The Changing Nature of Research
and the Future of the University

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INTRODUCTION

This summer I had the opportunity to co-chair a four-day workshop in Switzerland concerning the future of the university. In attendance were roughly two dozen leaders of the world's leading research universities from both North America and Europe, sharing their perspectives of the future of the research university. Midway through our workshop, the Supreme Court handed down its decision on the Michigan affirmative action cases, an event of rather considerable interest both to me (as a named defendant) and to the American university presidents (and particularly Nils Hasselmo of AAU and David Ward of ACE, who had multiple press releases prepared to cover any court decision).

Of course when ever any group of university presidents get together, they usually begin with all the usual topics: money, students, politics, and, for an unfortunate few, intercollegiate athletics. This meeting was no exception, and much of the discussion concerned issues such as the staggering budget crunch facing public higher education both in the United States and Europe; the changing education needs of both the digital generation and adults facing the life-long education demands of a global knowledge economy; and, the challenge and opportunity posed by the educational needs of an increasingly diverse society, both within nations and globally.

Yet, interesting enough, much of the discussion concerning the future of the research university concerned more fundamental intellectual issues. Although the changing needs and nature of society have been important factors in shaping the evolution of the university over the centuries, so too has been the changing nature of research and scholarship. Intellectual transformations ranging from scholasticism to the Enlightenment to the scientific revolution have played a major role in defining the nature of the university in the past and are continuing to do so today. This afternoon I would like to offer some observations and perhaps also some speculation about how the changing nature of research might affect the future of the research university.

First, however, it seems appropriate to establish a benchmark by summarizing how changes occurring in the nature of research over the past 50 years have been important determinants in shaping the contemporary research university. Although much of this discussion will be focused on the American experience, many of these factors have influenced the evolution of research universities in other nations and are even more likely to do so in the decades ahead as the nature of learning, research, and scholarship becomes increasingly international.

THE AMERICAN RESEARCH UNIVERSITY, CIRCA 2000

The character of today's American research university was shaped some fifty years ago by the seminal report, *Science, the Endless Frontier*, produced by a World War II study group chaired by Vannevar Bush (Bush, 1945, p. 192). The central theme of the document was that the nation's health, economy, and military security required continual deployment of new scientific knowledge; hence the federal government was obligated in the national interest to ensure basic scientific progress and the production of trained personnel. It stressed a corollary principle: that the government had to preserve freedom of inquiry, to recognize that scientific progress results from the "free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for explanation of the unknown". Rather than attempting to build separate research institutes or academies, the federal government decided instead to rely on a partnership with the leading American universities by supporting research on the campuses through a system of competitive, peer-reviewed grants and a framework for contractual relationships between universities and government sponsors. Faculty investigators were encouraged to work on research of their own choosing, with the anticipation that eventually this unconstrained research would lead to significant social benefits.

The resulting partnership between the federal government and the nation's universities has had an extraordinary impact. Federally supported academic research programs on the campuses have greatly strengthened the scientific prestige and quality of American research universities, many of which now rank among the world's best. The academic research enterprise has not only provided leadership in the pursuit of knowledge in the fundamental academic disciplines, but through the conduct of more applied-mission-focused research, it has addressed national priorities such as health care, environmental sustainability, economic competitiveness, and national defense. It has laid the technological foundations for entirely new industries such as microelectronics, biotechnology, and information technology. Furthermore, by combining research with advanced training, it has produced the well-trained scientists, engineers, and other professionals capable of applying this new knowledge.

> The solution of virtually all the problems with which government is concerned: health, education, environment, energy, urban development, international relationships, space, economic

> competitiveness, and defense and national security, all depend on creating new knowledge—and hence upon the health of America's research universities.
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> —Erich Bloch, director, National Science Foundation, 1986

Yet, it is also clear that while the research university model evolving during the latter half of the 20th century has been remarkably successful, many of its most distinguishing characteristics have been mixed blessings. The single-investigator model of sponsored research, in which individual faculty members are expected to secure whatever resources are necessary for research and graduate training in their narrow area of scholarship, has driven the dominance of disciplinary specialization and reductionism. Faculty have learned that the best way to attract funding in a competitive, peer-reviewed research culture is to become as specialized as possible, since this narrows the group of those likely to review their proposals (perhaps even to their colleagues), thereby driving even more the disciplinary fragmentation of the academy. As a result, academic disciplines dominate the modern research university, developing curriculum, marshaling resources, administering programs, and doling out rewards.

Since competition for grants and contracts play such an important role in supporting research and graduate education, it is not surprising that research universities tend to set their sails to track the ever-shifting winds of federal research priorities. For example, as the space race of the 1960s was succeeded by the social programs of Lyndon Johnson's Great Society and concern about the environment of the 1970s, research universities throttled back academic programs in the physical sciences and engineering in favor of the applied social and health sciences (e.g., education, social work, medicine, dentistry, and public health). Today the health concerns of an aging baby-boom population has stimulated a doubling of the budget of the National Institutes of Health, triggering a massive shift from the physical and social sciences into the life sciences on many campuses, as universities have sensed the shift of federal priorities from "guns to pills". More specifically, during the past decade the budget of the National Institutes of Health increased by more than 150%, to $27 billion for FY2003, while the research budgets of those agencies such as the Department of Energy, Department of Defense, and the National Aeronautics and Space Administration remained relatively stagnant or declined. Even the National Science Foundation experienced only modest growth, to roughly $5 billion in FY2003. Today, roughly 62% of every federal research dollar flowing to the campuses is in biomedical research (Committee on Science, Engineering and Public Policy, 2003).

The faculty members of research universities are well aware that their careers–their compensation, promotion, and tenure–are determined more by their research productivity, as measured by publications, grantsmanship, and peer respect, than by other university activities such as undergraduate teaching and public service. This reward climate helps to tip the scales away from teaching and public service, especially when quantitative measures of research productivity or grantsmanship replace more balanced judgments of the quality of research and professional work. So too, the fragmentation of disciplines driven in part by increasing specialization of scholarship has undermined the coherence of the undergraduate curriculum. There appears to be a growing gap between what faculty members like to teach and what undergraduate students need to learn (Shapiro, 1991).

Just as the research interests of the faculty drove the fragmentation of undergraduate education, so too, graduate education has been reshaped largely to benefit faculty research. In a sense this was natural since Ph.D. programs have traditionally seen their role as training the next generation of academicians, that is, self-replication. All too often, however, the current research-driven paradigm tends to view graduate education as either a by-product activity, driven by the level of research funding, or as a source of cheap labor for research projects. Such exploitation of students for the benefit of faculty research extends to the postdoctoral level as well. Postdoctoral students have the sophistication to be highly productive research assistants. They are highly motivated and work extremely hard. And they are cheap. Hence, it is not surprising that in many fields, the postdoctoral student has become the backbone of the research enterprise. In fact, one might even cynically regard postdocs as the migrant workers of the research industry, since they are sometimes forced to shift from project to project, postdoc to postdoc appointment, even institution to institution, before they find a permanent position.

The growing pressures on faculty, not only to achieve excellence in teaching and research, but also to generate the resources necessary to support their activities, are immense (Clark, 1998). At a university like Michigan, with roughly 2,700 faculty members generating over $700 million of research funding per year, this can amount to an expectation that each faculty member will generate hundreds of thousands of research dollars per year, a heavy burden for those who also carry significant instructional, administrative, and service responsibilities. Pressures on individual faculty for success and recognition have led to major changes in the culture and governance of universities. The peer-reviewed grant system has fostered fierce competitiveness, imposed intractable work schedules, and contributed to a loss of collegiality and community. It has shifted faculty loyalties from the campus to their disciplinary communities. Faculty careers have become nomadic, driven by the marketplace, hopping from institution to institution in sea. As one junior faculty member exclaimed in a burst of frustration: "The contemporary university has become only a holding company for research entrepreneurs!"

THE CHANGING NATURE OF RESEARCH AND SCHOLARSHIP

What changes in the nature of research and scholarship might we identify as significant factors in determining the nature of the university in the century ahead?

Disciplines or Dinosaurs

It is important to acknowledge the dynamic nature of the disciplinary character of scholarship. What we regard as entrenched disciplines today have changed considerably in the past and continue to do so. New ideas and concepts continue to explode forth at ever-increasing pace. We have ceased to accept that there is any coherent or unique form of wisdom that serves as the basis for new knowledge. We have simply seen too many instances in which a new concept has blown apart our traditional views of the field. Just as a century ago, Einstein's theory of relativity and the introduction of quantum mechanics totally revolutionized the way that we thought of the physical world, today's speculation about dark matter and quantum entanglement suggest that yet another revolution may be underway. The molecular foundations of life have done the same to the biomedical sciences.

In part the knowledge explosion is driven by the increasingly sophisticated nature of the experimental apparatus used to gather data and the digital technology used to store, curate, and communicate knowledge. But it is also due simply to the fact that an ever-increasing population ever more dependent upon knowledge for economic prosperity has driven a major expansion in the numbers of scientists, engineers, and other scholars.

There are also qualitative changes in the nature of research itself. Twenty-first century science is marked by increasing complexity that frequently overwhelms the reductionist approach of the disciplines. As the Rita Colwell, the Director of the National Science Foundation notes,[1] the burgeoning quantities of data now available to us in many fields portray systems with a huge number of interdependent and interacting variables, characterized by dynamic, nonlinear behavior and emergent structures of order. Increasingly scientific progress depends upon the cross-fertilization of ideas, models, and experimental platforms from many disciplines. Modern biotechnology, for example, has developed with contributions from a broad range of fields including biology, chemistry, physics, mathematics, engineering, and computer science. Recent breakthroughs in the cognitive, behavioral and neurosciences, combined with the powerful tools of information technology have created an emerging frontier of knowledge that has promised to advance dramatically our understanding of the learning process and perhaps of scholarship itself.

As the speed of intellectual change continues to accelerate, it has become more evident that we need to make basic alternations in the discipline-focused culture and structure of the universities. As E. O. Wilson put it in his provocative book, *Consilience*, "Most of the issues that vex humanity daily cannot be solved without integrating knowledge from the natural science with that of the social sciences and humanities. Only fluency across the boundaries will provide a clear view of the world as it really is, not as seen through the lens of ideologies and religious dogmas or commanded by myopic response to immediate needs."[2]

Basic vs. Applied Research

There is a definite hierarchy of academic prestige—or, perhaps better stated, an intellectual pecking order—within the university. In a sense, the more abstract and detached a discipline is from “the real world,” the higher its prestige. In this ranking, perhaps mathematics or philosophy would be at the pinnacle, with the natural sciences and humanities next, followed by the social sciences and the arts. The professional schools fall much lower down the hierarchy, with law, medicine, and engineering followed by the health professions, social work, and education at the bottom. Clearly, within this culture of academic snobbery, the distinction of basic (“curiosity-driven” or *Baconian*) versus applied (“mission-oriented” or *Newtonian*) research becomes significant, perhaps tracing back to the Humboldtian ideal of pure *Wissenschaft*.

In reality, however, the progression of basic knowledge from the library or the laboratory to societal application is far from linear, and the distinction between basic and applied research is largely in the eye of the beholder (Sonnert and Holton, 2002). Furthermore, there is yet another mode of research that represents a conscious combination of basic and applied research: so-called *Jeffersonian science* (using as an analogy the Lewis and Clark expedition, which was justified to Congress as discovering paths to further westward expansion, and portrayed to the Spanish as a purely scientific expedition, sampling unknown fauna and flora). Such research aims at providing the fundamental knowledge essential to address a key social priority (also known as *Pasteur's quadrant* (Stokes, 1997), referring to Pasteur's discovery of micro-organisms when trying to find a better way to brew beer) is not only important in its own right, but it creates the opportunity to make public support of all types of research more palatable to policy makers and taxpayers. Contemporary examples would include the neuroscience and cognitive science necessary to create better schools, the atomic and quantum physics necessary for nanotechnology, and, of course, the molecular biology necessary for progress in health care (providing an excellent case study through the growth in the NIH budget of the effectiveness of Jeffersonian research in building the case for strong public support).

The Conduct of Research

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 is driven by many factors. The enormous expense of major experimental facilities such as high energy physics accelerators, astronomical observatories, and biochemical laboratories compel scientists to work in teams consisting not only of primary investigators but specialists such as systems engineers and software developers that may number in the hundreds. Similarly the complexity of contemporary research topics such as protein function or global change span many disciplines that require multidisciplinary teams.

While this may be a marked departure from the Humboldtian notion of the isolated scholars attempting to attain objective truth, it is actually more consistent with the nature of human social interactions. In the past, these scholarly communities generally occurred within disciplines, at the department level within universities, or scholarly communities scattered across the globe in highly specialized areas. Today these communities are increasingly multidisciplinary teams aimed at the investigation of complex research topics.

New types of research organizations are appearing that are based on evolving information technology. An example is the "collaboratory," an advanced, distributed infrastructure that uses multimedia information technology to relax the constraints on distance, time, and even reality.[3] Scholars around the world can now join together to operate remote facilities such as telescopes on Mauna Kea or scientific equipment at the

South Pole Station, collaborating in data collection, analysis, and interpretation. A vast array of human team activities in commerce, education, and the arts would be supported by variants of this concept. In fact, such network-enabled scholarly communities may become the basis for the world universities in the decades ahead.

The International Nature of Scholarship

Any discussion about the future of the research university must account for the impact of the pervasively international character of research. To be sure, international cooperation in research is demanded by large and expensive facilities such as high-energy accelerators or astronomical observatories; for projects requiring coordinated research programs such as global climate change; and for cross-national comparisons of health, education, and economic development. However international cooperation is much more than joint financial support of major facilities with other nations. Scholarship is a global enterprise in which nations must participate both for their own benefit and that of the world.

American universities have been particularly fortunate in benefiting from the talents and energy of an influx of foreign-born students and scholars who have driven many of our advances in science, technology, and scholarship. Over half a century ago, Albert Einstein, Enrico Fermi, and many others from Western Europe laid the foundations for our global leadership in modern science. More recently, immigrants from other parts of the world–most notably China, India, and Southeast Asia–have joined our research university to become not simply contributors but leaders both in academic and industry. Today approximately half of the graduate students currently enrolled in the physical sciences and engineering at U.S. universities come from other nations. These foreign students are absolutely essential both for our research programs and technological development.

Information and communications technologies have provided a powerful new tool to facilitate and extend international scholarship. By forging new national and international alliances and by carefully exploiting the new communications technologies on the horizon–putting the entire world in nearly instantaneous low-cost contact through the Internet (and its successors)–we can link to our scientific and scholarly colleagues throughout the world. Driven by information technology, the network has become more than a web which links together learning resources. It has become the architecture of advanced learning organizations (Dolence and Norris, 1995). Information, knowledge, and learning opportunities are now distributed across robust computer networks to hundreds of millions of people about the globe. The knowledge, the learning, the cultural resources that used to be the prerogative of a privileged few are rapidly becoming available anyplace, anytime, to anyone.

The Tools of Research

The tools of research continue to evolve, increasing dramatically in power, scope, and, of course, cost. Research university leaders and funding agencies have long pointed to the staggering size and cost of the experimental facilities characterizing the physical sciences, e.g., the high energy physics accelerators such as the Large Hadron Collider or astronomical observatories such as the Keck telescopes or the Hubble Space Telescope. But today many research universities are making even larger investments in the biomedical sciences, building new "life sciences institutes" to achieve the critical mass of facilities and scientists to tap the massive funding flowing into molecular genetics, proteomics, and biotechnology. Over the longer term, one might well question whether these research facilities will soon follow the path of high-energy physics and astronomy, becoming too large and expensive for single institutions–and perhaps even nations–and instead requiring international consortia of institutions, sponsors, and scientists.

The rapid evolution of digital technology also poses both new opportunities and challenges. A new age has dawned in S&E research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive cyberinfrastructure on which to build new types of knowledge environments and organizations and to pursue research in new ways and with increased efficiency. The emerging vision is to use cyberinfrastructure (Atkins, 2003) to build more ubiquitous, comprehensive digital environments that become interactive and functionally complete for research communities in terms of people, data, information, tools, and instruments and that operate at unprecedented levels of computational, storage, and data transfer capacity.

Digital computation, data, information, and networks are now being used to replace and extend traditional efforts in science and engineering research, indeed to create new disciplines. The classic two approaches to scientific research, theoretical/analytical and experimental/observational, have been extended to *in silico* simulation to explore a larger number of possibilities at new levels of temporal and spatial fidelity. Beyond solving complex mathematical models or managing large data sets, we are increasingly able to simulate complex phenomena from first principles, e.g., solving the equations of motion for millions of atoms representing a material, analyzing the complex dynamics of the global climate, or simulating the crash of an automobile. The use of information technology to simulate natural phenomena has created a third modality of research, on par with theory and experimentation.

Computer simulation provides a way to probe deeply into the behavior of complex systems, to try out new theories on idealized systems. Scientists still develop hypotheses to be tested in the laboratory or in the field. But a new step has been added to the scientific process: More and more often, the experimental data that emerge are compared to computer simulations. The appearance of new computer-based disciplines such as computational chemistry, computational neuroscience, computational genetics, and bioinformatics suggest that the computer is being used increasingly to augment the scientific mind as it attempts to digest the deluge of data coming from new laboratory instrumentation. In a very real sense, all experimental science is becoming computer science, to the extent that computer technology is the common interface between data collection, analysis, and interpretation.

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 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.

Digital technology also provides the tools to create, from desktop publishing to digital photography and video to synthesizing objects atom-by-atom. We are developing the capacity to create new life forms through the tools of molecular biology and genetic engineering. And, we are now creating 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 analytical skills of the scientist.

But herein lies a great challenge. While we are experienced in teaching the skills of analysis, we have far less understanding of the intellectual activities associated with creativity. In fact, the current disciplinary culture of our campuses sometimes discriminates against those who are truly creative, those who do not fit well into our stereotypes of students and faculty.

The Relationship Among Research, Education, and Learning

For decades, the conventional wisdom in the United States has been that research and teaching were mutually reinforcing and should be conducted together, at the same institutions by the same people (Peliken, 1992, p. 238). Higher education has long attempted to weave together research and education, particularly in making the case for public support of the research mission of the university. Yet, the relationship of research to teaching quality is far from obvious. For example, in most research universities there is an ever-widening gap between the research activities of the faculty and the undergraduate curriculum.

There is a certain irony here. The research university provides one of the most remarkable learning environments in our society—an extraordinary array of diverse people with diverse ideas supported by an exceptionally rich array of intellectual and cultural resources. Yet we tend to focus our educational efforts on traditional academic programs, on the classroom and the curriculum. In the process, we may have overlooked the most important learning experiences in the university.

Increasingly, we realize that learning occurs not simply through study and contemplation but through the active discovery and application of knowledge. From John Dewey to Jean Piaget to Seymour Papert, we have ample evidence that most students learn best through inquiry-based of "constructionist" learning. As the ancient Chinese proverb suggests "I hear and I forget; I see and I remember; I do and I understand."

Perhaps it is time to integrate the educational mission of the university with the research and service activities of the faculty by ripping instruction out of the classroom–or at least the lecture hall–and placing it instead in the discovery environment of the laboratory or studio or the experiential environment of professional practice.

From Partnership to Procurement

We noted earlier the profound shift in federal research priorities that has occurred over the past several decades, shifting from the support of the physical sciences and engineering (e.g., in areas such as microelectronics and aerospace engineering) to support the Cold War and the space race, to the biomedical sciences, reflecting the demands for better health care from an aging population. There is growing recognition that our nation needs to address possible imbalances among the fields of science and engineering – at a time when many fields are increasingly interdependent for achieving optimal results in the productivity of the economy and the pursuit of knowledge.

Over this period, there have been other important changes in the national research enterprise. For example, since 1987, the fraction of national R&D conducted by industry has increased by 196% while the federal share of total R&D has dropped from 46% to 27%. In part this remarkable growth in private sector R&D has been stimulated by the importance of applied research and development in a technology-driven economy. But it also reflects a conscious federal decision to throttle back federal investment in R&D in the face of other priorities such as national security, health care, and social services. Today, one might well question whether the current federal investment is adequate to sustain the necessary private sector investment in these activities, so critical to our economic prosperity.

One might attribute such shifts in federal research policy to a strategic consideration of the role played by various disciplines in addressing key national priorities of the times, such as the urgency of military security during the Cold War, the health care needs of an aging population, or, most recently, homeland security in the face terrorist threats. Yet, perhaps more cynically, one might also consider such priorities determined more by the complex process our Congress uses to authorize and fund research. The current appropriations process relies heavily on a Congressional committee structure strongly favoring biomedical research and susceptible to lobbying influence (particularly from Hollywood celebrities), while penalizing many other science and engineering disciplines by embedding their support in mission agencies subject to appropriations cuts (e.g., DOD and DOE).

Perhaps even more disturbing are signs suggesting that the basic principles of the extraordinarily productive research partnership that has existed for the past half-century between the federal government and the research university has begun to unravel. Today this relationship is rapidly changing from a partnership to a procurement process. The government is increasingly shifting from being a partner with the university—a patron of basic research—to becoming a procurer of research, just as it procures other goods and services. In a similar fashion, the university is shifting to the status of a contractor, regarded no differently from other government contractors in the private sector. In a sense, today a grant has become viewed as a contract, subject to all of the regulation, oversight, and accountability of other federal contracts. This view has unleashed on the research university an army of government staff, accountants, and lawyers all claiming to want to make certain that the university meets every detail of its agreements with the government.

This situation is compounded by an array of new legislation and policies seeking both to demand and measure the performance associated with programs supported by federal tax dollars:

1. The Government Performance Results Act (GPRA), a law passed by Congress in 1992 that demands accountability by developing performance measures for programs funded from federal sources.
2. The President's Management Agenda, a relatively recent effort by the Office of Management and Budget, to provide "motivational" guidance to federal agencies through a rating system ("red, yellow, and green" indicators for performance).
3. The Performance Assessment Rating Tool, again a White House (Office of Management and Budget) analysis intended to measure performance at the level of individual programs, using a 100-point system based on a series of questions.
4. The R&D Criteria effort, involving the Office of Management and Budget, although working with both the Office of Science and Technology Policy and the National Academies, to assess research programs according to an array of subjective criteria such as "quality" and "relevance."

The difficulty has to do both with the diversity of these measures and the difficulty in applying them in a uniform fashion across all federal research agencies and programs. As these performance measures become more widespread, they not only will affect the priorities given federal investment in various areas of research, but burden research investigators (and their universities) with increasing bureaucracy.

The university research community is increasingly concerned about restoring the mutual trust and confidence of a partnership and move away from the adversarial contractor/procurer relationship that we find today. Surely, the most ominous warning sign for academic research is the erosion, even breakdown, in the extraordinarily productive fifty-year partnership uniting government and universities. Scientists and universities are questioning whether they can depend on the stable and solid relationship they had come to trust and that has paid such enormous dividends in initiative, innovation, and creativity. It is alarming that the partnership that has been in large measure responsible for our national prosperity and security should be threatened at the very moment when it has become most critical for our future.

Technology

Two years ago the presidents of our National Academies launched a project to understand better the implications of information technology for the future of the research university, which I was asked to chair. Let me mention three key conclusions from first phase of this study:

Point 1: The extraordinary evolutionary pace of information technology will not only continue for the foreseeable future, but it could well accelerate on a superexponential slope.

Digital technology is characterized by an exponential pace of evolution in which characteristics such computing speed, memory, and network transmission speeds for a given price increase by a factor of 100 to 1000 every decade. Over the next decade, we will evolve from "giga" technology (in terms of computer operations per second, storage, or data transmission rates) to "tera" and then to "peta" technology (one million-billion or 10^{15}). To illustrate with an extreme example, if information technology continues to evolve at its present rate, by the year 2020, the thousand-dollar notebook computer will have a data processing speed and memory capacity roughly comparable to the human brain.4 Except it will be so tiny as to be almost invisible, and it will communicate with billions of other computers through wireless technology.

For planning purposes, we can assume that by the end of the decade we will have available infinite bandwidth and infinite processing power (at least compared to current capabilities). 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", since digital devices will increasingly become our primary interfaces not only with our environment but with other people, groups, and social institutions.

Point 2: The impact of information technology on the university will likely be *profound, rapid, and discontinuous*–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 is a *disruptive* technology.

Information and communications technology will affect the activities of the university (teaching, research, outreach), its organization (academic structure, faculty culture, financing and management), and the broader higher education enterprise. However, at least for the near term, meaning a decade or less, we believe 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. Procrastination and inaction are the most dangerous courses for universities during a time of rapid technological change.

> Point 3: It is our belief that universities should begin the development of their strategies for technology-driven change with a firm understanding of those key values, missions, and roles that should be protected and preserved during a time of transformation.

The Commercialization of the Academy

The efforts of universities and faculty members to capture and exploit the soaring commercial value of the intellectual property created by research and instructional activities create many opportunities and challenges for higher education. To be sure, universities recognize and exploit the increasing commercial value of the intellectual property developed on the campuses as an important part of their mission. But there are also substantial financial benefits to those institutions and faculty members who strike it rich with tech transfer. This has infected the research university with the profit objectives of a business, as both institutions and individual faculty members attempt to profit from the commercial value of the products of their research and instructional activities. Universities have adopted aggressive commercialization policies and invested heavily in technology transfer offices to encourage the development and ownership of intellectual property rather than its traditional open sharing with the broader scholarly community. They have hired teams of lawyers to defend their ownership of the intellectual property derived from their research and instruction. On occasions some institutions and faculty members have set aside the most fundamental values of the university, such as openness, academic freedom, and a willingness to challenge the status quo, in order to accommodate this growing commercial role of the research university (Press and Washburn, 2000, p. 39-54).

Markets

The growing and changing nature of higher education needs will trigger strong economic forces. There is simply no way that today's tax system can support the massification of higher education required by knowledge-driven economies, in the face of other compelling social priorities (particularly the needs of the aging). 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 our experience with other restructured sectors of the 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.[5]

The market forces currently driving the evolution of higher education in the United States are global in extent, and they will sweep aside institutions dependent only upon public support. This situation is likely to continue for at least several decades, at least until a new generation restores a more appropriate balance between the consumption of an aging population and meeting the educational needs of the young. But there are warning signs.

Warning Sign 1: Darwinian Competition: Evidence of this increasingly market driven character of higher education is provided by the competition among universities. The arms race is escalating, as institutions compete ever more aggressively for better students, better faculty, government grants, private gifts, prestige, winning athletic programs, and commercial market dominance. This is aggravated by vast wealth accumulated by several of the elite private universities that allows them to buy "the best and brightest" students through generous financial aid programs (including merit-based programs) and raid outstanding faculty from less well-endowed institutions. The growing gap between faculty salaries characterizing private and public research universities have created a Darwinian ecosystem in which wealthy elite universities have become predators feeding on the faculties of their less well-endowed prey, causing immense damage to the quality of the latter's programs by luring away their top faculty with offers they are unable to match.

Warning Sign 2: Commercialization of the Academy: Yet another warning sign concerns the efforts of universities and faculty members to capture and exploit the soaring commercial value of the intellectual property created by research and instructional activities. This has infected the research university with the profit objectives of a business, as both institutions and individual faculty members attempt to profit from the commercial value of the products of their research and instructional activities. Universities have adopted aggressive commercialization policies and invested heavily in technology transfer offices to encourage the development and ownership of intellectual property rather than its traditional open sharing with the broader scholarly community. They have hired teams of lawyers to defend their ownership of the intellectual property derived from their research and instruction. On occasions some institutions and faculty members have set aside the most fundamental values of the university, such as openness, academic freedom, and a willingness to challenge the status quo, in order to accommodate this growing commercial role of the research university.[6]

Warning Sign 3: From Public Good to Private Benefit: There is a deeper issue here. The American university has been seen as an important social institution, created by, supported by, and accountable to society at large. The key social principle sustaining the university has been the perception of education as a *public good*--that is, the university was established to benefit all of society. Like other institutions such as parks and police, it was felt that individual choice alone would not sustain an institution serving the broad range of society's education needs. Hence public policy dictated that the university merited broad support by all of society, rather than just by the individuals benefiting from its particular educational programs, through direct tax subsidy or indirect tax policies (e.g., treatment of charitable giving or endowment earnings).

Yet, today, even as the needs of our society for postsecondary education intensifies, we also find an erosion in the perception of education as a public good deserving of strong societal support.[7] State and federal programs have shifted from investment in the higher education enterprise (appropriations to institutions or students) to investment in the marketplace for higher education services (tax benefits to students and parents). Whether a deliberate or involuntary response to the tightening constraints and changing priorities for public funds, the new message is that education has become a private good that should be paid for by the individuals who benefit most directly, the students. Government policies that not only enable but intensify the capacity of universities to capture and market the commercial value of the intellectual products of research and instruction represent additional steps down this slippery slope.

Warning Sign 4: Threats to the Survival of the Public Research University: This shift from the perception of higher education as a public good to an individual benefit has another implication. To the degree that higher education was a public good, benefiting all (through sustaining democratic values, providing public services), one could justify its support through taxation of the entire population. But viewed as an individual benefit, public higher education is, in fact, a highly regressive social construct since, in essence, the poor subsidize the education of the rich, largely at the expense of their own opportunities.

The implications are that the marketplace coupled with a commitment to provide educational opportunities to all, regardless of economic ability, will increasingly drive many of the best public universities toward high-tuition, high financial aid policies in which state support becomes correctly viewed as a tax-supported discount of the price of education that should be more equitably distributed to those with true need. The leading public universities may increasingly resemble private universities in the way they are financed and managed. They will use their reputation, developed and sustained during earlier times of more generous state support, to attract the resources they need from federal and private sources to replace declining state appropriations. Put another way, many will embrace a strategy to become increasingly privately financed, even as they strive to retain their public character. Not that those public universities with the political capacity to move to high tuition will suffer, since the marketplace teaches us that high quality is frequently far more competitive than low cost (the Lexus sells better than the Neon!).

Warning Sign #5: The Loss of Public Purpose: In this process of responding to the market place by privatizing public higher education we could lose something of immense importance: the public purpose of the university. Markets are inexorable, and it is both fruitless and dangerous to pretend they are not. Yet, if they are allowed to dominate and reshape the higher education enterprise without constrain, some of the most important values and traditions of the university will likely fall by the wayside.

Will higher education retain its special role and responsibilities, its privileged position in our society? Will it continue to prepare young students for roles as responsible citizens? Will it provide social mobility through access to education? Will it challenge our society in the pursuit of truth and openness? Or will it become, both in perception and reality, just another interest group driven along by market forces? As we assess these market-driven emerging learning structures, we must bear in mind the importance of preserving the ability of the university to serve a broader public purpose.

SOME IMPLICATIONS FOR THE 21ST CENTURY RESEARCH UNIVERSITY

Intellectual Architecture

The changes in the nature of scholarship, from disciplinary to multi/inter-trans/cross-disciplinary, from specialization and reductionism to complexity and consilience, from Baconian or Newtonian to Jeffersonian, from analysis to creativity, will likely reshape the intellectual architecture of the University, as well as its organizational structure. Clearly top-down organizations, imposed by administrators with little experience or understanding of life in the intellectual trenches will fail to tap the energy and creativity of faculty and students. Managing intellectual change in the university is not about putting centralized command-and-control systems in place. On the other hand, leaving the future of the university to faculty entrenched in traditional disciplines would similarly doom it to ossification. The organization of the university will become increasingly driven by innovative scholarship, teaching, and learning at the grassroots level. To preserve vitality will require flexible, decentralized structures, competing with one another for survival.

The increasingly rapid and nonlinear nature of the transfer of knowledge from the library and laboratory into practical application suggests that more basic research activities may shift from the academic disciplines into professional schools. For example, the clinical applications (and revenue) associated with molecular genetics and proteomics have already drawn much of the most exciting basic research in the life sciences into clinical departments such as immunology and internal medicine. So too, engineering is becoming increasing dependent upon and involved in basic research topics such as quantum computing and nanoscience. Some of the most exciting basic work in the social sciences is now found in professional schools such as business, public policy, and law.

The development of information and communications technologies, the increased mobility of people, and the migration of populations driven by economic, social, and political factors will provoke even greater cultural contact and the internationalization of public life, education and scholarship, and academic institutions. If universities are to be able to capitalize on discoveries made elsewhere and facilities located elsewhere, they must have world-class researchers who maintain constant communication and work frequently in collaboration with the best scholars throughout the world. International science and technology cooperation is also necessary in order to make progress on many common problems that require a global perspective, i.e., stopping new infectious diseases, understanding volcanic hazards, cataloguing biological diversity, reversing soil degradation.

NEW PARADIGMS FOR THE RESEARCH UNIVERSITY

So what might we anticipate as possible future forms of the university? The monastic character of the ivory tower is certainly lost forever. Although there are many important features of the campus environment that suggest that the most universities will continue to exist as a place, at least for the near term, as digital technology makes it increasingly possible to emulate human interaction in all the senses with arbitrarily high fidelity, perhaps we should not bind teaching and scholarship too tightly to buildings and grounds. Certainly, both learning and scholarship will continue to depend heavily upon the existence of communities since they are, after all, highly social enterprises. Yet as these communities are increasingly global in extent, detached from the constraints of space and time, we should not assume that the scholarly communities of our times, constrained to a physical campus, would necessarily dictate the future of our universities.

As illustrations, let me suggest several possible visions of the future, that progress ever more toward an unpredictable and unknowable future (and, as some might contend, toward the lunatic fringe…).

The Core-in-Cloud University

Many research universities are already evolving into so-called "core in cloud" organizations (Gibbons, 1994), in which academic departments or schools conducting elite education and basic research, are surrounded by a constellation of quasi-university organizations--research institutes, think tanks, corporate R&D centers—that draw intellectual strength from the core university and provide important financial, human, and physical resources in return. Such a structure reflects the blurring of basic and applied research, education and training, the university and broader society.

More specifically, while the academic units at the core retain the traditional university culture of faculty appointments (e.g., tenure) and intellectual traditions (e.g., disciplinary focus), those quasi-academic organizations evolving in the cloud can be far more flexible and adaptive. They can be multidisciplinary and project focused. They can be driven by entrepreneurial cultures and values. Unlike academic programs, they can come and go as the need and opportunity arise. And, although it is common to think of the cloud being situated quite close to the university core, in today's world of emerging electronic and virtual communities, there is no reason why the cloud might not be widely distributed, involving organizations located far from the campus. In fact, as virtual universities become more common, there is no reason that the core itself has to have a geographical focus.

To some degree, the core-in-cloud model could revitalize core academic programs by stimulating new ideas and interactions. It could provide a bridge that allows the university to better serve society without compromising its core academic values. But, like the entrepreneurial university, the cloud could also become a fog, scattering and diffusing the activities of the university and creating a shopping mall character with little coherence.

New Civic Lifeforms

Today, as knowledge becomes an ever more significant factor in determining both personal and societal well being, and as rapidly emerging information technology provides the capacity to build new types of communities, we might well see the appearance of new social structures (Benton Foundation, 1996). A century ago, stimulated by the philanthropy of Andrew Carnegie, the public library became the focal point for community learning. Today, however, technology allows us to link together public and private resources such as schools, libraries, museums, hospitals, parks, media, and cultural resources. Further, communities can easily be linked with the knowledge resources of the world through the Internet. Perhaps a new "civic life form" will evolve to provide community education and knowledge networks that are open and available to all. These might evolve from existing institutions such as libraries or schools or universities. They might be a physically located hub or virtual in character. However, they also might appear as entirely new constructs, quite different than anything we have experienced to date. Perhaps it is time to consider a blank sheet approach to learning, by setting aside existing educational systems, policies, and practices, and instead first focusing on what knowledge, skills, and abilities a person will need to lead a productive and satisfying life in the century ahead. Then, by considering the diversity of ways in which people learn, and the rich array of knowledge resources emerging in our society, one could design a new ecology of learning for the 21st Century.

The University a la Neuromancer (Gibson, 1984)

Ray Kurzweil's *The Age of the Spiritual Machine* provides a provocative vision of possible futures for our society by projecting Moore's Law–the exponential evolution of digital technology–over the next several decades. He suggests that over the next decade intelligent courseware will emerge as a common means of learning, with schools and colleges relying increasingly on software approaches, leaving human teachers to attend primarily to issues of motivation, psychological well-being, and socialization (Kurzweil, 1999).

More specifically, Kurzweil speculates that by the end of this decade, although schools are still not on the cutting edge, the profound importance of the computer as a knowledge tool will be widely recognized. Many children will learn to read on their own using their personal computers before entering grade school. Within two decades, most learning will be accomplished using intelligent software-based simulated teachers. To the extent that human teachers do teaching, the human teachers are often not in the local vicinity of the student and will be viewed more as mentors and counselors than as sources of learning and knowledge.

Within three decades (2030), Kurzweil suggests that human learning will primarily accomplished using virtual teachers and enhanced by the widely available neural implants that improve memory and perception (although not yet able to download knowledge directly, thereby bypassing formal education entirely). Although enhanced through virtual experiences, intelligent interactive instruction, and neural implants, learning still requires time-consuming human experience and study. This activity comprises the primary focus of the human species, and education becomes the largest profession, as human and nonhuman intelligences are primarily focused on the creation of knowledge in its myriad forms. Finally, a century hence, Kurweil speculates that learning will no longer the struggle it once was. Rather the struggle will be discovering new knowledge to learn.

While many would argue (indeed, many have argued) with Kurzweil's view of the future, it does illustrated just how profoundly different the future may be both for our society and our universities.

CONCLUDING REMARKS

As one of civilization's most enduring institutions, the university has been extraordinary in its capacity to change and adapt to serve a changing society. Far from being immutable, the university has changed considerably over time and continues to do so today. The remarkable diversity of institutions of higher education, ranging from small liberal arts colleges to gigantic university systems, from storefront proprietary colleges to global "cyberspace" universities, demonstrates the evolution of the species.

Today we have entered yet another period of rapid change, as an array of powerful economic, social, and technological forces are transforming social institutions such as the university. This impending revolution in the structure and function of higher education stems from the worldwide shift to a knowledge-based society. Educated people and the knowledge they produce will increasingly become the source of wealth for nations. The knowledge produced on our campuses is expanding exponentially with no slowing in sight.

As we look to the profound changes ahead of us, as we explore possible visions for the future, it is important to keep in mind that throughout their history, universities have evolved as integral parts of their societies to meet the challenges of their surrounding environments. This disposition to change is a basic characteristic and strength of university life, the result of our constant generation of new knowledge through scholarship that, in turn, changes the education we provide and influences the societies that surround us. In a very real sense, the university is both driving and being driven by technological, social, and economic forces at work throughout the world.

This propensity of universities to change is nicely balanced by vital continuities, especially those arising from our fundamental scholarly commitments and values and from our roots in democratic societies. While the emphasis, structure, or organization of university activity may change over time to respond to new challenges, it is these scholarly principles, values, and traditions that animate the academic enterprise and give it continuity and meaning. An integral part of the life of the university has always been to evaluate the world around us in order to adjust our teaching, research, and service missions to serve the changing needs of our constituents while preserving basic values and commitments. We must always bear in mind those deeper purposes of the university that remain unchanged and undiminished in importance. Our institutions must remain places of learning where human potential is transformed and shaped, the wisdom of our culture is passed from one generation to the next, and the new knowledge that creates our future is produced.

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