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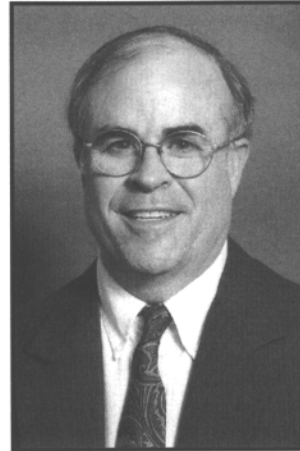
“Information Technology and Chemical Engineering Education: Evolution or Revolution?”

by Thomas F. Edgar

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Recent efforts include the development of model-based control algorithms using nonlinear programming. Dr. Edgar also co-directs the Texas-Wisconsin Modeling and Control Consortium. Edgar has co-authored the textbooks Optimization of Chemical Processes (McGraw-Hill, 1988) and Process Dynamics and Control (Wiley, 1989). A Director of AIChE (1989-92), and past chair of the Computing and Systems Technology Division, Dr. Edgar received AIChE's Colburn Award in 1980 and Computing in Chemical Engineering Award in 1995.

Thomas F. Edgar was the 1997 President of AIChE.

“Information Technology and Chemical Engineering Education: Evolution or Revolution?”

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ABSTRACT

Society is undergoing a transformation from the Industrial Age to the Information Age, which is having a profound impact on both industry and academia. Universities have moved to networked environments, which permit faculty, staff, and students to have access to the World Wide Web anytime and anywhere. Educators are using information technology (IT) to enhance the quality of education, with an increased focus on the learning process; interaction with students is limited only by bandwidth. Chemical engineering research will be impacted by IT in a number of ways, e.g., increased use of advanced computing to replace experimentation, access to digital libraries and use of intelligent agents for literature searching, and the formation of networks of faculty, who will share ideas and data over the internet on a daily or hourly basis (a virtual collaboratory). Faculty will share courses over the Internet, write electronic books, and perhaps even form a virtual chemical engineering department using courses from multiple departments. Seers predict that IT will have a comparable impact to that of the printing press in the 15th century. Whether this change will be evolutionary or revolutionary may become moot, since it will affect all institutions, not just higher education.

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The digital revolution driving societal change is as significant as the invention of the printing press or the Industrial Revolution. Since the introduction of the transistor and the integrated circuit, people have not just been doing things differently; they have been doing quite different things. Nicholas Negroponte [1] of MIT's Media Lab describes it as the difference between atoms and bits. Atoms are about physical things and bits are about intangible information. As the emphasis shifts from one to the other, almost every aspect of society is altered.

In manufacturing, business, and finance, such structural change has already transformed workplaces and marketplaces. Throughout the world, information technology (IT) and telecommunications are increasing the flow of information, expanding the possibilities for collaboration across distances. The pace of change is accelerating in virtually every field of human endeavor. As an example, consider the time span to reach maturity for the following technological inventions once they were first commercialized in this century:

the telephone	50 years
personal computer	15 years
World Wide Web	3 years

It is interesting to note that the last two items were not invented to meet a social need but came out of curiosity-driven research.

The Changing Environment for Higher Education

Universities are now confronted with a rapidly changing environment and a growing realization that ignoring change is no longer an option. The challenge facing higher education is to prepare for an uncertain future and to provide a technology-rich environment where students can obtain the continuously changing knowledge and skills needed to shape that future. The national transition to a knowledge-based service economy also will have an effect upon higher education. Similar to what is happening in the private sector, academic institutions need to offer instructional and support services oriented to the customer's convenience.

The days of considering technology simply as an enhancement for the instruction of students, a tool for computational academic scholarship, or the means to the efficient operation of the institution are past. Today, information technology is becoming a mission-critical, central foundation to the future of higher education. Nearly every significant change in the learning environment requires some application of information technology, from distributing instruction beyond the classroom, providing access to knowledge too recent to be available through traditional publishing, or creating simulations for student manipulation.

As stated by Dolence and Norris [2], "Society is undergoing a fundamental transformation from the Industrial Age to the Information Age. Those who realign their practices most effectively to Information Age standards will reap substantial benefits." Over the next decade, many research universities will broaden their current student clientele to include degrees, courses, certifications, and training

made more easily available and customized through information technology. Competing for students, faculty, and especially financial resources in this environment will require a richer vision of education and a restructuring of the organizations, strategies and policies required to achieve it. Table 1 illustrates some of the paradigmatic changes that have begun to occur.

During the next decade, new patterns in the economy, demographic changes, and government spending will force a large number of colleges and universities to restructure fundamentally, as many U.S. business firms and local and national governments have been doing for the past decade or more. Funding for public universities has been stagnant in many states, if not in outright decline in real dollar terms. Nationally, the tuition and fee costs of a typical college education are increasing faster than the rate of inflation. Various external constituencies, namely governments, businesses, parents, and students, are demanding improved quality and reduced costs, and question the ability of colleges and universities to provide students with an education that leads to a good job upon graduation and

Table 1. Changing Educational Paradigms due to Information Technology (adapted from [3])

Old Paradigm	New Paradigm
Take what you can get	Courses on demand
Academic calendar	Year-round operations
University as a city	University as idea
Terminal degree	Lifelong learning
University as ivory tower society	University as partner in society
Student = 18 to 25 year old	Cradle to grave (K to Gray)
Books as primary medium	Information on demand
Student as a cost factor	Alumni as lifelong revenue resource
Competition is other universities	Competition is everyone
Student as a responsibility	Student as a customer
Delivery in a classroom	Delivery anywhere
Multi-cultural	Global
Bricks and mortar	Bits and bytes
Single discipline	Multi-discipline
Institution-centric	Market-centric
Government-funded	Market funded
Technology as an expense	Technology as differentiate

a rewarding career [4]. As students pay a larger percentage of the cost of their college education, they are looking for accountability and guarantees.

The job market is transforming rapidly to demand a trained work force which is technologically literate, able to engage in continuous lifelong learning, and

adaptable to a series of careers. The linkage between educational levels and personal economic well-being has been clearly documented, which in turn translates in the aggregate into regional and national economic development [5]. Thus the demand for information technology-based teaching and learning programs will probably grow greatly over the next decade.

The expectations and needs of incoming students for digital facilities and curricula are being shaped by a world of pervasive microprocessors and telecommunications which is foreign to the formative educational experience of most faculty and administrators. Duderstadt [5] has suggested that 21st century university students will be different than the ones we have experienced up to now. The new digital generation is not intimidated by computers, demands interaction, views learning as a plug and play experience, won't read a manual but learns through experimentation, and may not learn best through the linear seriatim process. In fact, their brains may be wired differently, at least in a neural sense. Over the next ten years, as personal computers, fiber optics, and digital networks expand into homes and businesses, new students will expect the ubiquitous availability of information technology in higher education.

Collaboration among students and faculty will also be facilitated by information technology. Collaboration means enabling virtual teams to share knowledge, projects, and processes across geographical and organizational boundaries. Collaboration utilizes asynchronous and synchronous modes and includes email, videoconferencing, shared information, discussions, real-time collaboration, tracking and routing, workflow applications, and custom business and academic applications. New tools from companies such as IBM and Microsoft will provide these capabilities in the near future. While these tools were designed principally for industry, they have nearly the same relevance for universities, and can be used as part of managing an academic course, either residential or at a distance.

More technological changes are coming in the near future [6], including

- wireless, handheld devices (digital assistants)
- household LANS, including audio, video, and appliances
- 60% of the public shopping on-line
- use of e-commerce growing 40% per year
- integrated voice, data, and video networks (the telephone is an extension of your computer)
- voice communication with computers
- 3-D representation of visual humans (avatars) in customer service

These changes are indicative of the increased levels of disintermediation that humans may prefer vs. interaction with another human. The meteoric rise of amazon.com in the book (now video and CD) market is one important sign of changing consumer preferences, with autos, drugs, insurance, clothing, travel, and computers and accessories next on the list. A certain percentage of people

will still prefer to go to a bookstore, browse, and drink Starbucks coffee, but clearly not everyone will behave the same. So why do we expect higher education to be immune from these trends? The suggestion here is that education may be offered in several forms, letting the customer (the student) decide how education will be acquired.

Technology – enhanced Teaching and Learning

Technology-enhanced learning environments can be active agents that interact with students, expand the information horizons of students, and enable effective interactions across both time and distance. Use of multimedia systems in teaching and learning is growing rapidly. Multimedia is the use of a computer to present and combine text, graphics, audio and video, with links and tools that let the user navigate, interact, create and communicate. Multimedia is emerging as a basic skill that university graduates must possess in the 21st century. This technology can interact with students in new ways, e.g., to give students experiences through simulations of logical and physical systems.

In the traditional teaching approach, a human instructor fulfills several roles. He/she assists in the acquisition and structuring of information, primarily through organized lectures where the instructor interacts with a group of students. Experience with processes relevant to the course is typically obtained either through outside assignments that are evaluated via the student products or through supervised laboratories where the students are guided through the steps of the processes by instructors. Interaction of instructors either with individuals or with small groups can spark the insights that allow information to grow into knowledge. Information technology can play a significant role in assisting in the presentation and acquisition of information, reinforcing it, and in leading students through the processes of structuring of information into knowledge.

The only active agents in traditional instruction and learning are the human instructor and the students. Human instructors typically fulfill the roles discussed above because traditional information media (books, printed material, etc.) are essentially passive. Information technology can implement active agents. An active agent not only presents information but also interacts with the student to evaluate his/her levels of understanding with appropriate responses. Knowledge-based and simulation systems can interact with students on a level which approximates intelligence, at least in the context of well-structured information. Information technology systems can present information and its structure with all of the richness of human instructors through the use of multimedia technology.

Information technology enables a new form of teaching and learning in which pure lecturing to passive students can be replaced by an integrated lecture/laboratory situation. In this mode the instructional material is presented on the computer with the conceptual elements explained and supplemented by the instructor's lecture. At the end of the presentation, a laboratory exercise is executed on the computer under the supervision of the instructor to give experience in application of the concepts or processes. This approach is embodied in the studio teaching method developed recently at Rensselaer Polytechnic Institute [7].

To make this example more concrete, consider a chemical engineering example in a separations course. Suppose the topic of instruction is the impact of operating variables in a distillation column. The lecturer presents the concepts followed by demonstration of the equations and simulation results, perhaps augmented by McCabe-Thiele plots. The students immediately prepare examples following the presented directions, using laptops they bring to class or with shared workstations in the classroom. This cycle may be repeated several times in a given lecture. This interactive mode of intermingled lecture and laboratory has a very high reinforcement value. The computer system is used to mediate the rate at which information is presented to each individual student.

Note that the lecturer is not removed from the cycle. While the laboratory exercises are going on, the lecturer can move among the students, looking over their shoulders and serving as an advisor and facilitator. Teaching and learning becomes more a one-on-one or small group exercise and less a remote lecture exercise. The instructor is transformed from being a “sage on a stage” to a “guide on the side.” This integrated lecture/laboratory mode of instruction is now being used in industrial training, particularly in the software industry. Learning and cognitive studies have shown definitively that technology used to personalize learning via immediate feedback has significant impact, as shown in Table 2. The range of cognition and retention actually achieved depends upon nature and tone of remediation.

Table 2. Retention for Different Learning Strategies
(source: Andersen Consulting)

Teaching others	90%
Learn by Doing	75%
Discussion Group	50%
Demonstration	30%
Audio/Visual	20%
Reading	10%
Lecture	5%

There are wide-ranging debates in academia about the role of technology in education. Advocates of technology-enhanced education state: “technology-based instruction improves student learning and makes it more interesting. It prepares students to live and work in the digital age.”

Contrarians contend:

“technology-enhanced learning is unproven and does not impact achievement. It costs more and is not a panacea. Self-paced education was tried in the 1970s and it did not work. Besides, employers will hire team-oriented creative people and teach them the necessary computer skills.”

There is one irrefutable conclusion regarding use of technology, namely anything that enhances the learning process improves quality, but quality should be determined by both learners and instructors. Integrating information technology into instruction at most universities will require careful planning, experimentation, and assessment over the next 10 to 20 years to effect a major change in teaching and learning. This will not be an easy process. Many faculty members and administrators believe that gradual evolutionary change over a period of thirty years or so is the best path to transformation. However, responding to evolutionary technological change may be an inefficient way to manage a comprehensive research university. Simply adding technology in an incremental way to curriculum and instruction will not reduce costs, although it may slightly enhance the classroom experience.

In 1994, Vartan Gregorian, now President of Harvard University, offered the following observation about the quandary of a university president in leading the information technology-driven transformation in teaching and research:

“On some days the president will be beset by the prophets of the new technology. They will grab you by the arm and feverishly press upon you the revelation that things are completely different now! Then on other days you will be dogged by the self-styled protectors of ancient wisdom and old ways. What is good is not new and what is new is not good, they will whisper darkly. To both you will give the same answer: some things change, and some remain the same – our identity, values, principles, and goals are the same; the technological accidentals we use to exemplify these values in the late 20th century will vary. In fact these must vary, for we cannot remain the same in our essentials unless we change, in our accidentals, to meet the new circumstances.”

The traditional modes of teaching and research will still dominate ten years from now, but changes at the perimeter can and should occur. The paradigm shift offered by technology-enhanced learning can be illuminated by comparing two models of student learning:

- Traditional (linear) model: a sequence of topics are covered in a series of lectures, held in classrooms at weekly intervals, with homework practice in between. All teaching is done synchronously. Everyone proceeds at the same pace, regardless of their interests, prior experience, talents, or demands on their time. At the end, grades indicate the level of comparative or relative achievement attainable in the fixed time period for the course. The faculty member is the gatekeeper and arbiter of quality.
- Assess/Learn/Master (nonlinear) model: there are a series of check points (learning stations) with a starting point and ending point for each, which is guarded by a certifier to assess student competence against well-defined

standards (validated outcomes). The student can visit any station to learn certain topics in an order consistent with his or her current knowledge, so it is learner-constructed. Trial certifications and self-assessment tests are taken by the student periodically to check progress. Everyone who completes the course and passes the certification test gets the same grade (“competency”): This approach is called nonlinear because of the ability to jump to different topics and take different paths enroute to the final objective. Learning can take place asynchronously where the instructors and student may be separated by time and place. In this model the richness of the latest instructional technology tools are exploited in order to ensure learning outcomes and student satisfaction comparable to the traditional approach.

Not every course or cohort of students will benefit from the second approach. However, the nonlinear model may figure prominently in addressing new issues that education customers are now raising, e.g., requests for post-baccalaureate professional education, access to asynchronous, Internet-based learning, distance education, wider ranges of student preparation, certification of practical specialized competencies, collaboration in education and research, and competition with private organizations entering the education market. In order to change the current teaching and learning environment, universities and departments will need to:

- reconsider faculty rewards and incentives (e.g., promotion and tenure, compensation), especially given the extra time and effort required to develop courses enhanced with technology,
- find resources to provide technical support (infrastructure), classroom facilities and training/release time to faculty who want to adopt new methods,
- find the appropriate balance between productivity increases, faculty overloads, and quality of education, including the incorporation of off-campus students into residential classes.

Distance Education – So Near Yet So Far

Distance education is the combination of technology-based education with technology-based delivery of a complete course. Distance education has been defined as any formal approach to learning in which a majority of the instruction occurs while educator and learner are at a distance from one another. There are a variety of delivery techniques for education, depending on the time-space coordinates that are employed (see Figure 1).

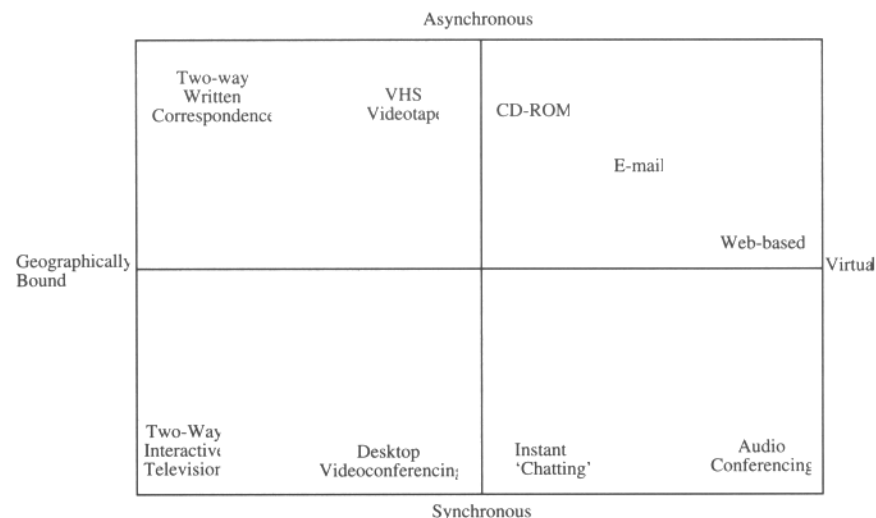


Figure 1. Distance Education Technologies Categorized by Space and Time Variables

Hardly a week goes by that there is not an article appearing in most newspapers or magazines about this subject. Distance education has been hyped as the quick fix to many of the problems of higher education, with the vague promise of delivering a higher quality of education at lower cost. Expensive regular faculty will not be needed, being replaced with part-time adjunct faculty, such as done at the University of Phoenix. There needs to be a more thoughtful approach to distance learning at research universities. Simply putting textual information on a web page is not an improvement in quality of education, comparable to correspondence courses as they have been traditionally offered.

Some aspects of using distance learning are appealing, and probably some middle ground can be agreed upon [8, 9]. Anyone who has listened to a Pavarotti CD but never heard the great tenor in person has certainly received a certain level of enjoyment (and perhaps inspiration). So the hardliners who suggest education can only be delivered in the traditional face-to-face mode are overstating their point. In addition, it is well-documented from teaching evaluations that not all classes taught at a university are of uniformly high quality. A student sitting in the last row of a large lecture class of several hundred students is certainly “at a distance” from the instructor. We ought to be seeking ways to enhance the classroom experience for residential students through use of distance education tools.

One model of where distance learning concepts could be used would be in a hybrid form, in which the web is used to deliver fundamental information that would otherwise be contained in lecture [10]. Class time could be reduced

somewhat, replaced by more informal meetings of a seminar type. This approach could be valuable in teaching introductory math and science courses (for example) to large numbers of students who may have quite different backgrounds, thus allowing students to move ahead at different speeds.

Another model that may have some economic attractiveness is the concurrent offering of residential classes and off-campus courses to industry. This could include advanced undergraduate courses and graduate courses. Such an approach has been used at several chemical engineering departments, such as University of Delaware, Lehigh University, and University of Texas. This provides a different type of revenue model, where faculty can receive extra compensation for the additional courseload. Another type of concurrent enrollment could have a course offered jointly by two or more universities, where students from several departments would take the course. This would expand a course with 10 or fewer students to one with say 20 students. It is not unreasonable to believe that faculty from around the U.S. could even form virtual chemical engineering departments in the future.

Distance education does appear to be a good fit for continuing education, where highly motivated, mature students will make sure they learn what is needed. Having such classes offered at a convenient time and place (asynchronous mode) is critical for professionals with full-time jobs, who need to update their skills and knowledge base in response to changes in the economy. This non-traditional student population is rapidly growing in the U.S. The availability of streaming media technology (audio and video) over the Internet eventually will make delivery of courses to personal desktop computers a reality. The faculty member's office then becomes the studio, which will make educational delivery at lower cost than with the interactive television mode.

Research

The digital science and information revolution is rapidly transforming the ways faculty and students conduct research, collaborate, solve problems, and disseminate knowledge. The integration of computers, telecommunications, audio, video, multimedia, and other digital technologies creates a worldwide information environment that can be accessed easily from the laboratory, office, field, and home. In this new environment, supervision of dissertation or thesis research is sometimes carried out over a distance, where email and videoconferencing augment face-to-face meetings between a research student and members of the supervising committee. On the other hand, research utilizing laboratory experimentation requires a structured environment (e.g., well-equipped laboratories). Hence it is difficult to perform experimental research at a distance, although sharing of expensive specialized equipment through virtual connections will become more common in the future.

Consider the following vignette as indication of the future.

Faculty and graduate students of a midwestern university are carrying out a joint research project with Oak Ridge National Laboratories.

On the computer screens of the researchers are the working draft of a paper and presentation slides for the upcoming national colloquium. The final copies are due this week and they are using on-line videoconferencing and shared documents to work out the final details. Also on the screen are live images from a high resolution transmission electron microscope at Oak Ridge, clearly showing the atoms in their super thin metal experiment, with each participant able to position the view and magnification. The lively debate as to how best to present their findings continues over the Internet late into the night.

A review of the current literature shows how chemical engineering research is being impacted by information technology:

- molecular modeling: simulation of the effects of molecular structural properties such as stereochemistry in order to develop improved drugs, without having to resort to numerous chemical and analytical tests of the drug.
- materials science: prediction of the strength and toughness of a polymer (how well it resists cracking) and the number of defects when two dissimilar materials are combined in a composite material.
- process analysis: data mining where intelligent agents infer cause and effect from large databases.
- manufacturing: using simulation to design and operate efficient factories that manufacture high quality, just-in-time products as well as to understand and predict three-dimensional, time-dependent phenomena in process equipment.
- biology: coupling of different organ models to gain a holistic view of how organs function in health and disease.
- neuroscience: development of a complete structural and functional map of the brain, including the inner working of individual nerve cells.

It is suggested from the above examples that experimentally-oriented faculty in the future will rely more heavily on computational and visualization tools, possibly with less intensive capital investment in equipment and laboratory facilities. Experimentation is relatively more expensive to perform with today's stringent safety requirements.

Clearly information technology will impact the kinds of faculty hired by chemical engineering departments, and most faculty will need to stay up to date in some aspects of IT in order to carry out cutting-edge research. This suggests a greater need for training of faculty, not only in instructional tools, but also in research tools that are IT-based. One other impact of IT is the need to form interdisciplinary groups on campus in order to attack important, multi-faceted problems that involve advanced computing.

The increased use of data bases in research is leading to more interest in the field of informatics (information organization, storage, retrieval, processing, and

visualization) as one that cuts across a multitude of disciplines. This could be an area where groups in library science, computer science, bioengineering, and molecular biology, for example, could collaborate on real-time analysis using large data bases. Informatics could be used to access genomic databases in order to compare genes in healthy and diseased tissue, to identify new therapeutic targets, and to understand the impact of new drugs.

Changes in computer science and engineering will likely modify how research and scholarship are carried out in the 21st Century. This includes such items as:

- groupware for collaboration
- query of image content (vs. query of text)
- use of intelligent agents for searching the web
- speech synthesis and text to speech conversion

Advanced Networking

Many universities are now members of Internet 2 and have been awarded a grant from NSF to provide high bandwidth capabilities for faculty research and distance education, focusing on interactions between researchers at multiple universities. This may include, for example, digital libraries with audio and video content, collaboration and immersion environments, remote monitoring of experiments, and data-intensive applications. Over 150 US research universities are now members in a national network called Internet 2 (I2), that is dedicated to research and education. I2 is a nationally coordinated network architecture that offers vastly higher connection speeds and more reliable service. The charter university members have formed a new organization calledUCAID (University Corporation for Advanced Internet Development). This university consortium, together with a number of federal agencies and leading computer and telecommunications firms, design the network and develop applications for its use.

The larger “pipeline” – 100 to 1000 times faster than today’s Internet – allows the simultaneous transmission of voice, video, and data to enable distance learning, enhance digital libraries, and make possible new realms of on-line collaborative research. These higher-speed networks will enable a new generation of applications that support multimedia, scientific research, national security, distance education, and health care. For example, Universities are now piloting near term technologies such as two-way video to remote desktops. VCR-like replay of past lectures, modeling and simulation, collaborative environments, and on-line access to courseware are potential applications.

Multimedia aided by hardware and software advances is expanding the realm of applications of high performance computing and networking. Distributed multimedia technology is increasingly critical in applications, such as computer animation, navigation of image-intensive databases, and 3D virtual environments. New computing technology offers the opportunity for significant enhancements

in research productivity not available today. These areas are receiving new emphasis in 1999 in a multi-agency federal funding initiative called “Information Technology for the 21st Century.”

Collaboration

In the past it was common for a researcher to spend many years working on some difficult or esoteric problem, unaware that someone else was interested in the same thing. Collaborative tools now allow people to share results more regularly, on a daily or even hourly basis. William Wulf, President of the National Academies, first termed the global networking of faculty groups as a “collaboratory,” a merging of the words collaboration and laboratory. No longer is it a requirement that a department maintain multiple experts in a single field so colleagues can have face-to-face interaction in a specialized research area. In some cases, a faculty member’s ties to the collaboratory which is global in its makeup may be stronger than the connections to his or her own department or university. Independent scholars can use recently developed tools to see new patterns and trends, not just the facts but the contexts in which they arise, and share the results on-line without the normal journal publication delay. One such software tool for real-time collaboration is being developed at the University of Illinois (National Center for Supercomputing Applications) and is called Habanero. Some features of Habanero support multi-user tools for work groups, utilizing synchronous communication over the Internet even with low bandwidth modems (28.8 kb/s). These tools can be used on any computer platform that supports Java; see <http://www.ncsa.uiuc.edu/SDG/software/Habanero/>.

A number of agency-sponsored collaboratories on topics such as AIDS research, molecular structure, NMR spectrometry, health care, and space physics have already been established. The Space Physics and Aeronomy Research Collaboratory, based at the University of Michigan, allows space physicists access to data on the earth’s ionosphere, without having to leave their offices or laboratories. This collaboratory started in 1992 with the goal of giving researchers remote-control access to a single radar installation in Greenland that monitors the ionosphere. The system is now available to researchers via the world wide web (which was not established when the project was started). Additional data (digital libraries or data bases) are now available from four satellites and four other land-based radar installations. Researchers can also connect to supercomputers to compare the data with simulations with several computer models of the ionosphere (and “space weather” in general), as well as participate in real-time chat sessions. So this collaboratory has evolved from one focused on remote data collection to a forum for discussion and debate on-line.

As such collaboratories develop, a logical extension will be holding technical conferences on-line, with keynote lectures via webcasting, paper presentation and discussion, and even virtual vendor expositions. The Internet World Congress on Biomedical Sciences, held in December, 1998, was an experimental meeting termed a success. However, such virtual meetings will not totally replace face-to-face experiences such as the AIChE Annual Meeting but will augment these regular

events (hopefully with reduced cost, including a minimal registration fee). The electronic format will make such meetings even more accessible to faculty and graduate students with limited travel budgets. The question and answer sessions in technical sessions could become even more lively, since there is no time constraint on the Q&A period.

Digital Libraries and Publishing

Electronic publishing and the gradual replacement of paper-based modes for carrying out the business of higher education will certainly impact faculty and students in the future. We have seen the first wave of construction of digital libraries; both the American Chemical Society and Elsevier are being fairly aggressive in moving toward complete digitization of scientific and engineering journals, while AIChE has proceeded more cautiously. Clearly a user of the literature would find having access to the text of journal articles on one's desktop to be a tremendous productivity tool. The value of such digital libraries is greatly enhanced by having the ability to access references cited in the article, but this will be problematic until the "back issue" problem in technical journals has been solved. There have been some experiments such as JSTOR, a digitization project for a group of humanities and social sciences journals, funded by the Mellon Foundation. This involves scanning the contents of paper journals, and then libraries license the contents of JSTOR, at a price that is incremental to the cost of the paper-based journal. Publishers are not inclined to sell only the electronic version at a lower cost and give up current income levels with the standard subscription package.

Since faculty and students demand the electronic version when it is available, this means the costs of journal subscriptions will continue to rise, causing most university libraries to cancel some fraction of their subscriptions each year in order to hold their budgets roughly constant. The irony of this situation is that faculty and graduate students who provide most of the papers for a typical research journal must pay page charges to the publisher, who then sells that same material back to the university libraries. This is a cost cycle that clearly will be restructured in the future, and already a number of professional groups are beginning to take action on the problem. I believe that with the help of electronic commerce (i.e., credit cards processed over a secure connection), a transaction-based system where users pay for access to journals might make more sense in the future. Such fees might run from \$200 to \$500 per year for an active researcher. This is similar to the plan proposed by music publishers in dealing with technology changes such as MP3 music on the Internet.

The World Wide Web offers a nearly free mechanism for publishing, where faculty and graduate students can publish preprints of their research work (but not copyrighted papers that appear in journals). This could include M.S. and Ph.D. dissertations, such as done at a few universities today. ACS has taken a dim (but misguided) view of web publishing of research papers, and ACS journals currently refuse to accept articles that have previously appeared on the web. It is interesting that chemists have adopted such a stringent view, when almost all of the other

sciences have encouraged preprint publishing on the web. The differences seem to be cultural. In fact Los Alamos National Laboratories operates a server for the physics community (Journal of High Energy Physics) to encourage the exchange of information. Other societies such as ACM are devising mechanisms for handling submission, reviewing, and final publication of computer science manuscripts using a totally electronic approach, and are making original versions of the paper available for a limited period of time. In 1999 the National Institute of Health proposed to use the Internet to disseminate papers generated by biomedical researchers who have received NIH grants, thus saving millions of dollars in page charges and journal subscriptions.

There will be further developments in the rather confused world of electronic journal publication [11]. Several electronic journals started one year ago by MIT Press in areas such as computer science and neurology have not caught on, even though they had research leaders on the editorial boards. Some of the reasons behind this is that the prestige of a certain journal is historically-determined, so faculty are circumspect about submitting articles to a new journal without a track record, whether it is electronic or not. Considerations such as which journals have the greatest currency for gaining tenure are a factor. Because of economic constraints, few university libraries are willing to add new subscriptions, so the electronic journals must survive on individual subscriptions. New, unproven journals are unlikely to be included in various scientific indexes, such as that of Institute for Scientific Information (ISI); Chemical Abstracts tracks about 30 electronic-only journals. National efforts by AAUP and the Association of Research Libraries may lead to breakthroughs in the electronic publishing morass. Over one hundred research libraries have formed SPARC (Scholarly Publishing and Academic Resources Coalition) to increase market competition and reduce journal prices.

Electronic books may eventually replace part of the traditional book publishing market. The high cost of textbooks and the collective weight of five books in a backpack are certainly incentives for students to use electronic media in the future. Of course book reading is a social and cultural activity, and the touch and feel of a book is part of the experience. However, computer companies are developing devices that feel like a book but permit downloading of material from the web. So one electronic book could eventually access a large store of books. Two products (Rocket Book and Softbook) are now available, and technological enhancements will make them more user-friendly and cheaper in the near future. Both of these ventures are backed by an array of publishers. Carrying two pounds of electronics instead of twenty pounds of books or magazines would be attractive, assuming you can obtain the on-line version of such material. Eventually you will be able to download such content from the web.

One survey categorized the nature of the media (electronic vs. non-electronic) that will be used in 20 years as follows:

>65% likely to be read in electronic form: ads, newspapers, personal letters, catalogs, junkmail, reference, legal documents, memos, professionals, journals/reports/letters

<65% likely: magazines, nonfiction novels

This survey shows that while paperless communications will dominate, there still will be a place for the traditional paperback novel.

As a co-author of two chemical engineering textbooks with mainline publishers (McGraw-Hill and Wiley), I believe there is an opportunity to change the paradigm of textbook publishing over the next five to ten years, where the contents of a book would be entirely on-line. This would be advantageous for incorporating interactive exercises based on simulation in an integrated way, converting the traditional textbook into courseware that is much more comprehensive than the hard copy versions used today. Faculty can selectively incorporate parts of books into their courses. While most universities have taken a position of benign neglect regarding faculty writing textbooks (and have not claimed intellectual property rights), that view may change when courseware becomes the product, since such a package may be more valuable to a university. This should be an interesting development to watch in the future.

Concluding Remarks

I have attempted to paint a picture of how universities will be undergoing change during the next 10 to 20 years and how that will affect faculty and student processes. The compressed time scales that we are experiencing due to technological advances are referred to as "Internet Years," versus the normal metrics for time. While it is useful for academicians to cling to the fact that in many ways universities have not changed much in the past 200 years, clearly universities must adapt to maintain their core values. External forces may cause the evolution to in fact become a revolution. There are many possible paths to the future, and universities need to be exploring various options and be proactive in carrying out experiments and innovation, rather than merely hoping these external forces will go away.

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