de-skill professors and administrators and to make existing physical plant and equipment obsolete.

How has resistance to technological change been overcome in the past? After World War II, U.S. Air Force officers experienced in, and enthusiastic about, flying aircraft resisted the introduction of intercontinental ballistic missiles (ICBMs). They raised doubts about the ability of missiles to carry heavy atomic warheads to targets in the Soviet Union; they questioned the possibility of designing a missile-guidance system that would ensure reasonable missile accuracy; and they argued that materials for a heat shield that would protect the warhead during reentry into the atmosphere could not be developed. Advocates of ICBMs within and outside the air force, on the other hand, countered that adequately funded research and development could bring early solutions to the problems. They contended that conservative air force policy-makers customarily exaggerated the severity of problems and then failed to allocate funds to solve them.

As is often the case in the history of technology and culture, authorities outside a high-momentum system provided the leverage for change. In this case, highly placed civilians in the Defense Department, citing a presumed threat from Soviet missiles, threatened to turn the development of ICBMs over to a civilian agency. The U.S. Air Force hierarchy capitulated.[11]

Pattern 6 Analogy: Leverage for Change

In the ICBM case, authorities from outside the system instituted change. In the case of higher education, those with power outside the system may overcome resistance to technology-enabled education. Who might they be?

In the case of public institutions, state legislatures have, in principle, the power to bring about changes in the system of higher education. Yet rarely do they exercise that power except in matters financial. If technology-enabled education were defined as a financial matter and if a committee or commission were established to investigate it, then a legislature might ask to appoint several members of the group.[12] Boards of overseers have similar financial leverage in private institutions. Coming from the private and philanthropic sectors, they have a point of view often differing from that of academe. Funding agencies, philanthropic and governmental, could cultivate technology-enabled education by soliciting and supporting funding in particular areas of change.

Resistance to disruptive technology on a cultural level may be overcome by a participatory approach.

Pattern 7: Participatory Change

Resistance to disruptive technology on a cultural level may be overcome by a participatory approach. A case in point is the approach taken by advocates of the Boston Central Artery and Tunnel, a technologically complex highway project that is now under way. This project will place an elevated highway underground in downtown Boston, offer a new harbor tunnel to Logan Airport, and construct a new bridge across the Charles River.

In the 1980s, activists offered effective resistance to highway construction in Boston and elsewhere in the United States. Highway engineers had a reputation for thrusting highways through cities and across the countryside without taking into consideration the disruptive effects on communities and people.

The advocates of the Boston Central Artery and Tunnel countered this resistance in part by promising that the highway system would be subject to public scrutiny and hearings during preliminary and final design. The Massachusetts Highway Department responded to the comments of groups and individuals appearing at the hearings or participating through written comment.

Pattern 7 Analogy: Faculty Participation in Technology-Enabled Education

Because relatively few faculty are able to perform, or are unwilling to take the time to perform, the complex tasks associated with technology-enabled education—especially the use of media and the interactive mode—leading colleges and universities have established technology centers staffed by experts to carry out these tasks. Professors can simply turn over distance learning delivery to experts on their campus.[13] The drawback in this procedure is that faculty are disempowered; they lose control over essential teaching and learning experiences. Often the experts are driven by technical and economic considerations and tend to overlook other values dear to the faculty.

To counter these negative effects, administrators and departmental chairs can encourage, even require, faculty participation in the introduction of technology-enabled education. A technology expert would not simply take over the technology function but would work with faculty members making use of technology. Faculty would take a hands-on role in the process. To participate positively in the introduction of technology-enabled education, faculty would become technologically literate through participation in instruction sessions organized by the college or university, probably by the library.

Conclusion

Technological change has been as rapid in the past as it is today but only during those transformation periods we label industrial revolutions. These revolutions involved basic alterations in the way energy was generated and transmitted. We are in such a period of transformation today: the effects of basic changes in the way information is generated and transmitted also cascade through social structures.

Inventors, engineers, and scientists enjoying freedom of problem choice have shown themselves adept in presiding over radical technological change during the so-called information revolution. They often flourish in research centers associated with universities rather than in discipline-bound, academic departments.

System builders are needed to create and preside over the sociotechnological systems that contain and sustain technological change. A technology-enabled education system in the future may incorporate a college or university department, a for-profit software developer, a venture-capital firm, a consulting group of experts in technology-enabled education, and Internet hardware and software facilities.

Resistance to technology-enabled education, especially among faculty, abounds. Vested interest in the status quo has high momentum, but it can be overcome by leverage from outside the faculty. It may also be overcome by organizing widespread faculty participation in the introduction of technology-enabled education.

Individuals and organizations now dominating the system of higher education may not be those who develop and control technology-enabled education in the future. The providers of gas-light did not introduce electric lighting; the telegraphy companies did not take over telephone technology; carriage-maker companies did not prevail in Detroit; and telephone companies did not introduce point-to-point computer network communications. The list of dominant, high-momentum organizations that failed to introduce the next radical breakthrough in their domain is lengthy.

Presiding over breakthroughs in technology-enabled education requires more than a rational projection of present trends. The future holds unanticipated applications of present technical systems and the introduction of entirely new systems. Thus, technological change is usually unpredictable. One sees its future through a glass, darkly. Those who want to further technology-enabled education may have to cast off from their present organizational mooring and launch themselves into a risk-filled environment, heartened by the belief that unforeseen changes lying over the horizon may be more desirable than those changes seen today. *e*

Notes

1. Graham Swift, *Waterland* (1983; reprint, New York: Vintage Books, 1992), 108.
2. The question of the Internet and change is considered in Richard C. Larson and Glenn P. Strehle, "Edu-Tech: What's a President to Do?" in Paul Goodman, ed., *Technology Enhanced Learning: Opportunities for Change* (Mahwah, N.J.: L. Erlbaum Associates, 2001), 21–59.
3. Midway through his magnum opus, *Technics and Civilization* (1934), Mumford changes course and espouses value-shaped technology. See Agatha C. Hughes and Thomas P. Hughes, general introduction to *Lewis Mumford: Public Intellectual* (New York: Oxford University Press, 1990), 3–13.
4. T. R. Nicholson, *The Birth of the British Motor Car, 1769–1897*, 3 vols. (London: Macmillan, 1982), 2:300.
5. Anthony Bird, *The Motor Car, 1765–1914* (London: B. T. Batsford, 1960), 41.
6. Larson and Strehle, "Edu-Tech: What's a President to Do?," 27.
7. Examples of such research centers in the computer field are the Media Laboratory at MIT and the Institute for Learning Sciences and the Cognitive Arts associated with Northwestern University.
8. Before 1905, General Electric used the United Electric Securities Company to hold its utility securities and to fund its utility customers who purchased GE equipment. See Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983), 395–96.
9. Thomas Midgley Jr., "How We Found Ethyl Gas," *Motor*, January 1925, 93.
10. Thomas P. Hughes, "The Evolution of Large Technological Systems," in Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge: MIT Press, 1987), 51–82, esp. 57–62 and 71–76.
11. I have developed the concept of technological momentum in several essays, including "Technological Momentum," in Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History?: The Dilemma of Technological Determinism* (Cambridge: MIT Press, 1994), 101–13.
12. Morey Meyer, a lawyer and former adviser to the governor of Pennsylvania on legal matters, pointed out to me some of the realities of the relationship between legislatures and state higher education institutions.
13. Professor Timothy Lenoir of Stanford University, who has pioneered in the use of technology-enabled education, points out that in the old research-and-teaching model, there was a fit between lecturing, research, and publication. But when faculty begin publishing interactive, multi-threaded narratives, for instance, there will be a closer fit between research incentives and teaching in the technology-enabled education mode. Communication from Lenoir to the author, August 30, 2000.

This article was developed from a presentation delivered at the Forum on the Internet and the University, held at the annual symposium of the Forum for the Future of Higher Education in Aspen, Colorado, in September 2000. Another version of the article will appear in a book to be published by EDUCAUSE in August 2001.