Graduate Education Faces the Digital Age

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> "The impact of information technology will be even more radical than the harnessing of steam and electricity in the 19th century. Rather it will be more akin to the discovery of fire by early ancestors, since it will prepare the way for a revolutionary leap into a new age that will profoundly transform human culture."
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> —Jacques Attali, *Millennium*[1]

Introduction

Today our society and our social institutions are being reshaped by the rapid advances in information technology: computers, telecommunications, and networks. Modern digital technologies have increased vastly our capacity to know and to do things and to communicate and collaborate with others. They allow us to transmit information quickly and widely, linking distant places and diverse areas of endeavor in productive new ways. This technology allows us to form and sustain communities for work, play, and learning in ways unimaginable just a decade ago. Information technology changes the relationship between people and knowledge. And it is likely to reshape in profound ways knowledge-based institutions such as our colleges and universities.

Of course higher education has already experienced significant change driven by information technology. Our management and administrative processes are heavily dependent upon this technology, as the millions of dollars our institutions spent preparing for the date reset of Year 2000 made all too apparent. Research and scholarship depend heavily upon information technology, for example, the use of computers to simulate physical phenomena, networks to link investigators in virtual laboratories or "collaboratories," or digital libraries to provide scholars with access to knowledge resources. There is an increasing sense that new technology will also have a profound impact on teaching, freeing the classroom from the constraints of space and time and enriching the learning of our students through access to original materials.

Yet, while this technology has the capacity to enhance and enrich teaching and scholarship, it also poses certain threats to our colleges and universities. We can now use powerful computers and networks to deliver educational services to anyone, anyplace, anytime, no longer confined to the campus or the academic schedule. Technology is creating an open learning environment in which the student has evolved

into an active learner and consumer of educational services, stimulating the growth of powerful market forces that could dramatically reshape the higher education enterprise.

Some have even suggested that in the face of rapidly evolving technology and emerging competition, the very survival of the university, at least as we know it, may be at risk. Several recent quotes illustrate the concerns:

> "Thirty years from now the big university campuses will be relics. Universities won't survive. It is as large a change as when we first for the printed book." Peter Drucker, business sage

> "If you believe that an institution that has survived for a millennium cannot disappear in a just a few decades, just ask yourself what has happened to the family farm." William Wulf, President of the National Academy of Engineering

> "I wonder at times if we are not like the dinosaurs, looking up at the sky at the approaching asteroid and wondering whether it has an implication for our future." Frank Rhodes, President Emeritus, Cornell University

While most believe the university will survive the digital age, few deny that it could change dramatically in form and character. Knowledge is both a medium and a product of the university as a social institution. Hence it is reasonable to suspect that a technology that is expanding our ability to create, transfer, and apply knowledge by factors of 100 to 1,000 every decade will have a profound impact on the both the mission and the function of the university.

Today our focus concerns the impact of digital technology on graduate education and particularly on the relationships among its various stakeholders: graduate students, the faculty, the university administration, and the broader society they serve. Clearly as the nature of teaching and scholarship are reshaped by our digital technologies, so too will be both the content and process of graduate education. But beyond that, change will also characterize intellectual organization of the university; the relationships between students, faculty, and the university; and even the faculty needs of what could well become a global postsecondary education industry. These, too, will challenge the status quo in graduate education.

To address these issues, I have organized my speculative remarks into three layers. First I will discuss the impact of information on the fundamental activities of the university, teaching and scholarship. Next I will consider its impact on the structure

and form of the university. Finally I would like to offer some observations concerning the impact on the broader post-secondary education enterprise.

Here I will draw on two efforts of the National Academies, which I currently chair. The first is a project to develop a handbook for students and faculty concerning "Scholarship in the Digital Age". The second is a project to understand better the possible impact of digital technology on the future of the research university. Although both efforts are still in progress, I will provide you with a brief update since both have significant implications for graduate education.

However, before discussing the future of the graduate education in the digital age, it seems appropriate to first provide–indeed, acknowledge–some background concerning how this technology is transforming our economy, our society, and our world.

The Evolution of Information Technology

It is difficult to understand and appreciate just how rapidly information technology is evolving. Four decades ago, one of the earliest computers, ENIAC, stood 10 feet tall, stretched 80 feet wide, included more than 17,000 vacuum tubes, and weighed about 30 tons. Today, the University of Michigan has 10 percent of ENIAC on display as an artifact looming over students in the lobby of the computer science department. But today you can buy a musical greeting card with a silicon chip more powerful than the ENIAC computer. Already a modern $1,000 notebook computer has more computing horsepower than a $20 million supercomputer of the early 1990s. For the first several decades of the information age, the evolution of hardware technology followed the trajectory predicted by "Moore's Law"—that the chip density and consequent computing power for a given price doubles every eighteen months.[2] This corresponds to a hundredfold increase in computing speed, storage capacity, and network transmission rates every decade.

To put this statement in perspective, if information technology continues to evolve at its present rate, by the year 2020, the thousand-dollar notebook computer will have a computing speed of 1 million gigahertz, a memory of thousands of terabits, and linkages to networks at data transmission speeds of gigabits per second. Put another way, it will have a data processing and memory capacity roughly comparable to the human brain.[3] Except it will be so tiny as to be almost invisible, and it will communicate with billions of other computers through wireless technology.

This last comment raises an important issue. The most dramatic impact on our world today from information technology is not in the continuing increase in computing power. It is in a dramatic increase in bandwidth, the rate at which we can transmit digital information. From the 300 bits-per-second modems of just a few years ago, we now routinely use 10-100 megabit-per-second local area networks in our offices and houses. Gigabit-per-second networks now provide the backbone communications to link local networks together, and with the rapid deployment of fiber optics cables and optical switching, terabit-per-second networks are just around the corner. Fiber optics cable is currently being installed throughout the world at the astounding equivalent rate of over 3,000 mph! In a sense, the price of data transport is becoming zero, and with rapid advances in photonic and wireless technology, telecommunications will continue to evolve very rapidly for the foreseeable future.

Already the Internet links together hundreds of millions of people. It is estimated that there will be over 1.5 billion net-enabled cellular phones or PDAs ("personal digital appliances" such as the Palm Pilot) by 2004. Estimates are that by the end of the decade, this number will surge to billions, a substantial fraction of the world's population, driven in part by the fact that most economic activity will be based on digital communication. Bell Laboratories suggests that within two decades a "global communications skin" will have evolved, linking together billions of computers that handle the routine tasks of our society, from driving our cars to watering our lawns to maintaining our health.

As a consequence, the nature of human interaction with the digital world—and with other humans through computer-mediated interactions—is evolving rapidly. We have moved beyond the simple text interactions of electronic mail and electronic conferencing to graphical-user interfaces (e.g., the Mac or Windows world) to voice to video. With the rapid development of sensors and robotic actuators, touch and action at a distance will soon be available. The world of the user is also increasing in sophistication, from the single dimension of text to the two-dimensional world of graphics to the three-dimensional world of simulation and role-playing. With virtual reality, it is likely that we will soon communicate with one another through simulated environments, through "telepresence," perhaps guiding our own software representations, our digital agents, our avatars, to interact in a virtual world with those of our colleagues.

This is a very important point. A communications technology that increases in power by 100-fold decade after decade will soon allow human interaction with essentially any degree of fidelity we wish—3-D, multimedia, telepresence, perhaps even

directly linking our neural networks into cyberspace, à la Neuromancer,[4] a merging of carbon and silicon.

Are there any limits to the evolution of information technology. To be sure, it is likely that silicon devices will run into fundamental constraints within a decade or two. So too, single optical fibers face fundamental data transmission limits of about 50 terabits per second. But, although there are potential limits, from a practical perspective we are currently so far away from them as to still see infinite horizons. Furthermore, it is likely that new technologies such as molecular computing (the use of individual molecules as computing elements) and quantum computing will take over from current silicon technology as we begin to encounter limits. Hence, during the decade ahead, we can be reasonably confident that information technology will become "peta-everything" (where "peta" corresponds to 10^{15}, that is to one million-billion), in terms of processing power (operations per second), data transmission (bytes per second) and storage (bytes). In a similar sense, in several years we will have over 10^{10} sensors, 10^{9} servers, and 10^{12} software agents linked into the net.

Put another way, within our lifetimes you can depend on using a wireless device to reach anyone in the world and having any request for information answered with the touch of a button.

The Impact of Information Technology on the Activities of the University

The university has survived other periods of technology-driven social change with its basic structure and activities intact. But the changes driven by evolving information technology are different, since they affect the very nature of the fundamental activities of the university: creating, preserving, integrating, transmitting, and applying knowledge. More fundamentally, because information technology changes the relationship between people and knowledge, it is likely to reshape in profound ways knowledge-based institutions such as the university.

There are several characteristics of information technology that set it apart from earlier experiences with technology-driven change:

1) Its active rather than passive nature;
2) The way that it obliterates the constraints of space and time (and perhaps
3) reality);
4) Its extraordinary rate of evolution, relentlessly increasing in power

5) by factors of 100 to 1000 fold decade after decade; and
6) The manner in which it unleashes the power of the market place.

Although it has been slower in coming, we are beginning to see the impact of technology on university teaching. Today's "digital generation" of students, media savvy, are demand new forms of pedagogy. They approach learning as a "plug-and-play" experience; they are unaccustomed and unwilling to learn sequentially—to read the manual—and instead are inclined to plunge in and learn through participation and experimentation. Although this type of learning is far different from the sequential, pyramidal approach of the traditional college curriculum, it may be far more effective for this generation, particularly when provided through a media-rich environment. It challenges the faculty to design technology-rich experiences and environments based upon interactive, collaborative learning.

Sophisticated networks and software environments can be used to break the classroom loose from the constraints of space and time and make learning available to anyone, anyplace, at any time. The simplest approach uses multimedia technology via the Internet to enable distance learning. Yet many believe that effective computer-network-mediated learning will not be simply an Internet extension of correspondence or broadcast courses. Since learning requires the presence of communities, the key impact of information technology may be the development of computer-mediated communications and communities that are released from the constraints of space and time. There is already sufficient experience with such asynchronous learning networks to conclude that, at least for many subjects, the learning process is just as effective as the classroom experience. There are presently for-profit entities[5] competing directly with traditional colleges and universities in the higher education marketplace through virtual university structures.

The attractiveness of computer-mediated distance learning is obvious for adult learners whose work or family obligations prevent attendance at conventional campuses. But perhaps more surprising is the degree to which many on-campus students are now using computer-based distance learning to augment their traditional education. Broadband digital networks can be used to enhance the multimedia capacity of hundreds of classrooms across campus and link them with campus residence halls and libraries. Electronic mail, teleconferencing, and collaboration technology is transforming our institutions from hierarchical, static organizations to networks of more dynamic and egalitarian communities. The most significant advantage of computer-mediated distant learning is access. Perhaps we should substitute "distributed" for

"distance" learning, since the powerful new tools provided by information technology have the capacity to enrich all of education, stimulating us to rethink education from the perspective of the learner. The rich resources and new forms of social interaction enabled by information technology create the possibility of the objective of "better than being there" for distributed learning environments.

Distance learning based on computer-network-mediated paradigms allows universities to push their campus boundaries outward to serve learners anywhere, anytime. Those institutions willing and capable of building such learning networks will see their learning communities expand by an order of magnitude. In this sense, the traditional paradigm of "just-in-case" degree-based education can be more easily replaced by the "just in time" and "just-for-you" customized learning paradigms, more appropriate for a knowledge-driven society in which work and learning fuse together.

In the near term, at least, traditional models of education will coexist with new learning paradigms, providing a broader spectrum of learning opportunities in the years ahead. The transitions from student to learner, from teacher to designer / coach / consultant, and from alumnus to lifelong member of a learning community seem likely. And with these transitions and new options will come both an increasing ability and responsibility to select, design, and control the learning environment on the part of learners.

So, too, information technology is reshaping the nature of research. The earliest applications of information technology have been for solving mathematical problems in science and technology. Today, problems that used to require the computational capacity of rooms of supercomputers can be tackled with contemporary laptop computer. The rapid evolution of this technology is enabling scholars to address previously unsolvable problems, e.g., proving the four-color conjecture in mathematics, analyzing molecules that have yet to be synthesized, or simulating the birth of the universe. The use of information technology to simulate natural phenomena has created a third modality of research, on par with theory and experimentation

New types of organizations are appearing that are based on evolving information technology. An example is be the "collaboratory" concept, an advanced, distributed infrastructure that uses multimedia information technology to relax the constraints on distance, time, and even reality. The process of creating new knowledge is evolving rapidly away from the solitary scholar to teams of scholars, often spread over a number of disciplines. This technology provides the tools to create, from desktop publishing to digital photography and video to creating objects atom-by-atom. There may even be a shift in knowledge production somewhat away from the analysis of what

has been to the creation of what has never been—drawing more on the experience of the artist than upon analytical skills of the scholar.

The preservation of knowledge is one of the most rapidly changing functions of the university. The computer—or more precisely, the "digital convergence" of various media from print-to-graphics-to-sound-to-sensory experiences through virtual reality—will likely move beyond the printing press in its impact on knowledge. Throughout the centuries, the intellectual focal point of the university has been its library, its collection of written works preserving the knowledge of civilization. Today such knowledge exists in many forms—as text, graphics, sound, algorithms, and virtual reality simulations—and it exists almost literally in the ether, distributed in digital representations over worldwide networks, accessible by anyone, and certainly not the prerogative of the privileged few in academe.

The library is becoming less a collection house and more a center for knowledge navigation, a facilitator of information retrieval and dissemination.[6] In a sense, the library and the book are merging. One of the most profound changes will involve the evolution of software agents, collecting, organizing, relating, and summarizing knowledge on behalf of their human masters. Our capacity to reproduce and distribute digital information with perfect accuracy and with essentially zero cost has shaken the very foundations of copyright and patent law and threatens to redefine the nature of the ownership of intellectual property. The legal and economic management of university intellectual property is rapidly becoming one of the most critical and complex issues facing higher education.

The Form and Function of the University

Colleges and universities are organized along intellectual lines, into schools and colleges, departments and programs, that have evolved over the decades (some would say largely following the structure of 19th Century science and literature rather than 21st Century knowledge). Furthermore, the governance, leadership, and management of the contemporary university are structured as well to reflect this intellectual organization as well as academic values of the university such as academic freedom and institutional autonomy rather than the command-communication-control administrative pyramid characterizing most organizations in business and government. The "contract" between members of the faculty and the university also reflects the unusual character of

academic values and roles, the practice of tenure being perhaps the most visible example.

Yet we have suggested that information technology is already having great impact on the university. It has modified its fundamental activities of education, scholarship, and service to society quite significantly. Technology has created new channels of communication throughout the university and with broader society through mechanisms such as electronic mail and website conferences that largely bypass traditional administrative arrangement and external relationships. Technology has also completely transformed the manner in which information concerning the university, its people, and its activities is gathered, stored, and utilized.

Just as the university is challenged in adapting to new forms of teaching and research stimulated by rapidly evolving information technology, so too its organization, governance, management, and its relationships to students, faculty, and staff will require serious re-evaluation and almost certain change. For example, the new tools of scholarship and scholarly communication are eroding conventional disciplinary boundaries and extending the intellectual span, interests, and activities of faculty far beyond traditional organizational units such as departments or schools. This is particularly the case with younger faculty members whose interests and activities frequently cannot be characterized by traditional disciplinary terms.

Beyond driving a restructuring of the intellectual disciplines, information technology is likely to force a significant disaggregation of the university on both the horizontal (e.g., academic disciplines) and vertical (e.g., student services) scale. Faculty activity and even loyalty is increasingly associated with intellectual communities that extend across multiple institutions, frequently on a global scale. New providers are emerging that can far better handle many traditional university services, ranging from student housing to facilities management to health care. Colleges and universities will increasingly face the question of whether they should continue their full complement of activities or “outsource” some functions to lower cost and frequently higher quality providers.

It has become increasingly important that university planning and decision making not only take account of technological developments and challenges, but draw upon the expertise of people with technological expertise. Yet all too often, university leaders, governing boards, and even faculties ignore the rapid evolution of this technology, treating it more as science fiction than as a serious institutional challenge. To a degree this is not surprising, since in the early stages, new technologies sometimes look decidedly inferior to long-standing practices. For example, few would regard the

current generation of computer-mediated distance learning programs as providing the socialization function associated with undergraduate education in a residential campus environment. Yet there have been countless instances of technologies, from personal computers to the Internet, that were characterized by technology learning curves far steeper than conventional practices. Such "disruptive technologies" have demonstrated the capacity to destroy entire industries, as the explosion of e-commerce makes all too apparent.

In a sense, just as information technology has brought us to an inflection point in the nature of education and scholarship, it could also force us to redefine the relationship between the university and its teachers and students. Beyond this, we will face an ever mounting challenge in helping our faculties to keep pace with the extraordinary pace of technology evolution. In the old days we would wait for a generation of professors to pass on before an academic unit could evolve. In today's high-paced world, when the doubling time for technology evolution has collapsed to a year or less, we simply must look for effective ways to reskill our faculties or risk rapid obsolescence.

All universities face major challenges in keeping pace with the profound evolution of information and its implication for their activities. Not the least of these challenges is financial, since as a rule of thumb most organizations have found that staying abreast of this technology requires an annual investment of roughly 10 percent of their operating budget. For a very large campus such as the University of Michigan, this can amount to hundreds of millions of dollars per year!

But there are other challenges. Many universities are simply unprepared for the new plug-and-play generation, already experienced in using computers and net-savvy, who will expect—indeed, demand—sophisticated computing environments at college. More broadly, information technology is rapidly becoming a strategic asset for universities, critical to their academic mission and their administrative services, that must be provided on a robust basis to the entire faculty, staff, and student body.

In positioning itself for this technology, universities should recognize several facts of contemporary life. First, robust, high-speed networks are becoming not only available but also absolutely essential for knowledge-driven enterprises such as universities. Powerful computers are available at reasonable prices to students, but these will require a supporting network infrastructure. There will continue to be diversity in the technology needs of faculty, with the most intensive needs likely to arise in parts of the university such as the arts and humanities where strong external support may not be available.

Historically, technology has been seen as a capital expenditure for universities or as an experimental tool to be made available to only a few. In the future, higher education should conceive of information technology both as an investment and a strategic asset that will be used by the entire faculty, staff, and study body to sustain and enhance the mission of the university. Colleges and universities must learn an important lesson from the business community: Investment in robust information technology represents the table stakes for survival in the age of knowledge. If you are not willing to invest in this technology, then you may as well accept being confined to a backwater in the knowledge economy, if you survive at all.

The Post-Secondary Education Enterprise

The "e-economy" is growing at an annual rate of 175%. It is estimated that by 2004, the e-economy will be $7 trillion, roughly 20% of the global economy. Beyond providing the graduates and knowledge needed by this digital economy, the contemporary university must be able to function in an increasingly digital world, in the way that it manages its resources, relates to clients, customers, and providers, and conducts its affairs. Put another way, "e-commerce", "e-business", and the "e-economy" must become an integral part of the university's future if it is to survive the digital age.

We generally think of higher education as public enterprise, shaped by public policy and actions to serve a civic purpose. Yet market forces also act on our colleges and universities. Society seeks services such as education and research. Academic institutions must compete for students, faculty, and resources. To be sure, the market is a strange one, heavily subsidized and shaped by public investment so that prices are always far less than true costs. Furthermore, if prices such as tuition are largely fictitious, even more so is much of the value of education services, based on myths and vague perceptions such as the importance of a college degree as a ticket to success or the prestige associated with certain institutions. Ironically, the public expects not only the range of choice that a market provides but also the subsidies that make the price of a public higher education less than the cost of its provision.

In the past, most colleges and universities served local or regional populations. While there was competition among institutions for students, faculty, and resources—at least in the United States—the extent to which institutions controlled the awarding of degrees, that is, credentialling, gave universities an effective monopoly over advanced education. However, today all of these market constraints are being challenged. The

growth in the size and complexity of the postsecondary enterprise is creating an expanding array of students and educational providers. Information technology eliminates the barriers of space and time and new competitive forces such as virtual universities and for-profit education providers enter the marketplace to challenge credentialling.[7]

Today we are bombarded with news concerning the impact of information technology on the market place, from "e-commerce" to "edutainment" to "virtual universities" and "I-campuses". The higher education marketplace has seen the entrance of hundreds of new competitors that depend heavily upon information technology. Examples include the University of Phoenix, the Caliber Learning Network, Sylvan Learning Systems, the Open University, the Western Governors University, and a growing array of "dot-coms" such as Unext.com and Blackboard.com. It is important to recognize that while many of these new competitors are quite different than traditional academic institutions, they are also quite sophisticated in their pedagogy, their instructional materials, and their production and marketing of educational services. They approach the market in a highly sophisticated manner, first moving into areas characterized by limited competition, unmet needs, and relatively low production costs, but then moving rapidly up the value chain to more sophisticated educational programs. These IT-based education providers are already becoming formidable competitors to traditional postsecondary institutions.

The weakening influence of traditional regulations and the emergence of new competitive forces, driven by changing societal needs, economic realities, and technology, are likely to drive a massive restructuring of the higher education enterprise. From the experience with other restructured sectors of our economy such as health care, transportation, communications, and energy, we could expect to see a significant reorganization of higher education, complete with the mergers, acquisitions, new competitors, and new products and services that have characterized other economic transformations. More generally, we may well be seeing the early stages of the appearance of *a global knowledge and learning industry*, in which the activities of traditional academic institutions converge with other knowledge-intensive organizations such as telecommunications, entertainment, and information service companies.

Although traditional colleges and universities could play a role in such a technology-based, market-driven future, they could both threatened and reshaped by shifting societal needs, rapidly evolving technology, and aggressive for-profit entities and commercial forces. Together these could drive the higher education enterprise

toward the mediocrity that has characterized other mass media markets such as television and journalism.

A key factor in this restructuring has been the emergence of new aggressive for-profit educator providers that are able to access the private capital markets (over $4 billion in the last year). Most of these new entrants such as the University of Phoenix and Jones International University are focusing on the adult education market Some, such as Unext.com, have aggressive growth strategies beginning first with addressing the needs for business education of corporate employees. Using online education, they are able to offer costs reductions of 60% or more over conventional corporate training programs since they avoid travel and employee time off. They are investing heavily (over $100 million in 2000) in developing sophisticated instructional content, pedagogy, and assessment measures, and they are likely to move up the learning curve to offer broader educational programs, both at the undergraduate level and in professional areas such as engineering and law. In a sense, therefore, the initial focus of new for-profit entrants on low-end adult education is misleading, since in five years or less their capacity to compete with traditional colleges and universities formidable indeed. We might think of traditional higher education as sunning itself on the beach in the warm glow of a prosperous economy, unaware that the gentle surf lulling them to sleep is the precursor of a 100 foot tsunami of market forces beyond the horizon that could sweep over them before they can react or escape.

This perspective of a market-driven restructuring of higher education as a technology-intensive industry, while perhaps both alien and distasteful to the academy, is nevertheless an important framework for considering the future of the university. While the postsecondary education market may have complex cross-subsidies and numerous public misconceptions, it is nevertheless very real and demanding, with the capacity to reward those who can respond to rapid change and punish those who cannot. Universities will have to learn to cope with the competitive pressures of this marketplace while preserving the most important of their traditional values and character.

It is appropriate at this point to make one further comment concerning “the digital divide”, the concern many have about a widening gap between those who can afford access to information technology and those who cannot. Such stratification in our society among the haves and have-nots would be of great concern if information technology were not evolving so rapidly. However, this technology is migrating rapidly toward “thin client” systems, in which the personal computer becomes an inexpensive

and ubiquitous commodity available to anyone and everyone like today's television or telephone, while the real investment occurs in the supporting network infrastructure.

In reality, the concern should not be with the digital divide, but rather with the growing gap in prosperity, power, and social well-being between those who have access to quality education and those who do not, because of economic circumstances, jobs, families, or location. From this perspective, the development of technology-based methods for delivering educational services such as asynchronous learning networks and virtual universities may actually narrow the educational gap by providing universal access to quality educational opportunities.

Graduate Education in the Digital Age

There is general agreement that graduate education in America's research universities represents the world's leading effort for producing the next generation of researchers. By conducting graduate education in the same institutions where a large portion of the nation's basic research is done, our research universities have created a research and training system that is one of the nation's great strengths—and the envy of the rest of the world.

Our current paradigm of graduate education is based on an important, yet fragile, relationship between the graduate student and the faculty that evolves from mentorship into collegiality. Graduate students are expected to attach themselves early and tightly to individual professors. In fact, since many are supported by research grants, they are required to work on problems relevant to their faculty advisor's research grant with little opportunity to broaden their studies or their interests. In most universities, the faculty supervisor of a graduate dissertation becomes the primary determinant of the intellectual content, the duration, and the financing of the remaining education of the Ph.D. student, until the dissertation is written and the final dissertation defense is completed. In the best of circumstances, this final phase of graduate study can be very rewarding, since under the supervision of a skilled dissertation advisor, the graduate student learns the intricacies not only of basic research but also the trade of a faculty member.

It is not surprising that during these times of challenge and change in higher education, the nature and quality of graduate education has also come under scrutiny.

1) Traditionally the faculty and their universities prefer to focus concerns on the adequacy and nature of financial support for graduate education.

2) Graduate students are more concerned with the job market for graduates and the time to obtain a degree.
3) The federal government has expressed concerns about the number of advanced degrees relative to market needs and the high percentage of foreign graduate students.

But to these we should add an array of issues stimulate by the impact of digital technology on the activities, structure, and environment of the university. Let me do so by following our earlier discussion.

Research

We have already seen the profound impact of information technology on the methods used for research and scholarship, ranging from simulation of natural or historical phenomena to the creation of massive digital libraries and data warehouses to sophisticated tools for scholarly communication and collaboration. Clearly these new tools and technology-based methods create new pressures on institutions to provide the technology-rich environments necessary for cutting-edge research but also on faculties to keep pace with these tools, since graduate students will typically be far more knowledgeable and comfortable with digital technology than their faculty supervisors.

Today's research problems are becoming increasingly complex, and their solution requires interdisciplinary teamwork. The training of new Ph.D.s currently is often too narrow intellectually, too campus centered, and certainly too long. The acceptance of overspecialization can result in a lack of both perspective and self-confidence. New Ph.D.s often believe themselves ill prepared to venture outside their specialty. This is due in part to the lack of serious requirements for breadth in the typical graduate curriculum. It is also due to the fact that there is little or no encouragement and a lot of implicit discouragement for one who wants to depart from the straight and narrow.

Teaching

Since we really don't "teach" graduate students how to teach anyway, one might well question whether digital technology will have much impact on this area. Yet here the challenges may be particular acute. After all, since we expect graduate students to learn the trade from their own experience as students, one might well doubt whether they will learn the new "tricks" of technology-based instruction from the old dogs of the

"sage-on-the-stage" lecture paradigm. Even more formidable will be developing a generation of faculty equipped with the skills necessary to design and manage active learning environments.

Creating the Environment for Teaching and Research in the Digital Age

Of course, one of the most formidable challenges faced by graduate schools and their host institutions will be the creation and financing of the digital infrastructure necessary for graduate studies and scholarship. Over the past two decades we have found that to stay at the cutting edge, one must be prepared to invest roughly 10% of the academic budget in information technology. And what happens if an institution is not prepared to do this? Graduate students and faculty are both migratory species, and they will rapidly leave lagging institutions for those who lead in the quality of their IT environment.

Aggregation and Disaggregation

As we have noted, universities will experience the same forces of technology-enabled or driven aggregation and disaggregation characterizing other sectors of society. In the case of graduate education, this will be stimulated in part by the remarkable impact of digital technology on research communication and collaboration. While the faculty culture may tolerate and embrace an organization of academic programs along the lines of traditional disciplines, the tendency of the most exciting scholarship to obliterate disciplinary boundaries (after all, nature cares little about the such disciplinary distinctions) coupled with new technology-based research structures such as the collaboratory may lead naturally to graduate programs that easily cross disciplinary and institutional lines. Graduate students will be able to build alliances of institutions to support both their studies and their research.

Content and Mindshare

The university will face a major challenge in retaining instructional "mindshare" among their best known faculty. Although we have long since adapted to the reality of those faculty getting released time and very substantial freedom with regard to research activities, there will be new challenges as instructional content becomes a valuable commodity in a for-profit postsecondary education marketplace. Do we need new

policies that restrict the faculty's ability to contract with outside organizations for instructional learningware. Can these policies be enforced in the highly competitive marketplace for our best faculty? Clearly these issues will affect the relationship between the university and its faculty, staff, and students.

Democratization of Learning and Scholarship

We have suggested that rather than stratifying our society, information technology will likely become a democratizing force in higher education. It will democratize learning by distributing learning opportunities far more broadly than our currently highly selective education system is capable of or inclined to do. Moreover, it will likely democratize scholarship as well by providing a far broader spectrum of institutions, scholars, and perhaps even lay citizens with access to the rich intellectual resources of our most prestigious institutions. Although this democratizing character may threaten both elite colleges and research universities, it may also be key to meeting the mass educational needs of our knowledge-driven society.

The Future of the Research University

As a primary source of basic research and the next generation of scholars and professionals, the research university will remain an institution of great value. In an age in which knowledge and educated people become a society's most valuable resources, the research university has become ever more important as an intellectual force in our society. Today the research faculties in these institutions have become both the leaders and the arbiters of science and scholarship for the world. This group not only leads in knowledge production and distribution, but they have become the gatekeepers and standard-bearers, leading a complex knowledge system that both drives and sustains world education and learning. Furthermore, as highly educated scholars and professionals are increasingly sought as leaders in a knowledge-driven world, these institutions should continue to play a critical role.

Yet the broader higher education enterprise is changing rapidly–driven by changing social needs, powerful market force, and rapidly evolving technology–to serve a changing world. While the unique roles, the prestige, and the prosperity of the research university may allow it to defend the status quo for a time, this, too, will pose certain dangers. Furthermore, the research university is no longer seen as the top level of academic pecking order but instead as just one player in a broader higher education

enterprise, where the priority will be educational services for a knowledge-driven society rather than specialized scholarship. To be sure, it would be both unrealistic and inappropriate for our research universities to abandon their critical roles in elite education and scholarship to become heavily involved in the universal education, the ubiquitous education, needed by our society. Furthermore, the market for educational services will be broad and diverse, and the brand name for exceptional quality characterizing these institutions will still carry considerable value.

Throughout most of history of higher education in America, these same institutions have been the leaders for the broader enterprise. They have provided the faculty, the pedagogy, the textbooks and scholarly materials, and the standards for all of higher education. They have maintained a strong relationship and relevance to the rest of the enterprise, even though they were set apart in role and mission. Yet, as the rest of the enterprise changes, there is a risk that if the research university becomes too reactionary and tenacious in its defense of the status quo, it could well find itself increasingly withdrawn and perhaps even irrelevant to the rest of higher education in America and throughout the world.

It is within this context of recognizing the unique mission and value of the research university even as we seek to preserve its relevance to the rest of higher education that we should examine several possible strategies for the future:

Isolation. Some of the most elite institutions may adopt a strategy of relying on their prestige and their prosperity to isolate themselves from change, to continue to do just what they have done in the past, and to be comfortable with their roles as niche players in the higher education enterprise. And this may be a very appropriate strategy for some unique institutions, places such as MIT, Caltech, Princeton, and Chicago. But for most of the larger and comprehensive institutions, the activities of elite education and basic research are simply too expensive to sustain without some attention to the marketplace.

Pathfinders. Perhaps a more constructive approach would be to apply the extraordinary intellectual resources of the research university to assist the broader higher education enterprise in its evolution to new learning forms. Although the research universities may not be appropriate for direct involvement in mass or universal education, they certainly are capable of providing the templates, the paradigms, that others could use. They have done this before in other areas such as health care, national defense, and the Internet. To play this role, the research university must be prepared to participate in experiments in creating possible futures for higher education.

Alliances. Extending this role somewhat, research universities might enter into alliances with other types of educational institutions, regional universities, liberal arts colleges, community colleges, or even newly emerging forms such as for-profit or cyberspace universities. This would allow them to respond to the changing needs of societies while remaining focused on their unique missions as research universities. One could also imagine forming alliances with organizations outside of higher education, for example, information technology, telecommunications, or entertainment companies, information services providers, or even government agencies.

The Challenge of University Leadership in the Digital Age

More generally, today's academic leaders face myriad important questions and decisions concerning the impact of information technology on their programs and their institutions. For example, they need to understand the degree to which this technology will transform their basic activities of teaching, research, and service. What will be the impact of this technology on the basic activities of the university, upon teaching and research? Will the classroom disappear? Will the residential campus experience of undergraduate education be overwhelmed by virtual universities or "edutainment." And what about the role that traditional forms of pedagogy will play in an increasingly online world? How should the university integrate information technology into its educational programs at the undergraduate, graduate, and professional school level? Will information technology alter the priorities among various university activities, e.g., the balance of educational activities related to socializing high school graduates compared to the rapid growth in the need for advanced education by adults in the high performance workplace?

What kind of information technology infrastructure will the university need? How will it finance the acquisition and maintenance of this technology? To what degree should an institution outsource the development and management of IT systems? How should the university approach its operations and management to best take advantage of this technology? How can institutions better link planning and decision making with likely technological developments and challenges? How can one provide students, faculty, and staff with the necessary training, support, and equipment to keep pace with the rapid evolution of information technology? What is the role of universities with respect to the "digital divide", the stratification of our society with respect to access to technology?

How do colleges and universities address the rapidly evolving commercial marketplace for educational services and content, including, in particular, the for-profit and dot.com providers? What strategies and actions should colleges and universities consider? What kind of alliances are useful for colleges and universities in this rapidly changing environment? With other academic institutions? With business? On a regional, national, or global scale? Should colleges and universities join together to create a "best practices" organization that provides assistance in analyzing needs and opportunities?

How can colleges and universities grapple with the forces of disaggregation and aggregation associated with a technology-driven restructuring of the higher education enterprise? Will universities be forced to merge into larger units as the corporate world has experienced, or will they find it necessary to outsource or spinoff existing activities. Will more (or perhaps most) universities find themselves competing in a global marketplace, and how will that square with publicly supported universities? Will new learning lifeforms or ecologies evolve based upon information technology that will threaten the very existence of the university?

And what about those questions specific to graduate education. Of course there are highly pragmatic questions such as: How do our graduate schools provide the environment for research and graduate education demanded by students and faculty in the digital age? How do we provide graduate students with the knowledge and skills they will need to utilize the tools of digital technology in their teaching and research when many of our faculty members are members of the "pre-computer" generation and largely ignorant of these tools themselves?

But there are also deeper questions raised by the impact of digital technology on higher education: What is the purpose of graduate education? Who will be the faculty and graduate students of the digital age? Will the traditional one-on-one apprenticeship model of graduate education remain relevant? Will graduate programs continue to be identified with and managed by the disciplines? Will the unique American research university model which combines graduate study with basic research continue to be an acceptable paradigm, either to the higher education community or its government and industrial sponsors?

The list of questions and issues seems not only highly complex but overwhelming to university leaders, not to mention the state and federal governments that support higher education in America. Yet, surveys suggest that despite the profound nature of this issues, information technology usually does not rank high among the list of priorities for university planning and decision making.[8] Perhaps this is

due to the limited experience most college and university leaders have with this emerging technology. It could also be a sign of indecisiveness and procrastination. Yet, as the pace of technological change continues to accelerate, indecision and inaction can be the most dangerous course of all.

A National Academy Project

Last year the National Academies (Science, Engineering, and Medicine) launched a major new study to explore the impact of information technology on the future of the research university, which I was asked to chair. The premise was that rapidly evolving information technology would pose great challenges and opportunities to higher education in general and the research university. Yet there was an increasing sense that many of the most significant issues were neither well recognized nor understand by either university leaders or federal research agencies.

To this end, a broad steering committee was established, comprised of leaders in the areas of information technology, higher education, and federal research policy:

Jim Duderstadt, Michigan (chair)
Dan Atkins, Michigan
John Seely Brown, Xerox PARC
Gerry Butters, Lucent
Marye Anne Fox, NCSU
Ralph Gomory, Sloan Foundation
Nils Hasselmo, AAU
Paul Horn, IBM
Shirley Jackson, RPI
Frank Rhodes, Cornell
Marshall Smith, Stanford
Lee Sproull, NYU
Doug Van Houweling, Internet2
Bob Weisbuch, Woodrow Wilson
Bill Wulf, NAE
Joe Wyatt, Vanderbilt
Tom Moss, NAS/GUIRR
Charlotte Kuh, NRC

Ray Fornes, NRC

The work of the committee has been proceeding along three fronts:

Technology Scenarios: What technologies are likely (possible) in the future (perhaps a 10 year planning horizon).

Implications for Research Universities: What are the implications of this evolving technology for the activities, organization, and enterprise of the research university?

Policies, Programs, Investments: What is the role, if any, for the federal government in protecting the valuable contributions of the research university in the face of these challenges?

Although we are less than a year into the study, the group has already arrived at several preliminary yet provocative conclusions:

1) There is no evidence of slowdown in the pace of IT evolution, by any measure or characteristic. In fact we appear to be on a superexponential technology learning curve that is likely to continue for at least the next several decades.
2) Photonic technology is evolving at twice the rate of silicon chip technology (e.g., Moore's Law), with miniaturization and wireless technology moving even faster, implying that the rate of growth of network appliances will be incredible.
3) For planning purposes, we can assume that within the decade we will have infinite bandwidth and infinite processing power (at least compared to current capabilities).
4) There are likely to be major technology surprises, comparable in significance to the PC in 1980 and the Internet browser in 1994, but at more frequent intervals.
5) Getting people to think about the implications of accelerating technology learning curves as well as technology cost-performance curves is both very difficult and very important. The event horizons are much closer that most realize.
6) Most universities still look at IT as a cost, not as an investment with staggering cost benefits. If you are not going to invest in IT, you may as well get out of the game. Investment in robust information technology represents the table stakes for survival in the age of knowledge!
7) We need to distinguish between two time frames for the university:

A decade or less: Comprehensible if profound change
Two decades and beyond: All bets are off. (The "singularity"?)

We have scheduled a major conference in January at the National Academies that will bring together faculty leaders, academic administrators, and technologists to discuss the implications of our technology scenarios for the activities, organization, and function of the research university. Stay tuned.

The Darwinian World of Digital Technology

The digital age poses many challenges and opportunities for the contemporary university. For most of the history of higher education in America, we have expected students to travel to a physical place, a campus, to participate in a pedagogical process involving tightly integrated studies based mostly on lectures and seminars by recognized experts. Yet, as the constraints of time and space—and perhaps even reality itself—are relieved by information technology, will the university as a physical place continue to hold its relevance?

In the near term it seems likely that the university as a physical place, a community of scholars and a center of culture, will remain. Information technology will be used to augment and enrich the traditional activities of the university, in much their traditional forms. To be sure, the current arrangements of higher education may shift. For example, students may choose to distribute their college education among residential campuses, commuter colleges, and online or virtual universities. They may also assume more responsibility for and control over their education.

Although the digital age will provide a wealth of opportunities for the future, we must take great care not simply to extrapolate the past, but instead to examine the full range of possibilities for the future. There is clearly a need to explore new forms of learning and learning institutions that are capable of sensing and understanding the change and of engaging in the strategic processes necessary to adapt or control it.

No one knows what this profound alteration in the fabric of our world will mean, both for academic work and for our entire society. As William Mitchell, dean of architecture at MIT, stresses, "the information ecosystem is a ferociously Darwinian place that produces endless mutations and quickly weeds out those no longer able to adapt and compete. The real challenge is not the technology, but rather imagining and

creating digitally mediated environments for the kinds of lives that we will want to lead and the sorts of communities that we will want to have."[9] It is vital that we begin to experiment with the new paradigms that this technology enables. Otherwise, we may find ourselves deciding how the technology will be used without really understanding the consequences of our decisions.

To be sure, information technology poses certain risks to the university. It will create strong incentives to standardize higher education, perhaps reducing it to its lowest common denominator of quality. It could dilute our intellectual resources and distribute them through unregulated agreements between faculty and electronic publishers. It will almost certainly open up the university to competition, both from other educational institutions as well as from the commercial sector. But it will also present extraordinary opportunities. Information technology is rapidly becoming a liberating force in our society, not only freeing us from the mental drudgery of routine tasks, but also linking us together in ways we never dreamed possible, overcoming the constraints of space and time. Furthermore, the new knowledge media enables us to build and sustain new types of learning communities, free from the constraints of space and time. This technology will democratize and distribute more broadly access to the unique resources of the university for teaching and scholarship. Higher education must define its relationship with these emerging possibilities in order to create a compelling vision for its future as it enters the next millennium.[10]

It is our collective challenge as scholars, educators, and academic leaders to develop a strategic framework capable of understanding and shaping the impact that this extraordinary technology will have on our institutions. We are on the threshold of a revolution that is making the world's accumulated information and knowledge accessible to individuals everywhere, a technology that will link us together into new communities never before possible or even imaginable. This has breathtaking implications for education, research, and learning and, of course, for the university in the digital age.

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