

Higher Education Alert

The Information Railroad Is Coming

Wm. A. Wulf

It's New Year's Day, 1895. My name is Hans. For seven generations my family has made the finest buttons in the region, using the good local horn.

Today I learned that the railroad is coming to our village. My friend Olaf says that cheap factory buttons will come on the trains, but they will never compete with my craftsmanship.

I think he is right, and wrong. They will come, but they will compete with my buttons. I must make some choices. I can become a distributor for the new buttons, or I can invest in the machinery to make buttons and export them. Or, closest to my heart, I can refine my craft and sell exceptional buttons to the wealthy.

My family's business is dead. I cannot stop the train; I must change.¹

WITH 20/20 HINDSIGHT, we can easily accept the demise of a quaint industry—or, more accurately, the demise of

a quaint method of manufacture, distribution, and sale. The button industry still flourishes, of course. Even the craft of handmade buttons is doing well, if local art fairs are any indication. However, the nature of the industry changed dramatically as technology allowed the manufacture, distribution, and sale of vastly less expensive but highly serviceable buttons.

How does this relate to higher education? Colleges and universities are in the information business, and the information railroad is coming! Let me be clear. Higher education will flourish, just as does the button industry. If anything, the need for advanced education is increasing in multiple dimensions. A greater percentage of the world's population needs more education to be productive in an increasingly technological workplace. The period during which particular skills are relevant is shortening, and so the need for "lifelong learning" is increasing. The level of skills necessary to function at the frontier of knowledge is rising as well, resulting in a corresponding increase in the need for advanced degrees.

Higher education is not in danger. Although its roots are millennia old, the university² has changed before. In the seventeenth and eighteenth centuries, scholasticism slowly gave way to the scientific method as the way of knowing truth. In the early nineteenth century, universities embraced the notion of secular, "liberal" education. In the late nineteenth century, they included scholarship and advanced degrees as integral parts of their mission. After World War II, they accepted an implied responsibility for national security, economic prosperity, and public health in return for federally funded research.

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Though the effects of these changes have been assimilated and now seem natural, at the time these developments involved a profound reassessment of the mission and structure of the university as an institution.

We would be wise to conduct a similar reassessment today—to ask whether the particularly quaint ways that we manufacture, distribute, and deliver higher education will survive the arrival of the information railroad. They may, but I don't think so. I think there will be major changes—changes not only in the execution of the mission of colleges and universities but in our perception of the mission itself. Moreover, as noted by Marye Anne Fox, chancellor at North Carolina State University, the changes will be profound, rapid, and discontinuous.³ We must engage in an intellectually honest exercise of understanding, as best we can, the implications of information technology on our institutions. The university is simply too important to our society to evade this discussion. To begin, we need to answer two questions: First, is the technology for higher education really going to change all that much? Second, is the button analogy truly valid?

The Changing Technology

One of the hardest things for most people to understand is the compound effect of the exponential rate of improvement of information technology. For the last four decades, both the speed and the storage capacity of computers have doubled every

eighteen to twenty-four months; the cost, size, and power consumption have become smaller at about the same rate. The bandwidth of computer networks has increased at an even faster rate (a thousandfold in just the last decade), and the traffic on the Internet continues to double every one hundred days. For the foreseeable future, all of these trends will continue; the basic technology to support them exists *now*.

To appreciate the compound effect of this rate of improvement, consider a 1949 article in *Popular Mechanics*. The author wrote about ENIAC, the first fully electronic digital computer: “Where a calculator like the ENIAC today is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and perhaps weigh only 1.5 tons.”⁴ Today, I carry in my briefcase a computer that is one hundred times faster than the ENIAC. This is not my laptop computer or even a PDA. It’s a holiday card that plays a tune when opened! The computer in the card costs about 25 cents. The computer card is intended to be opened once, to make the recipient smile, and then to be discarded. Yes, its technology really is 100 times faster than that of the 30-ton ENIAC.

The extraordinary pace of evolution in information technology is likely not only to continue for the next several decades but to accelerate. During the four decades that I have been in computing, someone has always observed that there are physical limits—that this exponential pace of change can’t go on forever. That’s obviously true, but the slowdown is not on the horizon, and it’s not going to spare us from rethinking the uni-

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versity. Thus the wise thing to do is to imagine a *range* of scenarios that might result; none of them will be exactly right, but the discipline of thinking about them will improve our ability to respond to what does actually happen. The only really dangerous course is to assume that something won't change because today's technology does not support that change. This assumption is a guaranteed route to being unprepared.

How might the changing technology be used to change higher education and scholarship? That seems like a simple question, but as both an academic and a computer scientist, I don't know the answer. Ironically, although we can predict the improvement in technology with great precision, predicting the societal impact of that improvement has been difficult. Knowledge—its creation, storage, and communication—is part of the essence of a university. The ability to process information, the “raw stuff” of knowledge, thus sits at the heart of what the university is and does. A technology that alters that ability by orders of magnitude cannot avoid having an impact on at least how the university fulfills its mission—and possibly on the mission itself.

Buttons and Universities

Certainly some specifics of the button parable are inappropriate here. For example, universities don't make a product that can be mechanically mass-produced. But it would be a mistake to dismiss the similarities in the two industries. Both are highly

labor-intensive and depend on the skill of master craftsmen. Both are regional, requiring collocation of the producer and the customer. Both have long traditions. Both contribute to the prestige of their locale. Both formed powerful guilds to protect the masters. And now, like the button industry previously, the university is facing a technological revolution.

Universities share at least some of the attributes of other vertically integrated industries as well. They “manufacture” information (scholarship) and occasionally “reprocess” it into knowledge or even wisdom; they distribute the information (books), warehouse it (libraries), and retail it (teaching). Information technology has already changed each of these processes; changes in the future will be much greater.

Scholarship

The impact of information technology on scientific research is both apparent and pervasive. Scientists routinely talk of computation as the “third modality” of scientific investigation, on a par with theory and experimentation. The easy examples are those that simply automate what was done manually: the reduction of data, the control of instruments. The profound applications, however, are those that lead to whole new areas of research and new methods of investigation and thus to science that was not and could not be done before: arriving at the final proof of the four-color conjecture; analyzing molecules that have not been synthesized; measuring the properties of a single neuron by growing it on a silicon chip; watching a model of

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galaxies collide; and letting a scientist “feel” the forces as a drug docks in a protein. These applications have transformed the nature of scientific investigation; they have led to questions that would not even have been asked before.

But science is not where we see the most dramatic impact. Despite a National Research Council report that I helped co-author—a report that paints an expansive image of the transformation of scientific research—I believe that a more dramatic transformation is about to shake the foundations of scholarship in the liberal arts.⁵ Humanists, more than scientists, will lead the way to innovative applications of technology in the university.

The comfortable stereotype of humanists as technophobic just doesn’t apply anymore. The availability of both text and images in electronic form, coupled with the processing power of modern computers, allows the humanist to explore hypotheses and to visualize relations that were previously lost in the mass of information sources. The presentation of humanists’ scholarly results in electronic form is progressing even more rapidly. Precisely because of the complexities of the relationships they need to present, because of the subtle webs of relation and inference they need to express, electronic “hypertext” books and journals are emerging. Indeed, they are emerging with more vigor and with more effect on their disciplines than are their counterparts in the sciences.

We all expect scientists and engineers to use computers in their research, but the notion that information technology could be central to humanistic scholarship is a bit more star-

ting—at least it was to me. In talking about the application of computers to historiography and the theory of text, I became aware of the larger issues that I am trying to raise here. These issues also formed the basis for the founding, in 1992, of the Institute for Advanced Technology in the Humanities (IATH) at the University of Virginia.⁶ The goal of IATH is to explore how information technology can be used to support humanistic scholarship. As with the sciences, there are applications that simply automate what had been done manually—creating concordances, for example. Again, the more profound applications enable scholars to ask and answer questions that would not even have been asked before. They also allow a shift in the sociology of scholarship—from individual scholars to teams, for example.

Books

The nostalgic say, “I don’t know anyone who prefers to read from a computer screen, and besides, you can’t take a computer to the beach.” They are right, and yet so profoundly wrong.

There are two fallacies here. The first is the assumption that electronic books will contain only text and thus will be essentially the same as paper books—just presented differently. In reality, it will not be possible to reproduce an electronic book on paper. Electronic books will not consist of a simple linear presentation of static information. They will contain animation and sound. They will let the user access the data behind a

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graph by clicking on it, and they will allow the user to try alternative analyses of that data. They will contain multidimensional links so that the user can navigate through the information in ways that suit his or her purpose rather than the author's. They will not contain references to sources but will contain the source material itself—for example, the critique of a play will “contain” its script and performance. They will have tools that let the user manipulate the equations, trying the equations with other data or modifying them to test scientific hypotheses. They will let the user annotate and augment the documents for later readers, making the electronic book a “living document.”

The second fallacy is presuming the use of today's technology. We should not be talking about reading these electronic books from today's screen. The advantages of the electronic book will be so strong that engineers will make the “form factor” of the medium humane. Flexible “digital paper” already exists, with a resolution about the same as the paper you are reading right now. Why would anyone lug around several heavy books when something with the size, clarity, and weight of a single one contains them all? And I mean them *all*—all the books in the Library of Congress. I *will* take my computer to the beach!

Libraries

For thousands of years, the focus of libraries has been on the *containers* of information—on books. The information itself

was the domain of the library's users, not the library. Information technology turns that premise on its head and, with it, many of the deepest unstated assumptions about the function of a library.

Tracing back to Alexandria and before, the principal objective of librarians has been to build a collection—to amass a set of materials. But in the future, a library will not “collect.” Electronic information can be virtually communicated instantaneously, so its source location is irrelevant. Instead of being a hoarder of containers, the library must become the facilitator of retrieval and dissemination.

If we project far enough into the future, it's not clear whether there is even a distinction between the library and the book. The “technology” of the bibliographic citation pales by comparison with the hypertextual link—to the ability to gain immediate access to the full referenced source and hence to browse through the context of the reference. It will take a long time to build the Web, and especially to incorporate the paper legacy, but the value of a seamless mesh will eventually doom the discrete, isolated volume.

As the library and the book merge, another merger will evolve—one precipitated by devolving disciplinary boundaries. Knowledge is not inherently compartmentalized: there is only one nature; there is only one human record. The division of the sciences into physics, chemistry, and so on and their further subdivision—into physical and organic chemistry, for example—are human impositions, as are the disciplinary divisions of history, English, and anthropology. For very practical

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reasons, paper texts have mirrored this artificial division, but those practical reasons evaporate in the electronic world. Clearly, the “long pole in the tent” will be human rather than technical; disciplines are complex and idiosyncratic social structures that will not easily dissolve. However—and here I can speak with only the smallest authority on technological disciplines—much of the most interesting work is already happening at the boundaries of traditional disciplines. That’s not new news; Albert Einstein opined that most of the important science lay at the interstices of traditional disciplines. What is new is that we have technology that facilitates the incremental accretion of knowledge at these interstices.

Finally, the book as we know it is passive; it sits on a shelf, waiting for us to read and interpret it. Although there is an intellectual thrill in discovery and interpretation, passivity of the text is not required for that. According to Marvin Minsky, a professor at MIT, people in the future will find it hard to imagine that there used to be libraries in which the books didn’t talk to each other. 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.

Teaching

The notion of computer-aided instruction has been touted for 30 years. But it has had relatively little impact, especially at

the college and university level. The reason is obvious: chalk and overhead projectors have been perfectly adequate technology, given the current nature of scholarship and texts.

If, however, most professors are using information technology in their scholarship, and if the results of that scholarship can be exhibited only by using the technology, the classroom will follow rapidly. How will it follow? Not, I think, by the “automated drill” scenario we have come to associate with Computer Aided Instruction, or CAI.

Beyond automated drill, the obvious application of technology is telepresence—the possibility of involving remotely sited individuals in a seminar, for example. Again, we must not think in terms of today’s teleconferencing technology; as the fidelity of communication improves, telepresence will certainly happen. Whereas now it is a big deal to bring a leading authority to campus, and access to the person is often limited to research colleagues and graduate students, this will not be the case in the future. The technology will give an increased number of undergraduates access to these authorities. Removed from the overhead of travel, what professors would not cherish a few hours each week with the bright young minds at a remote Harvard or Yale?

These are interesting but mundane applications—mundane in the sense that they do not change the educational process in a deep way. More fundamental is the opportunity to involve students in the *process* of scholarship rather than merely its results. The ideal is to teach students to think, not merely to learn rote facts, but the truth is that students are forced

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through the linear sequence of the text, course, and curriculum before being evaluated to see whether they “know enough” (facts) to embark on a scholarly project (think). Students are mostly limited to thinking about what has been thought before. They can’t be asked to explore new hypotheses because of the practicalities of access to sources and the sheer grunt work of collecting and analyzing data.

Information technology eliminates these “practicalities.” A hint of this kind of change can be detected in the effect of the *Thesaurus Linguae Graecae*. The release of this database, which now includes virtually all Greek literature from Homer through the fall of Byzantium, has had a fundamental impact on scholarship and education in the classics, enabling undergraduates to participate in research previously reserved for graduate students.⁷ A more personal example for me is a project by the Civil War historian Ed Ayers at IATH. Ed’s project, *The Valley of the Shadow*, details the lives of some 10,000 individuals—about half from opposite ends of the Shenandoah Valley, from communities that were virtually identical except for being on different sides of the Mason-Dixon Line. Richly hyperlinked, *The Valley of the Shadow* provides an invaluable resource for students and scholars alike, but it has also irrevocably changed Ed’s courses on the Civil War. He can no longer tell a simple linear story because his students have too much access to the messiness of real history. Instead, Ed now concentrates on historiography—the process of historical scholarship—using the Civil War and *The Valley of the Shadow* as resources.⁸

One cannot leave the subject of teaching without at least mentioning “productivity”—the current code word used to capture the public’s frustration with the rising cost of higher education and with the perceived emphasis on research over teaching. The simplistic answer is to have professors spend more time in the classroom and less in the laboratory. The irony, of course, is that one of the oldest figures of merit for any school—a low student/teacher ratio—is diametrically opposed to “productivity.” Information technology is not going to resolve this tension; it can, however, shift the focus of the discussion to the effectiveness and quality of the student-teacher interaction rather than the number of contact hours.

Indeed, in modest ways technology has already shifted that focus. For example, by removing the barriers of both space and time, e-mail has given students much greater access to their professors than ever before. Involving students in the process of scholarship and giving them greater access to international authorities are more profound shifts, but I suspect that these are still pale precursors of what can and will be done in the future.

The University as Place

It’s not a comfortable thought, but we must at least consider that a change in technology, a change that will facilitate the flow of the university’s essential products—information, knowledge, and even possibly wisdom—might provoke a change in the *nature* of the enterprise. One approach to inves-

tigating such a possibility is to examine unstated assumptions; here I would like to examine just one.

Historically a university has been a *place*. The stone walls of St. Benedict's cloister at Monte Cassino were the bastion that provided defense against the physical and intellectual vandals of the Dark Ages. In American colonial times, Thomas Jefferson's Academical Village provided access to scholarly materials as well as collegial interaction by collocation. In contemporary times, scholars flock to scientific instruments and library collections. And where the scholars assemble, the students follow.

In his influential nineteenth-century essays on "the idea of a university," Cardinal John Newman wrote: "If I were asked to describe . . . what a University was, I should draw my answer from its ancient designation of a Stadium Generale. . . . This description implies the assemblage of strangers from all parts in one spot." Cardinal Newman then goes on at some length to emphasize that books are an inadequate source of a true education, which must be buttressed with discourse—something that is feasible only if the discussants are collocated. Thus the notion of being "in one spot" is, to him, essential to the very definition of the university. He asks: "Else, how can there be any school at all?"⁹

But with the possible exception of teaching, to which I'll return in a moment, I believe that information technology obviates the need for the university to be a place. With powerful, ubiquitous computing and networking, each of the university's functions can be distributed in space and possibly in time.¹⁰ Remote scholarship and authoring are the direct analogues of

telecommuting in the business world, and are every bit as appealing. Academics tend to identify more closely with their disciplinary and intellectual colleagues than with their university. Freed from the need to be physically present in classroom, laboratory, or library, they will likely find grouping by intellectual affinity more appealing. But even then, physical grouping may be unnecessary and even undesirable when such things as location preference are taken into account.

Some disciplines that do need shared physical facilities—say, a telescope—suggest the need of a “place.” But large scientific instruments such as telescopes and accelerators are already run by consortia and are shared by faculty from many universities, and many of these facilities do not require the physical presence of investigators. They could be “online” and accessible via the network. Indeed some instruments, such as those for space physics at Sondre Stomfjord in Greenland, are already accessed on the Internet. Thus, the university as place is already irrelevant to at least some scientific scholarship.

As with instruments in the sciences, direct access to archival materials is necessary for some humanistic scholarship—but it is hardly necessary for all and certainly not all of the time. Much excitement, for example, was caused by the recent release of the images of the Dead Sea Scrolls even though the scrolls themselves are not accessible to most scholars. If anything, the ubiquitous information infrastructure will provide greater access to archival materials to a much larger set of scholars—access of a quality that’s “good enough” for most purposes.¹¹

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As for teaching, we don't really know whether it can be distributed or not. I do know that even asking the question is considered heretical by some good teachers—teachers who contend that physical eyeball-to-eyeball contact is necessary. Others, including me, contend that although we need feedback to teach well, there is a threshold of fidelity. Thus, there is some finite amount of information required to produce an adequate representation of the parties. If true, when that threshold of fidelity is reached electronically, high-quality teaching *will* be distributed. The fallacy in Cardinal Newman's reasoning was only that he could not imagine quality discourse at a distance—but that is precisely what the technology enables.

Can universities, which have existed for millennia—which are indeed icons of our social fabric—disappear in a few decades because of technology? If you doubt it, check on the state of the family farm. In particular, will the “university as place” disappear? I expect not: the reduced importance of place does not imply *no* place. But just as farming has been transformed, so will the university. The everyday life of both faculty and students will be very different.

Changes

I have more questions than answers as to the shape of the new university. Now that I've laid the groundwork, let me pose a few of them:

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- I believe that higher education not only will survive but will flourish. Still, are the choices for universities, like the choices for Hans, to become (1) mass-market manufactures or distributors or (2) niche tutors to the privileged? Alternatively, is there some other model more appropriate to academe?
- Does it make sense for every university to support the full complement of disciplines, or should universities specialize and share courses in cyberspace? This sharing might be a natural consequence of aggregation by disciplinary affinity, for example.
- The decision by MIT to make its courseware freely available has stimulated other universities to similar benevolence. Will these decisions enhance the ability of smaller and non-U.S. schools to deliver high-quality instruction in deeply technical areas?
- Might professors affiliate with several institutions or become “freelance” tutors to telepresent students? Indeed, might we “return to the future” of tele-itinerant scholar/tutors?
- Might some employers (and hence students) prefer a transcript that lists with whom certain courses have been taken rather than where? Presumably, a student who has taken a computer-architecture course from Professor David Patterson (at Berkeley) and a compiler course from Professor Ken Kennedy (at Rice) would at least appear to be better trained than one who has taken all courses at just one of these schools.

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- What about alumni and sports? Surely the allegiance of alumni to their alma mater has a great deal to do with place and is often cemented on fall football weekends; since the support of alumni is essential to universities, isn't that very human need sufficient to perpetuate the university as place? Perhaps. But broad alumni support has become essential to the financial model of the university only in relatively recent times. Moreover, alumni associations and large sports programs were created to support the university as place, not the other way around.
- Will universities merge into larger units, as has occurred in the corporate world, or will the opposite happen? I can argue either side of this question. On the one hand, if a university is not (just) a place, its major remaining function is certification—it certifies the competence of the faculty, programs, and graduates. We don't need thousands of organizations to do that. On the other hand, I can envision many small colleges being empowered to provide a broad curriculum via telelocation while retaining the intimacy so valued in small liberal arts institutions. I don't know anyone who really *wants* the impersonal ambiance of a mega-university. The current size of these universities seems optimized for the physical infrastructure, not for either education or scholarship.
- For-profit universities have flourished recently, and several have high customer-satisfaction ratings not only

because they are convenient for working students but also because they have developed curricula and pedagogy that take advantage of the most modern understanding of how people learn. Might we see the outsourcing of large introductory courses, which most research-oriented faculty don't like to teach anyway? If so, what happens to the cross-subsidy from these courses, the funding that supports small, upper-level undergraduate and graduate courses?

- Might the technology revive the talented amateur's participation in the scientific community? Except for a few disciplines like astronomy, the talented amateur has largely disappeared from scholarly discourse in science and engineering. Surely such individuals still exist, but they are isolated from the community of scholars. How can or should the university reengage them?
- What about the various businesses that have affiliated with universities—the university press being an especially poignant example? My guess is that each of these will be forced to rethink its principal mission, and many will be irrelevant.
- Will more (most?) universities serve a global clientele, and how would that change square with the publicly supported university in the United States? In particular, will private universities have greater flexibility to adapt to globalization, thus dooming the public universities?
- Does the function of socializing young adults, a function that perhaps remains a reason for the university as place,

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need to be coupled with the educational function, or could it be done better by some form of social service?

That there will be changes seems inevitable. But change implies opportunity, and in this case, it implies the opportunity to improve all facets of what we do in the academy. The challenge is to anticipate and exploit the changes. Procrastination and inaction are the most dangerous courses for colleges and universities in this time of continued technological evolution. A dispassionate contemplation of the what-if's and a careful examination of often unstated assumptions are the best preparation for preserving the critical functions that higher education institutions provide to society.

Colleges and universities are in the information business, and the information railroad is coming!

NOTES

The thoughts presented here are derived in part from an earlier article, "Warning: Information Technology Will Transform the University," *Issues in Science and Technology* (summer 1995), and in part from a set of insights at a workshop, "The Impact of Information Technology on the Future of the Research University," cochaired by myself and Jim Duderstadt at the National Academies in January 2001. The premise behind both my 1995 paper and the 2001 workshop was the same—namely, that the rapid evolution of information technologies presents numerous challenges and opportunities for

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universities but that these are not well understood by academic administrators or their faculty.

1. I owe the idea for this parable to remarks by Dr. Jeff Ullman at a meeting of the heads of Computer Science and Engineering Departments at Stanford University in July 1994.

2. The word *university* is used generically in this article to refer to colleges, universities, and other traditional, nonprofit forms of higher education.

3. Marye Anne Fox, speaker on “The Impact of IT on the Organization and Structure of the University” panel, National Academies workshop, January 2001, <http://www.researchchannel.org/program/displayevent.asp?rid=917>.

4. See http://www.popularmechanics.com/science/time_machine/2001/12/hits_and_misses/index4.phtml (by subscription only).

5. *National Collaboratories: Applying Information Technology for Scientific Research* (Washington, D.C.: National Academy Press, 1993).

6. See the IATH Web site: <http://www.iath.virginia.edu/>.

7. Beverly T. Watkins, “A Data Base of Ancient Greek Literature Revolutionizes Research in the Classics,” *Chronicle of Higher Education*, Vol. 38, No. 4, Sept. 18, 1991.

8. Edward L. Ayers, “The Valley of the Shadow: Two Communities in the American Civil War,” 2001, <http://jefferson.village.virginia.edu/vshadow2/>.

9. From Chapter 2 of John Henry Newman, *Rise and Progress of Universities*, Volume 3 of *The Works of Cardinal John Henry Newman* (Notre Dame, Ind.: University of Notre Dame Press, 2001).

10. An example is the work, sponsored by the Sloan Foundation,

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on asynchronous learning networks (ALNs). See Ralph E. Gomory, "Internet Learning," January 11, 2000, http://www.eng.yale.edu/sheff/Gomory_talk.htm.

11. One of the interesting sociological changes we have observed at IATH is that humanistic scholarship has become a year-round activity; whereas scholars could previously access material only during a summer trip to the place where the materials were housed, they can now access them online during the rest of the year.

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