The Future of the University in the Digital Age

James J. Duderstadt
President Emeritus
University Professor of Science and Engineering
The University of Michigan

The Glion III Conference
Glion, Switzerland
May 31, 2001

> *"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."*
>
> *Jacques Attali, Millennium* [1]

Introduction

One of the central topics of this third meeting of the Glion Colloquium[2] concerns the eroding boundaries of the contemporary university as traditional constraints disappear and new arrangements are demanded by a changing world. The forces driving this restructuring of the higher education enterprise are many and varied: the globalization of commerce and culture, the lifelong educational needs of citizens in a knowledge-driven society, the advanced educational needs of the high performance workplace, the exponential growth of new knowledge and new disciplines, and the compressed timescales and nonlinear nature of the transfer of knowledge from campus laboratories into commercial products. This paper will concern itself with the impact of information and communications technologies on higher education, which are rapidly obliterating the conventional constraints of space, time, monopoly, and even reality itself.

Modern digital technologies such as computers, telecommunications, and networks are reshaping both our society and our social institutions. These 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. They allow us to form and sustain communities for work, play, and learning in ways unimaginable just a decade ago.

Of course higher education has already experienced significant change driven by digital technology. Our management and administrative processes are heavily dependent upon this technology. Research and scholarship are also highly dependent upon information technology, for example, the use of computers to simulate physical phenomena, networks to link investigators in virtual laboratories or "collaboratories," and 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 learning of by providing our students with access to original source materials.

Yet, while information 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, at anyplace and 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.

Today we are bombarded with news concerning the impact of information technology on the marketplace, 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, 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.

Today some even suggest 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. In an interview in Forbes several years ago, Peter Drucker suggested: “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 got the printed book.”[3] William Wulf, President of the National Academy of Engineering, posed the question in a somewhat different way: “Can an institution such as the university which has existed for a millennium and become an icon of our social fabric disappear in just a few decades because of technology? If you doubt it, just check on the state of the family farm.”[4]

Ray Kurzweil, in his provocative speculation about the future, The Age of the Spiritual Machine, predicts that over the next decade intelligent courseware will emerge as a common means of learning, with schools increasingly relying on software approaches, leaving human teachers to attend primarily to issues of motivation, psychological well-being, and socialization.[5] Eventually, in two or three decades, Kurzweil sees human learning accomplished primarily by using virtual teachers and enhanced by widely available neural implants.

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.

Clearly, the digital age poses many challenges and presents many 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. As the constraints of time and space—and perhaps even reality itself—are relaxed by information technology, will the university as a physical place continue to hold its relevance?

More generally, are we entering just another period of evolution for the university? Or will the dramatic nature and compressed time scales characterizing the technology-driven changes of our time trigger a process more akin to revolution in higher education? Will a tidal wave of technological, economic, and social forces sweep over the academy, both transforming the university in unforeseen and perhaps unacceptable ways while creating new institutional forms to challenge both our experience and our concept of the university?

Typically, most discussions concerning information technology and higher education deal primarily with its impact upon instruction, for example, online distance education or virtual universities. But the roles of the contemporary university are broad and diverse, ranging from educating the young; to preserving our cultural heritage, providing the basic research essential to national security, economic prosperity, and social well-being; training our professionals and certifying their competence; and challenging our society and stimulating social change. Knowledge is the medium of the university in the sense that each of its many roles involves the discovery, shaping, transfer, or application of knowledge. In this sense, it is clear that the rapid evolution of information and communications technologies will reshape all of the roles of the university. To understand the future of the university in the digital age, it is important to consider the impact on each of its activities.

In an effort to adopt this broader perspective, 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 organization, management, and financing of the university. Finally I would like to offer some observations concerning the impact on the broader post-secondary education enterprise.

However, before discussing the future of the university in the digital age, it seems appropriate to begin first with 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 weighted about 30 tons. (We have 10% of ENIAC on display as an artifact in the lobby of the computer science department at Michigan.) Today you can buy a musical greeting card with a silicon chip more powerful than ENIAC. 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.[6] This corresponds to a hundred-fold increase in computing speed, storage capacity, and network transmission rates every decade. Of course, if information technology is to continue to evolve at such rates, we will likely need not only new technology but even new science. But with emerging technology such as quantum computing, molecular computers, and biocomputing, there is significant possibility that Moore’s Law will continue to hold for at least a few more decades.

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 terabytes, 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.[7] Except it will be so tiny as to be almost invisible, and it will communicate with billions of other computers through wireless technology and global networks.

This last comment raises an important issue. The most dramatic impact on our world today from information technology is not from the continuing increase in computing power but rather the extraordinary rate at which bandwidth is expanding, that is, 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 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.

The nature of human interaction with the digital world—and with other humans through computer-mediated interactions—is also 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 or 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 to 1000-fold decade after decade will soon will allow human interaction with essentially any degree of fidelity we wish—3-D, multimedia, telepresence, perhaps even directly linking

our neural networks into cyberspace, a la Neuromancer[8], a merging of carbon and silicon.

The penetration of digital technology into our society has proceeded at an extraordinary pace. In less than a decade the Internet has evolved from a research network to a commercial infrastructure now reaching a significant fraction of our population and essentially all of our schools and businesses. Access to computers and the Internet and the ability to use this technology are becoming increasingly important to full participation in our nation's economic, political, and social life. Furthermore, the transition from phone links to broadband and eventually fiber optics will transform the current drippy faucet of modem-connectivity to a deluge of gigabit-per-second data flow into our homes, schools, and places of work.

More specifically, IBM estimates that by 2004 there will be over 1.3 billion net-enabled cellular phones or personal digital appliances (e.g., Palm Pilots) in the world.[9] In fact, almost everyplace in the world will have robust wireless access to the Internet– except for the United States, where our continued reliance on traditional telephone networks and our archaic practices and regulations have limited the growth of wireless technology. 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. Estimates are that by the end of the decade, the number of people linked into the Internet 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.

Put another way, over the next decade, we will evolve from "giga" technology (in terms of computer operations per second, storage, or data transmission rates) to "peta" technology (one million-billion or 10^{15})[10]. We will denominate the number of computer servers in the billions, digital sensors in the tens of billions, and software agents in the trillions. The number of people linked together by digital technology will grow from millions to billions. We will evolve from "e-commerce" and "e-government" and "e-learning" to "e-everything"!

Beyond providing the graduates and knowledge needed by knowledge-intensive society, 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 in the digital age.

The Digital Age

Our world is in the midst of a social transition into a postindustrial society as our economies shift from material- and labor-intensive products and processes to knowledge-intensive products and services. A radically new system for creating wealth has evolved that depends upon the creation and application of new knowledge. We are in a transition period where intellectual capital, brainpower, is replacing financial and

physical capital as the key to our strength, prosperity, and well being. In a very real sense, we are entering a new age, an *age of knowledge*, in which the key strategic resource necessary for prosperity has become knowledge itself, that is, educated people and their ideas.[11]

Our rapid evolution into a knowledge-based society has been driven in part by the emergence of powerful new information technologies such as computers and digital communications networks. Modern electronic 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. We learn about events almost as they occur. The world has become linked electronically. One might think of the role of digital technology in a knowledge society as comparable to that of the railroad during the industrial revolution. Enabled by the Internet and propelled by e-commerce, an infrastructure of knowledge tracks are being extended through the marketplace, government, and into our homes and our lives.

Of course, our world has experienced other periods of dramatic change driven by technology, for example, the impact of the steam engine, telephone, automobile, and railroad in the late nineteenth century, which created our urban industrialized society. But never before have we experienced a technology that has evolved so rapidly and relentlessly, increasing in power by a hundred-fold or more every decade, obliterating the constraints of space and time, and reshaping the way we communicate, think, and learn.

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 reality);
3. Its extraordinary rate of evolution, relentlessly increasing in power by factors of 100 to 1000 fold decade after decade; and
4. The manner in which it unleashes the power of the market place.

Furthermore, this technology drives very significant restructuring of our society and social institutions through what John Seely Brown and Paul Duguid[12] term the 6-D effects: *demassification, decentralization, denationalization, despecialization, disintermediation*, and *disaggregation*. Perhaps we should also add a seventh “D”, *democratization*, since the technology provides unusual access to knowledge and knowledge services (such as education) hitherto restricted to the privileged few. Like the printing press, this technology not only enhances and broadly distributes access to knowledge, but in the process it shifts power away from institutions to those who are educated and trained in the use of the new knowledge media.

Over the past several decades, computers have evolved into powerful information systems with high-speed connectivity to other systems throughout the world. Public and private networks permit voice, image, and data to be made instantaneously available across the world to wide audiences at low costs. The creation of virtual environments where human senses are exposed to artificially created sights, sounds, and feelings liberate us from restrictions set by the physical forces of the world in which we live. Close, empathic, multi-party relationships mediated by visual and aural digital communications systems are becoming common. They lead to the formation of closely bonded, widely dispersed communities of people interested in sharing new experiences and intellectual pursuits created within the human mind via sensory stimuli.

New forms of knowledge accumulation are evolving: written text, dynamic images, voices, and instructions on how to create new sensory environments can be packaged in dynamic modes of communication never before possible. Computer-based learning systems are also being explored, opening the way to new modes of instruction and learning. New models of libraries are being explored to exploit the ability to access vast amounts of digital data in physically dispersed computer systems, which can be remotely accessed by users over information networks. The applications of such new knowledge forms challenge the creativity and intent of authors, teachers, and students. Technology such as computers, networks, wireless connectivity, ubiquitous computing, software agents, and other technologies may well invalidate most of the current assumptions and thinking about the future nature of the university.

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 roles 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 the roles and activities of knowledge-based institutions such as the university.

Education

Although it has been slow in coming, we are beginning to see the impact of information technology on teaching. Today's "digital generation" of media savvy students are demanding 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.

College and universities are among the most wired institutions in our society, with over 90% of college students accessing the Internet on regular basis. Hence it was natural that the earliest applications of information technology to education involved enhancing and enriching traditional on-campus courses. For example, electronic mail and computer conferencing was used to augment classroom discussions, while the Internet provided access to original source materials. Early applications of computer-aided-instruction technology attempted to automate the more routine aspects of learning. Like early stages of many technologies, at first higher education tended simply to repurpose the traditional lecture course for online access. Multimedia technology and networks were used to enable distance learning. But for the most part, this was simply an Internet extension of correspondence or broadcast courses.

However the most dramatic impact of this technology on the educational role of the university will occur when learning experiences are reconceptualized to capture the power of this technology. Although the classroom is unlikely to disappear, at least in the sense of its role as a place where students and faculty can come together, the lecture experience of a faculty member addressing a group of relatively passive students does appear to be threatened by powerful new tools such as gaming technology, teleimmersion, telepresence, and the simulation of physical phenomena. 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 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 and multicasting 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.

It is estimated that over 80% of four-year colleges in the United States will be offering distributed learning courses to over 2 million off-campus students by next year. Some estimate the near-term market for such technology-based instruction to be in excess of 30 million in the United States and well over 100 million globally. Little wonder

that there has been explosive activity in the commercial sector to develop both the content and technology necessary to support distributed learning. But developing and deploying quality distributed learning curriculum can be both difficult and expensive. Creating online courses is considerably more complex than simply posting lecture notes (or PowerPoint presentations) on the web or even video-streaming the "talking heads" of lecturing professors. Increasingly, universities are outsourcing much of the technology and expertise necessary for distributed learning from commercial providers such as Blackboard.com and WebCT.

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.[13]

Beyond the distributed learning efforts of established colleges and universities, we are beginning to see the emergence of new types of institutions such as virtual universities. In cybertalk, "virtual" is an adjective that means existing in function but not in form. A virtual university exists only in cyberspace, without campus or perhaps even faculty, with the mission of providing distributed learning opportunities. Unburdened by the constraints of a campus–or perhaps even a faculty–such virtual universities are able to experiment with a variety of different forms. Some, such as the Michigan Virtual University[14], serve only as brokers, providing a market channel for traditional colleges and universities to serve as "suppliers" of educational services to a distributed marketplace. Others such as Unext.com[15] disaggregate the production of educational programs, using the faculties of research universities to determine content, then hiring cognitive scientists to develop pedagogy and courseware, hiring instructors to guide students, and developing assessment tools to monitor learning. The commercial functions of marketing and distribution and even assessment and accreditation of learning can also be disaggregated and outsourced.

Distributed 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 could see their enrollments expand by an order of magnitude. This is particularly true for content-rich research universities, since augmenting their core competencies for content development with commercial application service providers to deploy and distribute learning services on the Internet could them to reach far broader markets in the corporate and global marketplace. It could also facilitate new forms of pedagogy more responsive to nature of knowledge-based society in which learning becomes a pervasive, lifetime need. 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.

Research

So, too, information technology is reshaping the nature of research. The earliest applications of information technology were to the solution of 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 computers. The rapid evolution of this computational technology is enabling scientists 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. In fact, the use of information technology to simulate natural phenomena has created a third modality of research, on par with theory and experimentation.

Yet some of the most powerful applications of this technology have been in the humanities, social sciences, and the arts. Scholars now can use digital libraries such as JSTOR or ARTSTOR to access, search, analyze the complete collection of scholarly journals or digital images of artistic objects. Archeologists are developing virtual reality simulations of remote sites and original materials such as papyrus manuscripts that can be accessed by scholars throughout the world. Social scientists are using powerful software tools to analyze massive data sets of verbal and visual materials collected through interviews and field studies. The visual and performing arts are exploring the new power of technologies which merge various media–art, music, dance, theatre, architecture–and exploit all the senses–visual, aural, tactile, even olfactory–to create new art forms and artistic experiences.

The emergence of vast data repositories with storage requirements of petabyte magnitude will provide both new opportunities and challenges. Although these are generally associated with experiment-intensive sciences such as high energy physics, space science, or genomics, such massive data sets will also characterize the humanities and social sciences as they become increasingly involved with video and holographic technologies. New forms of digital archives are evolving such as distributed data grids (e.g., the Grid Physics Network being developed to handle the projected data stream of 6 petabytes each year collected from the LHC accelerator). Developing the software necessary to access, manipulate, and analyze such vast data sets will be a particular challenge.

There are other, more subtle shifts in scholarship that can be related to emerging information technology. Information technology leverages and enhances intellectual span. 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 also provides the tools to create, from desktop publishing to digital photography and video to synthesizing objects atom-by-atom. Digital technology has been key in the development of the capacity to create new life-forms through the tools of molecular biology and genetic engineering as well as new intellectual entities through artificial intelligence and virtual reality. 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 rather more on the experience of the artist than upon the analytical skills of the scientist.

The Library and Scholarly Communication

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.[16] In a sense, the library and the book are merging. . Robert Lucky, former president of Bell Laboratories, notes that "in their influence on how science is transacted, the Internet and World Wide Web have had the greatest impact of any communications medium since possibly the printing press."[17] As with learning, these new electronic media allow the formation of spontaneous communities of unacquainted users, linked together in the many-to-many topology of computer networks. Researchers can now follow the work in their specialization on a day-by-day basis through web sites.

Yet even today, scholarship is still characterized and constrained by the publication of research results. The current confusion between traditional scholarly publication, through established journals characterized by peer review–and extraordinary costs–and less formal Net-based communications, linking together scholars essentially instantaneously, continues to present a challenge. But here too technology is evolving, with the rapidly evolving use of Web sites that serve as portals to integrate material of interest to particular scholarly disciplines. 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.

Impact on the Form and Function of the University

Colleges and universities are organized along intellectual lines, into schools and colleges, departments and programs, which have evolved over the decades (some would suggest following more the structure of 19th Century science and literature rather than 21st Century knowledge). Furthermore, the governance, leadership, and management of the contemporary university reflect both 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. It has created new channels of communication throughout the university and with broader society that largely bypass traditional administrative arrangement and external relationships. Information 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 academic units such as departments or schools.

Beyond driving a restructuring of the intellectual disciplines, information technology could 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.

This will pose a particular challenge to faculty, long accustomed to controlling the design of curriculum and the supervision of the learning environment. Higher education

as a cottage industry, in which individual courses are handicraft, made-to-order products developed by individual faculty for each course they teach, may not be able to compete much longer in either cost or quality with commodity educational products, developed by experts and distributed by professionals. The cost structures for technology-intensive curriculum development will increasingly be made on the front end, in the design and development of courseware, putting the amateur (read "professor") at a distinct competitive disadvantage. It may also force a redefinition of the role of the professor in the sense that teaching will increasingly involve content and learning ware developed by others.

So, too, colleges and universities will need to reconsider a broad array of policies that have become antiquated in the digital age. Clearly those policies governing intellectual property, whether created through research or instructional activities, require a total overhaul. Traditional patent, copyright, and technology transfer policies make little sense in a world in which the digital products of intellectual activity can be reproduced an infinite number of times with perfect accuracy and at zero cost.[18]

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. 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 members negotiating release 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 that exists for our best faculty? Is it possible that we will see an unbundling of students and faculty from the university, with students acting more as mobile consumers, able to procure educational services from a highly competitive marketplace, and faculty members acting more as free-lance consultants, selling their services and their knowledge to the highest bidder?

Universities face a particular challenge in enabling our students and faculties to keep pace with the extraordinary pace of technology evolution. We 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. In earlier times 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 few years or less, we simply must look for effective ways to reskill our faculties or risk rapid obsolescence.

It has become increasingly important that the university planning and decision process 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 positioning itself for this future of technology-driven change, 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 and network appliances 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 the 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.

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. It is of particular note that 40 percent of all new investment in capital facilities in our society today goes to purchase information technology. This need for investment in information technology applies to universities just as much as it does to the commercial or government sector. And it poses just as much of a challenge. As a rule of thumb most organizations have found that staying abreast of this technology requires an annual investment of 10 percent or greater of their operating budget. For a very large campus, this can amount to hundreds of millions of dollars per year.

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, critical to a university's academic mission that must be provided on a robust basis to the entire faculty, staff, and student body. Colleges and universities could 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 an organization is not willing to invest in this technology, then it may as well accept being confined to a backwater in the knowledge economy, if it survives at all.

Yet few universities have a sustainable financial model for investing in information technology. Accustomed to a budgeting culture driven by faculty appointments and physical facilities, they are unable to cope with investments that become obsolete on time scales of years rather than decades. Rather, they tend to lurch from one crisis to the next in their attempts to provide the IT infrastructure demanded by students and faculty, without a strategic sense of direction as they face the choice between "bricks" and "clicks".

Impact on the Post-Secondary Education Enterprise

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, credentialing, 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 credentialing.[19]

In higher education, just as other sectors of our economy, the Internet is redefining the basis for competitive advantage and survival. It is redefining boundaries and blurring roles. This technology, coupled with the emergence of new competitive forces driven by changing societal needs (e.g., adult education) and economic realities (the erosion in public support) is 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.

The size of the education component of this industry, consisting of K-12, higher education, and corporate learning, is enormous, estimated at over $740 B in the United States and $2 trillion globally.[20] And it is growing rapidly, driven by the increasing importance of human capital to our knowledge-driven economy. Business leaders are

united in their belief that there is no bigger challenge in the global marketplace today than how to obtain, train, and retrain knowledge workers. The new economy is a knowledge economy based on brainpower, ideas, and entrepreneurism. Technology is its driving force, and human capital is its fuel. [21]

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 2000). 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 but then migrating rapidly up the academic value chain. These new competitors are able to offer costs reductions of 60% or more over conventional corporate training programs since through online education they can avoid employee travel and time off costs. They are investing heavily (over $100 million in 2000) in developing sophisticated instructional content, pedagogy, and assessment tools, 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 could be formidable indeed.

Although traditional colleges and universities will also 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. To be sure, many of the predictions about the growth of demand for distance learning are overly optimistic, at least for the near term. But clearly the university will lose its monopoly for students, faculty, and resources, and it is likely to lose market share as well as commercial competitors position themselves to address the rapidly growing needs for adult education. The successful penetration of this market for most universities will involve partnerships with the commercial sector.

The research university will face particular challenges in this regard. Although rarely acknowledged, most research universities rely upon cross-subsidies from low-cost, high profit-margin instruction in general education (e.g., large lecture courses) and low cost professional education (e.g., business administration and law) to support graduate education and research. Yet these high margin programs are just the low hanging fruit most attractive to technology-based, for-profit competitors. In this sense, the emergence of a significant technology-based commercial sector in the post-secondary education marketplace could undermine the current business model of the research university and threaten its core activities in research and graduate education.

Furthermore, as a knowledge-driven economy places becomes ever more dependent upon new ideas and innovation, there will be growing pressures to commercialize intellectual assets of the university–its faculty and students, its capacity for basic and applied research, the knowledge generated through its scholarship and instruction–become ever more valuable. Public policy, through federal actions such as

the Bayh-Dole Act of 1985, have encouraged the transfer of knowledge from the campus to the marketplace. But since knowledge can be transferred not only through formal technology transfer mechanisms such as patents and licensing, but also through the migration of faculty and students, there is also a risk that the rich intellectual assets of the university will be "clear-cut" by its own faculty, even as support for graduate education and research erodes.

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.

The Challenge of University Leadership in the Digital Age

Today's college and university leaders face myriad important questions and decisions concerning the impact of information technology on their institutions. For example, they need to understand the degree to which this technology will transform the 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?" 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 young students 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 spin-off existing activities? Will more (or perhaps most) universities find themselves competing in a global marketplace, and how will that square with the regional responsibilities of publicly supported universities? Will new learning lifeforms or ecologies evolve based upon information technology that will threaten the very existence of the university?

The list of questions and issues seems not only highly complex but overwhelming to university leaders, not to mention the many stakeholders who support higher education. 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.[22] 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 in the face of the complexity and uncertainty of these issues. Yet, as the pace of technological change continues to accelerate, indecision and inaction can be the most dangerous course of all.

As information technology continues to evolve at its relentless, indeed, ever accelerating pace, affecting every aspect of our society and our social institutions, organizations in every sector are grappling with the need to transform their basic philosophies and processes of how they collect, synthesize, manage, and control information. Corporations and governments are reorganizing in an effort to utilize technology to enhance productivity, improve quality, and control costs. Entire industries have been restructured to better align with the realities of the digital age.

Yet, to date, the university stands apart, almost unique in its determination to moor itself to past traditions and practices, to insist on performing its core activities such as teaching much as it has done for decades. In spite of the information explosion and the profound impact of digital communications technology, the use of information and dissemination and learning remain fundamentally unchanged in higher education. Most universities continue to ignore the technology cost learning curves so important in other sectors of society. They insist that it remains simply too costly to implement technology on a massive scale in instructional activities–which, of course, it certainly does as long as we insist on maintaining their traditional character rather than re-engineering educational activities to enhance productivity and quality. Our limited use of technology thus far has been at the margins, to provide modest additional resources to classroom pedagogy or to attempt to extend the physical reach of our current classroom-centered, seat-time based, teaching paradigm. It is ironic indeed that the very institutions that

have played such a profound role in developing the digital technology now reshaping our world are the most resistant to reshaping their activities to enable its effective use.

For all the institutional inertia, there is considerable change underway in higher education. Yet, as you go up the higher education hierarchy, from community colleges to regional universities to research universities, there is less and less activity, particularly at the level of research universities. While there are experiments such as Unext.com, these are largely "hands off", without strong participation by the research university faculty. As a result, most American research universities are not learning how to do implement this technology like other colleges and universities in the enterprise. To some degree this has to do with their privileged position, at the top of the higher education food chain. It is also due to the good economic times they have experienced in recent years, which has provided sufficient prosperity to allow many institutions to buffer themselves from the pressures of external forces such as technological change and the marketplace. But sooner or later, exponential growth will overcome all resistance. To use a often-exploited analogy, today's research universities may be like bathers sunning 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 technology-driven market forces beyond the horizon that could sweep over them before they can react or escape.

A National Academy Project

Last year (2000) the presidents of the National Academy of Sciences, the National Academy of Engineering, and the Institute of 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 is a simple one. The rapid evolution of digital technology will present many challenges and opportunities to higher education in general and the research university in particular. Yet there is an increasing sense that many of the most significant issues are neither well recognized nor understood either by leaders of our universities or those who support and depend upon their activities..

The first phase of the project, organized under the Government-University-Industry Research Roundtable (GUIRR), was aimed at addressing three sets of issues:

1. To identify those technologies likely to evolve in the near term (a decade or less) which could have major impact on the research university.

2. To examine the possible implications of these technology scenarios for the research university: its activities (teaching, research, service, outreach); the organization, structure, management, financing of the university; and the impact on the broader higher education enterprise and the environment in which it functions.

3. To determine what role, if any, there is for the federal government and other stakeholders in the development of policies, programs, and investments to protect the valuable role and contributions of the university during this period of change.

To this end, a Steering Committee to guide the project was formed last year consisting of leaders drawn from industry, higher education, and government with expertise in the areas of information technology, research universities, and public policy. Since first convening in February 2000, the Steering Committee has held several meetings (including site visits to major technology development centers such as Lucent (Bell) Laboratories and IBM Research Laboratories) and held numerous conference calls to identify and discuss trends, issues, and possible recommendations. The key themes addressed by these activities were:

- The pace of evolution of information technology (e.g., Moore's Law).
- The ubiquitous/pervasive character of the Internet (e.g., wireless, photonics).
- The relaxation (or obliteration) of the conventional constraints of space, time, and monopoly.
- The democratizing character of IT (access to information, education, research).
- The changing ways we handle digital data, information, and knowledge.
- The growing importance of intellectual capital relative to physical or financial capital

In January 2001 a two-day workshop was held at the National Academies with invited participation of over 100 leaders from technology, higher education, and government. The purpose of the workshop was to stimulate a conversation, to launch a dialog, aimed at identifying key themes and issues, to suggest possible recommendations and strategies for research universities and their various stakeholders, and to provide guidance on the next phase of the project. The key presentations and discussion of the workshop were videotaped and broadcast on the Research Channel and video-streamed from its website during the spring to serve as an archive for further discussion.

Although the project is still in an early phase, there are already some important preliminary conclusions:

1. The extraordinary evolutionary pace of information technology is likely not only to continue for the next several decades, but it could well accelerate on a superexponential slope. 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. 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).

2. The event horizons are moving ever closer. Getting people to think about the implications of accelerating technology learning curves as well as technology cost-performance curves is very important. 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. The future is becoming less certain.

3. The impact of information technology on the university will likely be profound, rapid, and discontinous–just as it has been and will continue to be for the economy, our society, and our social institutions (e.g., corporations, governments, and learning institutions). It will affect our activities (teaching, research, outreach), our organizations (academic structure, faculty culture, financing and management), and the broader higher education enterprise as it evolves into a global knowledge and learning industry.

4. For at least the near term, meaning a decade or less, the research university will continue to exist in much its present form, although meeting the challenge of emerging competitors in the marketplace will demand significant changes in how we teach, how we conduct scholarship, and how our institutions are financed. Universities must anticipate these forces, develop appropriate strategies, and make adequate investments if they are to prosper during this period.

5. Over the longer term, the basic character and structure of the research university may be challenged by the IT-driven forces of aggregation (e.g., new alliances, restructuring of the academic marketplace into a global learning and knowledge industry) and disaggregation (e.g., restructuring of the academic disciplines, detachment of faculty and students from particular universities, decoupling of research and education).

6. Procrastination and inaction are the most dangerous courses for colleges and universities during a time of rapid technological change. To be sure, there are certain ancient values and traditions of the university that should be maintained and protected, such as academic freedom, a rational spirit of inquiry, and liberal learning. But, just as in earlier times, the university will have to transform itself to serve a radically changing world if it is to sustain these important values and roles.

7. Although we feel confident that information technology will continue its rapid evolution for the foreseeable future, it is far more difficult to predict the impact of this technology on human behavior and upon social institutions such as the university. It is important that higher education develop mechanisms to sense the changes that are being driven by information technology and to understand where these forces may drive the university.

8. Because of the profound yet unpredictable impact of this technology, it is important that institutional strategies include : 1) the opportunity for experimentation, 2) the formation of alliances both with other academic institutions as well as with for-profit and government organizations, and 3) the development of sufficient in-house expertise among the faculty and staff to track technological trends and assess various courses of action.

9. In summary, for the near term (meaning a decade or less), we anticipate that information technology will drive comprehensible if rapid, profound, and discontinuous change in the university. For the longer term (two decades and beyond), all bets are off. The implications of a million-fold increase in the power of information technology are difficult to even imagine, much less predict.

This second phase of the National Academy project will include a number of further activities: 1) the formation of an ongoing roundtable group consisting of leaders from higher education, industry, and government to monitor and assess the implications of evolving technology; 2) the conduct of campus-based discussions among faculty and administrators on a number of university campuses (similar to the “Stresses on the Academy” study jointly conducted by the National Academies and the National Science Board during the 1990s); 3) leadership development conferences drawing together key constituencies both from the campuses (e.g., university administrators, faculty leadership, trustees) and from the stakeholders of the research university (e.g., government agencies, foundations, scholarly societies); and 4) the launch of a series of more focused research projects and technology demonstration efforts designed to raise awareness and assist institutions in developing appropriate strategies. These activities will be supported through the development of web-based resources such as web portals and knowledge environments that are intended to be maintained and serve for the next several years as resources for the higher education community and its stakeholders.

The ultimate goal of the National Academies project is to assist research universities and their various stakeholders in responding to the challenges and opportunities presented by digital technology in such a way that strengthen and enhance those roles so important to the future of our nation and our world.

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. Although our faculty members have long been engaged in international scholarly communities, the locus of their personal scholarly communities have usually been the campus. 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 campus, 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. The scholarly activities of faculty will more frequently involve activities that use technology to access both distant resources and interact with colleagues around the world. The boundaries between the university and broader society will fade, just as its many roles will become ever complex and intertwined with those of other components of the knowledge and learning enterprise.

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. While we may successfully predict near-term evolution of information technology, it is far more difficult to predict its impact on society and its institutions. All we can say is that this technology has proven to be disruptive in character for other sectors of our society. It has driven rapid, significant, and frequently discontinuous and unpredictable change.

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.”[23] 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.[24]

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.

---

[1] Jacques Attali, *Millennium: Winners and Losers in the Coming World Order* (New York: Times Books, 1992), 11.

[2] This paper was prepared for the third conference of the Glion Group, a gathering of university leaders from Europe and North America that met first in 1998 in Glion, Switzerland; then again in 2000 in La Jolla, California; and will meet for the third time in May, 2001, again in Glion. The proceedings of its first meetings can be found in *Challenges Facing Higher Education at the Millennium,* ed. Werner Z. Hirsch and Luc E. Weber (American Council on Education/Oryx Press, Phoenix, 1999).

[3] Peter F. Drucker, interview, *Forbes*, 159 (1997), 122–28.

[4] William A. Wulf, "Warning: Information Technology Will Transform the University," *Issues in Science and Technology* (Summer 1995), 46-52.

[5] Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (New York: Viking, 1999).

[6] Peter J. Deming and Robert M. Metcalf, *Beyond Calculation: The New Fifty Years of Computing* (New York: Springer-Verlag, 1997).

[7] Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (New York: Viking, 1999).

[8] William Gibson, *Neuromancer* (New York: Ace, 1984).

[9] Stuart Feldman, Workshop on IT and the Research University, National Academy of Sciences, Washington, D.C., 2001

[10] Put another way, a petabyte of data is roughly equivalent to the capacity of a stack of CD-ROMs nearly 2 km high.

[11] Erich Bloch, National Science Foundation, testimony to Congress, 1988.

[12] John Seely Brown and Paul Duguid, The Social Life of Information (Harvard Business School Press, Cambridge, 2000).

[13] On-Line Education: Learning Effectiveness and Faculty Satisfaction, John Bourne, Ed., (The Center for Asynchronous Learning Networks, Vanderbilt University, 2000).

[14] http://www.mivu.org/

[15] http://www.unext.com; http://www.cardean.edu/

[16] "Books, Bricks, and Bytes," *Daedelus* 125, no. 4, (1996), v-vii.

[17] Robert Lucky, "The Quickening of Science Communication", Science Vol. 289, July 14, 2000, pp. 259-264.

[18] John Perry Barlow, "The Economy of Ideas: A Framework for Rethinking Patents and Copyrights in the Digital Age," *Wired*, 2.03 (March 1994).

[19] Stan Davis and Jim Botkin, *The Monster Under the Bed* (Touchstone, New York, 1995); Ted Marchese, "Not-So-Distant Competitors: How New Providers Are Remaking the Postsecondary Marketplace," *AAHE Bulletin* (May 1998); David Collins, "When Industries Change: Scenarios for Higher Education", in *Forum Futures 1999* (Forum for the Future of Higher Education, New Haven, 1999) pp. 47-72.

[20] Michael T. Moe, The Knowledge Web: People Power–Fuel for the New Economy (Merrill Lynch, New York, 2000).

[21] An interesting data point: Compare the market-capitalization per employee of three companies: General Motors at $141,682; the Walt Disney Company at $743,530; and Yahoo at $33 million! Indeed the top 10 Internet companies have a market-cap-per-employee of over $38 million. The reason is simple: In the knowledge economy, the key asset driving corporate value is no longer physical or financial capital but rather intellectual and human capital.

[22] "Convocation on Stresses on Research and Education at Colleges and Universities" (Government-University-Industry Research Roundtable and National Science Board (Washington, D.C.: National Academy of Sciences, 1997). <http://www2.nas.edu/guirrcon/>.

[23] William J. Mitchell, *City of Bits: Space, Place, and the Infobahn* (Cambridge: MIT Press, 1995), <http://www-mitpress.mit.edu/City_of_Bits>.

[24] James J. Duderstadt, *A University for the 21st Century* (University of Michigan Press, Ann Arbor, 2000).