On Becoming a Scholar/Researcher in the Digital Age

I. Powerful New Tool that are Changing the Nature of Research

The goal of this introductory chapter is to provide both a sense of what research is all about and how it is being enhanced and reshaped by emerging information technology. The process of research, the discovery or creation of new knowledge, involves a range of functions, e.g., observations of the natural world, accessing current knowledge bases, interacting with colleagues, testing hypotheses through experimentation or simulation, and distributing results. All of these activities are being affected in profound ways by new technologies that change the way in which knowledge is acquired, stored, integrated, transmitted, and applied. These are dramatically changing the practices both of research scientists and engineers and research institutions.

Introduction. New digital tools are revolutionizing the conduct of research, just as they are recasting business and leisure. At a pace set by Moore's law, it grows easier every day to gain access to information, and easier to manipulate and communicate that information. These tools are vastly improving the productivity of research, but in doing so they challenge nearly every tradition of academic research. Academic institutions and individual researchers will need to change the ways they do things. Constraints on inquiry will need to be removed. Traditional norms of conduct will come under attack. [They already have!]"

> Rapidly evolving technologies are dramatically changing the way we collect, manipulate, and transmit information. In the last three 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. 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.
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> 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. The applications of such new knowledge forms challenge the creativity and intent of authors, teachers, and students. Technology such as computers, networks, HDTV,

ubiquitous computing, knowbots, and other technologies may well invalidate most of the current assumptions and thinking about the future nature of the university.

(Wm. Wulf) The hardest thing for people to understand about information technology is the effect of its exponential rate of improvement. For the last four decades, the speed and storage capacity of computers have doubled every 18-24 months; the cost, size, and power consumption have become smaller at about the same rate. The bandwidth has increased a thousand-fold in just the last decade, and the traffic of the network continues to grow at 300% to 500% annually. For the foreseeable future, all of these trends will continue; the basic technology to support them exists now.

(Wm. Wulf) To my knowledge there has never beena similarly rapid, sustained change in technology, especially one with such broad social application. We need to work harder to imagine the impact of future computers and networks. Thinking about the current ones can be misleading; it is all to easy to assume that something won't change just because today's technology doesn't support that change.

B. Examples. As engaging illustrations of the difference digital tools make to the process and incentives of research, the chapter will include hypothetical examples, such as:

- How much faster would Watson and Crick have described the DNA molecule if they had today's digital tools? (Or would Rosalind Franklin, the crystallographer, have gotten there first?)
- What about Newton's discovery of the laws of motion?
- Or Einstein's thought experiments leading to the general theory of relativity?
- A story about collaboration in the extreme (perhaps the 200-author paper from an accelerator experiment).
- An anecdote illustrating the problem of archiving digital results. (This piece might note the importance of recent congressional moves to require public disclosure of data and results of federal funded research.)
- The use of large-scale simulation in understanding natural phenomena, (global climate modeling, galactic dynamics)
- New ways to store and manipulate massive amounts of data, (data warehouses, virtual reality simulations)
- New methods for distributing the results of research, (Net publishing, algorithm distribution)
- The most dramatic transformation will shake the foundations of scholarship in the liberal arts
- The humanist can now explore hypotheses and visualize relations that were previously lost in the mass of information sources.

- Electronic "hypertext" books and jouranls are emerging, with more vigor and with more effect on their disciplines than their counterparts in the sciences.

C. Hyperlinks for the Web Edition. This chapter (and the others) should include a variety of hyperlinks, including (a) internal links that provide background information and references, and (b) links to actual Internet sites that illustrate the wealth of information sources and tools and/or the ethical and scientific concerns raised by the digital environment for research. [Note that the Internet links present the problem of updating and replacing obsolete links.]

II. Practices and Processes (Tools and Opportunities)

This chapter should discuss the impact of information technology on each phase of the research process, both in terms of research practice and perhaps even on the fundamental research paradigms used in particular fields. Here the stress should be on the changing nature of practice in research, the tools that investigators will be using, and the skills they will need. It probably should be organized to parallel the research process.

A. Introduction. Digital tools (networks and on-line databases) are transforming the ways researchers investigate, collaborate, and publish. The explosion of information technology means that modelers, theoreticians, and experimentalists can work together more closely and productively, because their tools (digital sensors, simulation, networks, and databases) are converging. Distance is no longer a barrier to collaboration; whether your collaborator is down the hall or across the globe makes little difference. Disciplinary and institutional boundaries (and loyalties) are blurring.

But these new tools—because they are so powerful and easy to use—can be abused by the unsophisticated or dishonest. They must be systematically tested and validated. Protecting the integrity of research will require vigilance and ingenuity (and perhaps new professional institutions for information management).

(Wm. Wulf) We must at least consider that a change in techonology, a change that will facilitate the flow of our essential commodity, information, might provoke a change in the nature of the enterprise.

(Wm. Wulf) The easy examples are those that simpy automate what was once done manually; the reduction of data, the control of instruments, etc. The profound applications, howver, are those that lead to entirely new areas of research and new methods of investigation, and thus to science that was not and could not be done before, e.g.

- the final proof of the four color conjecture
- analysis of molecules that have not been synthesized
- measuring the properties of a single neuron by growing
- it on a silicon chip
- watching a model of galaxies collide

- letting a scientist "feel"t he forces as a drug docks in a protein

B. The Process of Research in a Digital Environment. Every stage of the process of research is being transformed by new digital tools and information resources:

1. Observation and inquiry
2. Creativity and analysis

    Integrative (synthesis) vs. reductionist (analysis) skills
    IT-based tools

    There is also increasing pressure to draw research topics more directly from worldly experience rather than predominantly from the curiosity of scholars. Even the nature of knowledge creation is shifting somewhat away from the *analysis of what has been* to the *creation of what has never been*—drawing more on the experience of the artist than upon analytical skills of the scientist.

3. Collaboration

    The most dramatic impact on our world today from information technology is not in the continuing increase in computing power. It is in a dramatic increase in bandwidth, the rate at which we can transmit digital information. From the 300 bits-per-second modems of just a few years ago, we now routinely use ten megabit-per-second local area networks in our offices and houses. Gigabit-per-second networks now provide the backbone communications to link local networks together, and with the rapid deployment of fiber-optics cables and optical switching, terabit-per-second networks are just around the corner.

    As a consequence, the nature of human interaction with the digital world—and with other humans through computer-mediated interactions—is evolving rapidly. We have moved beyond the simple text interactions of electronic mail and electronic conferencing to graphical-user interfaces 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 "avatars," to interact in a virtual world with those of our colleagues.

    This is a very important point. When we think of digitally mediated human interactions, we generally think of the awkwardness of e-mail or perhaps videophones. But as William Wulf puts it, "Don't think about today's teleconference technology, but one whose fidelity is photographic and 3-D. Don't think about the awkward way in which we access information on the network, but about a system in which the entire world's library is as accessible as a laptop computer. Don't think about the clumsy interface with computers, but one that is both high fidelity and intelligent."[1] It is only a matter of time before information technology will allow human interaction with essentially any degree of fidelity we wish—3-D, multimedia, telepresence. Eventually, we will reach a threshold of fidelity sufficient to allow distance education (and most other human activities) that will be comparable to face-to-face interaction

Within discipline; multidisciplinary

The process of creating new knowledge—of research and scholarship—is also evolving rapidly away from the solitary scholar to teams of scholars, perhaps spread over a number of disciplines. Indeed, is the concept of the disciplinary specialist really necessary—or even relevant—in a future in which the most interesting and significant problems will require "big think" rather than "small think"? Who needs such specialists when intelligent software agents will soon be available to roam far and wide through robust networks containing the knowledge of the world, instantly and effortlessly extracting whatever a person wishes to know?

Institutional, disciplinary, international
Communication technologies
Collaboratories

Perhaps we should pay more attention to developing new learning structures more appropriate for the evolving information technology. One example would be the "collaboratory" concept,[2] an advanced, distributed infrastructure that would use multimedia information technology to relax the constraints on distance, time, and even reality. It would support and enhance intellectual teamwork. There is a growing consensus that the next major paradigm shift in computing is in the direction of the collaboratory. Not only research but also a vast array of human team activities in commerce, education, and the arts would be supported by variants of this vision. Perhaps some form of the collaboratory is the appropriate infrastructure ("tooling") for the "learning organization" becoming popular in the business world; perhaps it is the basis for the world universities in the next century. It could well become the generic infrastructure on which to build the work place of the emerging information age.

Beyond automated drill, the obvious application of IT is telepresence, the possibility of involving remotely sited individuals in a seminar, for example.

Virtual reality—the use of visual, audio, and tactile sensations to create a simulated total sensory experience—has become common both in training and simulation and in gaming. But researchers are more likely first to make use of distributed virtual environments,[3] in which computers create sophisticated three-dimensional graphical worlds distributed over networks and populated by the representations of people interacting together in real time. Such software representations of people in virtual worlds are known as avatars. Here the goal is not so much to simulate the physical world, but to create a digital world more supportive of human interaction. The software required for such distributed virtual environments is social in nature. It is not so much designed to simulate reality as to enable conversation and other forms of human collaboration.

4. Experimentation and simulation
   Remote instrumentation
   Supercomputing

   Scientists now routinely talk of computation as the "third modality" of scientirfic investigation, on a part with theory and experimentation. There is increasing pressure to draw research topics directly from worldly experience rather than predominantly from the curiosity of scholars.

5. Data archiving and access
   Data repositories, digital libraries

   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—has already moved 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 role of the library is becoming less that of collecting and more that of a knowledge navigator, a facilitator of retrieval and dissemination.[4] In a sense, the library and the book are merging. One of the most profound changes will involve the evolution of software agents, collecting, organizing, relating, and summarizing knowledge on behalf of their human masters.

   This tendency of digital information to multiply and propagate rapidly through digital networks can also be a challenge. Already the vast scale of the Internet and the access it provides to vast storehouses of information threaten to overwhelm us. As anyone who has "surfed the Net" can testify, it is easy to be amused but usually difficult to find exactly what you need. Further, living and working in a knowledge-rich—indeed, knowledge-deluged—world will overload our limited human capacity to handle information.

The Net is already a complex and interesting organism, something which has evolved far beyond the comprehension of any human. It is more than just a medium incorporating text, graphics, and sound. It incorporates ideas and mediates the interactions among millions of people. It can do things no human has enough knowledge to explain.

As a result, it will become necessary to depend on intelligent software agents to serve as our interface with the digital world. Many already use primitive constructs such as filters for electronic mail or web-crawlers to search through databases on the Net. But with the use of artificial intelligence and genetic algorithms, one can imagine intelligence agents dispatched by a user to search the digital networks for specific information. These agents can also represent their human user, serving as avatars, in mediating the interaction with the agents of other human users.

6. Publication and dissemination
   - Desktop tools
   - Electronic journals
   - Documentation and validation

III. Resources and Infrastructure To Support Research?

Here the focus should be on the IT (or digital) resources that are necessary to support the research process. This section can be organized under headings that indicate who is responsible for providing and maintaining the infrastructure: "Local Infrastructure" (including academic departments and universities), "National Infrastructure," and "World [or "Community"] Infrastructure."

A. Introduction. Research in the digital age requires a new kind of infrastructure—digital libraries and databases, access to networks, adequate communications bandwidth, and various support services. These resources are growing cheaper and more widely accessible by the day. But they will not provide themselves. Traditional power relationships, built on ownership of these resources, are certain to be eroded by the expansion of a digital research environment.

The responsibility for (and control of) many elements of the research infrastructure remains to be determined. Will the authority of academic departments be eroded in a research environment in which networks (national resources) are valued more than the workstations and other instruments that serve as nodes on those networks? Will the growing use of remote access instruments reduce the power of academic institutions, as researchers organize themselves in virtual institutions centered around major instruments and facilities?

> An infrastructure of data archives is vital to the secure progress of research. At the same time, digital data tend to be fleeting, evanescent, and harder to archive than the traditional paper publications, which are stable in content and durable.

(Wm. Wulf) Electronic books are not like paper books. They will not be a simple linear presentation of static information. They contain animation and sound. They let you "see the data" behind a graph by clicking on it. They let you navigate thorugh the information in ways that suit your purposes rather than the authors. They won't contain just referenes to the source material but the source material itself--the critique of the play will "contain" its script and its prerformance. They will let one annotate and augment the documents for use by later readers, so making it a living document.

(Wm. Wulf) Note the impact of the Thesearus Lingue Graeece on the classics, a database that includes all Greek Literature from Homer through th fall of Byzantium.

(Wm. Wulf) They will also be far more portable. If you could lug the entire library of Congress to the beach, you might be tempted to set aside your book.

(Wm. Wulf) Libraries

For thousands of years the focus of libraries has been on the containers of information, books. The role of librarians has been to build the collection. But in the future a library will not "collect". Electronic information can be communicated virtually instantaneously, so its source location is irrelevant. Instead of a hoarder of containers, the library must either become the facilitator of retrieval and dissemination or be relegated to the role of a museum.

If we project far enough into the future, it is not clear whether there will be a distinction between the library and the book. It will take some time to build the web, and especially to incorporate the paper legacy, but the value of a seamless mesh of information will doom the discrete, isolated volume.

The merger of the book and the library will drive another merger... that percipitated by devolving disciplinary boundaries. Knowledge isn't inherently compartmentalized; ther eis only one nature, there is only one human record. The division of the sciences into physics, chemistry, and so on is a human imposition, as is the division into history, english, and antropology.

Of course, disciplines are complex and idiosyncratic social structurs that will not easily dissolve. However, much of the exciting work lies at the boundaries of traditional disciplines, and we now have a technology that facilitates incremental accretation of knowledge at these interstices.

Finally, the book today is passive; it sits on a shelf waiting for us to read and interpret it. While there is an intellectual thrill in discovery and interpretion, passivity of the text is not required for that. One of the profound changes in store for libraries is that parts of their collection will be active, software agents collecting, organizing, relating, and summarizing on behalf of their human authors. They will "spontaneously" become deeper, richer, and more useful as they talk to one another.

B. Local (Institutional) Infrastructure. Research institutions (mainly universities and departments) are responsible for local infrastructure (such as campus networks, personal computers for students, and software). Academic departments generally provide instruments and facilities for research, and control their use. [WHAT ABOUT COMPANIES?]

Expertise and support (IT specialists, librarians, etc.)
Personal computing and communication
Software
Local area networks

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

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

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

In the past, technology has been a capital expenditure for universities. In the future, higher education should conceive of information technology as an investment.

Invest in “Big Pipes”

While the processing power of computers is continuing to increase, of far more importance to universities is the increasing bandwidth of communications technology. Both Internet access to off-campus resources and “intranet” capability to link students, faculty, and staff together are the highest priority. The key theme will be connectivity, essential to the formation and support of digitally mediated communities.

Universities are straining to keep up with the connectivity demands of students. Today’s undergraduates are already spending hours every day interacting with faculty, students, and home while accessing knowledge distributed about the world. Simply keeping pace with an adequate number of modem ports to meet the demands of off-campus students for access to campus-based resources and the Internet is overloading many universities. Installing a modern on-campus network—a “wire plant”—has become one of the most critical capital investments faced by the university.

The Internet itself is evolving rapidly as a result of various efforts. University research initiatives such as the Internet II project and broader federal efforts such as the Next Generation Internet or the National Information Infrastructure projects are contributing to this growth. This will compel universities to move rapidly to keep pace with the bandwidth of available backbone networks.[5]

Strive for Multi-Vendor, Open Systems Environments

Universities should avoid hitching their wagons to a small set of vendors. As information technology becomes more of a commodity marketplace, new companies and equipment will continue to appear. The great diversity in needs of various parts of the university community also will demand a highly diverse technology infrastructure. Humanists will seek robust network access to digital libraries and graphics processing. Scientists and engineers will seek massively parallel processing. Social scientists will likely seek the capacity to manage massive databases, e.g., data warehouses and data mining technology. Artists, architects, and musicians will require multimedia technology. Business and financial operations will seek fast data processing, robust communications, and exceptionally high security. And the list goes on . . .

It will be an ongoing challenge to link together these complex multi-vendor environments. They are characterized not only by different equipment used for varying purposes, but also diverse software and operating systems. For this reason, it is important to insist on open-systems technology rather than relying on proprietary systems. Fortunately, most information technology is moving rapidly away from proprietary mainframes ("big iron") to client-server systems based on standard operating systems such as Unix , Linux, or Windows-NT. There is a vast array of commercial off-the-shelf software available for such open systems.

As digital technology becomes increasingly ubiquitous, universities will face the challenge as to just what components they will provide and which should be the personal responsibility of members of the community. While networks and specialized computing resources will continue to be the responsibility of the university, other digital devices such as personal communicators will almost certainly be left to the student, faculty, or staff member.

Universities will need to strive for synergies in the integration of various technologies. Beyond the merging of voice, data, and video networks, there will be possibilities as well to merge applications across areas such as instruction, administration, and research. The issue of financing will become significant as institutions seek a balance between institution-supported central services and point-of-access payments through technologies such as smart cards.

Cultural Issues

Although making the necessary investment in the technology infrastructure and support services will strain university budgets, the most critical challenges may involve the culture of the university. We have already noted that there will be great diversity in the technology needs of various disciplines and programs, and these needs will likely not be aligned with financial resources. There is an important strategic issue facing most universities: Should the evolution of information technology be carefully coordinated and centralized or allowed to flourish in a relatively unconstrained manner in various units? Perhaps because of our size and highly decentralized culture, at Michigan we have long preferred a "let-every-flower-bloom" approach. We have encouraged islands of innovation, in which certain units are strongly encouraged to move out ahead, exploring new technologies, and perhaps moving into leadership roles and serving as pathfinders for the rest of the university.

Another cultural issue involves just who within the university community will drive change. Many of our entering students—and soon, possibly most—have computing skills far beyond those of our faculty. Our experience has been that it will not be the faculty or staff but rather the students themselves that will lead in the adoption of new technology. As members of the digital generation, they are far more comfortable with this emerging technology. They also represent a fault-tolerant population, willing to work with the inevitable bugs in "Version 1.0" of new hardware and software.

Although information technology today is used primarily to augment and enrich traditional instructional offerings, over the longer term it will likely change the learning paradigm. It will likely change the paradigms of scholarship. And it will certainly change the relationship between faculty and staff and the university. For example, as the university is viewed increasingly as a "content provider," with the evolution of the commodity classroom, learning ware, and the like, we will need to rethink issues such as ownership of faculty course materials.

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."[6] 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.

C. National Infrastructure. A national infrastructure—long-distance communications, nationally significant instruments (many accessible by digital networks), software libraries, and high-performance computer facilities—will be needed. It is appropriate for these resources to be provided at the national level, by government, consortia of universities, or industries (or combinations of these institutions). They must be maintained and calibrated.

Digital libraries and databases
Wide area networks
High-end computing and storage
On-line instrumentation access
Preservation of data

There is an important implication here. Information technology may allow—perhaps even require—new paradigms for learning organizations that go beyond traditional structures such as research universities, federal research laboratories, research projects, centers, and institutes. If this is the case, we should place a far higher priority on moving to link together our students and educators among themselves and with the rest of the world. This would be a modest investment compared with the massive investments we have made in the institutions of the past—university campuses, transportation, and urban infrastructure. It is none too early to consider an over-arching agenda to develop deeper understanding of the interplay between advanced information technology and social systems. In some future time we may have the knowledge to synthesize both in an integrated way as a total system.

Global [Research Community] Infrastructure. Advancing information technology will tend to globalize the enterprise of research. Collaborators increasingly often will be in separate countries, often continents apart. They will increasingly use remotely sited automated instruments and facilities. Standards for communications protocols, data acquisition and data processing software, and data preservation must be applied globally, to ensure that data and results are comparable, reliable, and verifiable. These tasks extend beyond the limits of national sovereignty; they must be carried out by the research community (often acting alone, and sometimes through national governments as signatories to international technical conventions).

Virtual organizations/communities
Collaboratories
Software and communications standards

IV. New Expectations and Responsibilities

Researchers—students, faculty, staff—should expect a certain level of support both from host institutions and other bodies such as federal agencies and state government. This should include technology infrastructure (computing and networks, hardware and software), technical and administration support, and policies and procedures. In a similar manner, institutions should also expect that researchers will comply with appropriate institutional practices and procedures, e.g., scientific integrity and intellectual property disclosure. Together, these form a linked network of expectations and responsibilities that characterize research in the digital age.

A. Introduction. The very advantages of the digital environment for research call into question many of the traditional norms of academic education and research. Every element of the research enterprises—students, faculty, research groups, universities, and the public and private sponsors of research—will be shaken by the new opportunities. Traditional relationships and funding patterns will shift. Power will shift, too. The research community, worldwide, must fight to preserve its core values—freedom of inquiry, the relationship between teacher and student, knowledge as the ultimate goal—while letting dead traditions slip.

For example, digital publication of research results clouds the question of priority, a traditional scientific value. Because results can be disseminated so easily and widely, many researchers find it tempting to preempt the publication process, with its rigorous peer review, to stake their claims before the broader public and the press. The risk is that announcing poorly digested or incomplete results can impede progress.

Universities will need to change their incentive systems to encourage the full development and use of new digital tools. Promotion and tenure boards—weighted toward senior faculty—today tend to penalize junior faculty members who do untraditional things such as algorithm development. Computer science departments, in fact, are among the most conservative in all of academia when it comes to rewarding and promoting applications.

The very tools that make collaboration and communication easier and more efficient have their dark sides. Plagiarism is easier to do, and harder to detect. Students already can buy research papers on the Internet—a practice that is very difficult to combat.

Other ethical problems arise with the growing tendency toward secrecy in many rapidly advancing and economically significant disciplines, countering the opportunities for wider communication afforded by information technology. The norms of education and the traditional mentorship relationship of teacher and graduate student are challenged by intrusion of the profit motive. Under the Bay-Dole Innovation Act of 1980, faculty members and universities may hold patent rights to inventions made with federal funds. In some cases, for financial advantage, they may be tempted to withhold information from students and colleagues—damaging careers and impeding the progress of science.

B. Faculty
    - Expectations
    - Responsibilities

C. Students
    - Expectations
    - Responsibilities

D. Staff
    - Expectations
    - Responsibilities

E. Institutions (universities, laboratories, corporations)

F. Government
    - State
    - Federal

G. Legal Issues

H. Reward Structure

I. Sharing and Reuse (Software)

J. Intellectual Property

K. Professional Development

L. Tools and Talents

M. Private Sector Relationship

Restriction of publication

Ownership

Funding

N. Preservation

V. Best Practices, Pitfalls, and Opportunities [“Building Institutions to Match Our New Capabilities”?]

This chapter should contain an array of issues concerning the use of information technology in research, in part presented through vignettes and examples. This might be organized from the perspective of the researcher and the institution.

A. Introduction. Researchers and the public will need to build [are building?] new institutions to accommodate the enormous capabilities, and the corresponding risks, of digital tools. Expanding educational opportunities at all levels will strain the structure of today's academic institutions. So will the increasingly global collaborative networks. Reliable and secure data archives will be needed. The community of researchers and scholars needs to address a host of ethical, legal, and operational issues, and develop institutional structures that can manage them.

B. Individuals
Personal education and updating
Ethical Issues
Legal Issues
Electronic publishing
Documentation of research results
Verification and reliability of software
Teams (communication, collaboration, sharing resources)

C. Institutions
Building adequate IT infrastructures
Providing education and training for faculty and staff
Promotion and reward practices and policies
Legal issues
Intellectual property ownership

VI. Emerging and Unresolved Issues ["Surprise as a Way of Life"?]

This concluding chapter should alert both researchers and institutions to unresolved issues that could affect research.(Many, if not all, will have been discussed in the earlier chapters.) It should be forward-looking and basically positive, but acknowledge the extent of the risks and challenges. Below is the slightly reorganized list from the panel.

A. Introduction. Because the environment for research is changing so pervasively and rapidly, we are likely more often to be taken by surprise. The explosion of new capabilities will continue to bring astonishing new results at an ever-increasing pace. But it will also bring risks and challenges, which researchers will need to help society address.

B. Social and Organization Change in the Research Enterprise
- C. The Impact of Scale
- D. Interaction of the University with Industry and Government
- E. Market Pressures and Competition

F. Competing Allegiances
G. Ownership of Intellectual Property
H. Attribution of Credit
I. Enhanced Opportunity and Access vs. Wider Gaps Between Haves and Have-nots

Clearly, 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. As the constraints of time and space—and perhaps even reality itself—are relieved by information technology, will the university as a physical place continue to hold its relevance?

In the near term it seems likely that the university as a physical place, a community of scholars and a center of culture, will remain. Information technology will be used to augment and enrich the traditional activities of the university, in much their traditional forms. Yet 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.

It is our challenge collectively as scholars, educators, and leaders to build greater public understanding and support for these extraordinary tools, which are so key to our nation and the world as we prepare to enter the age of knowledge that is our future. We are on the threshold of a revolution that is making the world's accumulated information and knowledge accessible to individuals everywhere. This has breathtaking implications for education, research, and learning.

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.[7] It could well be that our present institutions, such as universities and government agencies, which have been the traditional structures for intellectual pursuits, may turn out to be as obsolete and irrelevant to our future as the American corporation of the 1950s. There is clearly a need to explore new social structures that are capable of sensing and understanding the change and of engaging in the strategic processes necessary to adapt or control it.

A Final Quote (Jacques Attali, Millennium)

> *"The impact of information technology will be even more radical than the harnessing of steam and electricity in the 19th century. Rather it will be more akin to the discovery of fire by early ancestors, since it will prepare*

> *the way for a revolutionary leap into a new age that will profoundly transform human culture*."

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

[2] "All the World's a Lab," *New Scientist* 2077, (April 12, 1997) 24-27.

[3] "Distributed Virtual Environments," *IEEE Spectrum*, (1996).

[4] "Books, Bricks, and Bytes," *Daedelus* Vol. 125, No. 4, (Fall, 1996).

[5] For information concerning the Internet II project, see the website for the University Corporation for the Advancement of Internet Development at http://www.internet2.edu;.

[6] William J. Mitchell, *City of Bits: Space, Place, and the Infobahn* (Cambridge: M.I.T. Press, 1995) http://www-mitpress.mit.edu/City_of_Bits.

[7] For an excellent introduction to scenario planning in this area, see the website http://www.si.umich.edu/V2010 for the Vision 2010 project, directed by Daniel E. Atkins, and sponsored by the Carnegie Foundation for the Advancement of Teaching.