INFORMATION TECHNOLOGY AND ChE EDUCATION
Evolution or Revolution?

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The digital revolution driving societal change is as significant as the invention of the printing press or the Industrial Revolution.[1] 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 impact of the World Wide Web in just the last three years. 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.[2] Academic institutions will need to offer instructional and support services that are more oriented to the student's desire to access such information at any time and from anywhere.

Over the next decade, many universities will broaden their current student clientele to include degrees, courses, certifications, and training all 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.

The expectations and needs of incoming students for digital facilities and curricula are being shaped by a world of pervasive microprocessors and telecommunications that is foreign to the formative education experience of most faculty and administrators. Duderstadt[3] has suggested that 21st century university students will be different than the ones we have previously enrolled. 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. There will also be new technologies available, such as wireless, handheld devices (digital assistants); household LANs, including audio, video, and appliances; integrated voice, data, and video networks (the telephone is an extension of your computer); voice communication with computers; and 3-D representation of visual humans (avatars) in customer service.[4]

These changes are indicative of the increased levels of disintermediation that humans may prefer vs. interaction with another human, as long as the quality of service is the same. The meteoric rise of amazon.com in the book (and 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

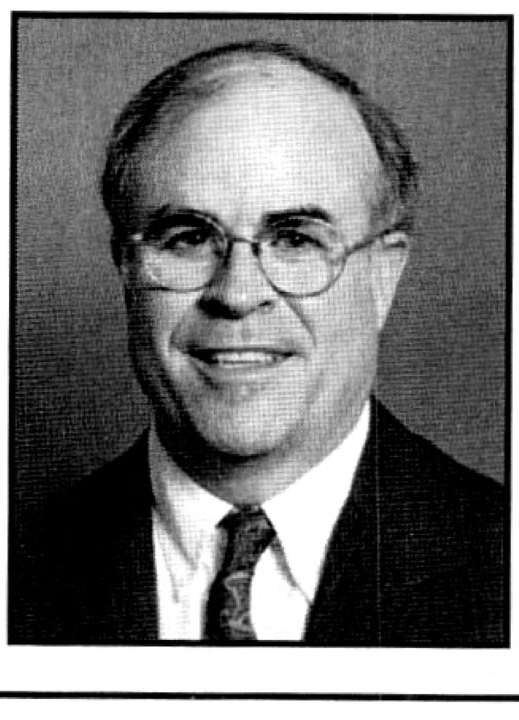

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TABLE 1
Changing Educational Paradigms Due to Information Technology

Old Paradigm	*New Paradigm*
Take what you can get	Courses on demand
Academic calendar	Year-round operations
University as a city	University as an idea
Terminal degree	Lifelong learning
University as ivory-tower society	University as partner in society
Student: 18 to 25 years 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
Multicultural	Global
Bricks and mortar	Clicks and mortar
Single discipline	Multidiscipline
Institution-centric	Market-centric
Government-funded	Market funded
Technology as an expense	Technology as differentiator

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 such systems in teaching and learning is growing rapidly. In such environments a computer presents and combines text, graphics, audio, and video, with links and tools that let the user navigate, interact, create, and communicate. This technology can interact with students in new ways, *e.g.,* 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. Alternatively, 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.

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. Information technology systems can present information and its structure with much of the richness of human instructors through the use of multimedia technology

Excellent teachers use varying lecture styles that actively engage students in the learning process. Information technology also allows a pure lecturing format to 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.[5] Other teaching models are being pursued by many universities, *e.g.,* those projects funded by the Pew Foundation (www.center.rpi.edu/PewGrant.html).

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 and 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 personalized learning via immediate feedback has a 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; you see conflicting views in almost every issue of the *Chronicle of Higher Education.* Faculty are taking sides in the debate; for example, see the report by the University of Illinois System (www.vpaa.uillinois.edu/tid/report), written by a committee chaired by Professor John Regalbuto, a chemical engineering professor.

There is one irrefutable conclusion regarding the 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 ten to twenty years. 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.

Responding to evolutionary technological change may be an inefficient way to manage a comprehensive university, however. Simply adding technology in an incremental way to curriculum and instruction will not save instructional costs even though it may slightly enhance the classroom experience. The traditional modes of teaching and research will still dominate ten years from now, but changes at the perimeter can and should occur. Sharing of electronic instructional and educational materials over the web may offer some economies. The CACHE Corporation is developing a web site for chemical engineering educators to facilitate such sharing (www.cache.org).

Technology-enhanced learning 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.*

The University of Texas at Austin just completed a yearlong study on such issues; see <www.utexas.edu/admin/evpp/planning/ITCC/TELC.html>

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. 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 for many of the problems in higher education, with the vague promise of delivering a higher quality of education at a lower cost. Expensive regular faculty will not be needed—they will be replaced with part-time adjunct faculty, such as the University of Phoenix is doing. But there needs to be a more thoughtful approach to distance learning at most universities. Simply putting textual information on a web page is not an improvement in quality of education; it is comparable to correspondence courses as they have been traditionally offered.

Some aspects of using distance learning even for residential students are appealing.[6,7] 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) from this great singer. So those who suggest that real 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-educational 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 a lecture.[8] 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.

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 nontraditional student population is rapidly growing in the U.S. The availability of streaming media technology (audio and video) over the Internet will eventually 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 currently employed at many universities.

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IMPACT OF INFORMATION TECHNOLOGY ON 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 e-mail and videoconferencing augment face-to-face meetings between a research student and members of the supervising committee. Multi-university research projects can be coordinated via weekly videoconferences, such as those in the supercritical fluids research center sponsored by the National Science Foundation. On the other hand, research using 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.

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 can 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, multifaceted problems that involve advanced computing.

Most U.S. universities are now members of Internet 2, which provides high bandwidth capabilities (over 100 times as fast as today's commodity Internet) for faculty research and distance education. This includes, for example, digital libraries with audio and video content, collaboration and immersion environments, remote monitoring of experiments, and data-intensive applications (see www.internet2.edu).

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. The global networking of faculty groups can be called 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 collaboratory is in the area of molecular modeling (www.cmsef.aiche.org). There are a number of agency-sponsored collaboratories on topics such as AIDS research, molecular structure, NMR spectrometry, health care, and space physics.

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.

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 of 1998, was just such an experimental meeting and was termed a success. But virtual meetings will not totally replace face-to-face experiences such as the AIChE annual meeting; they can, however, augment these regular events (hopefully with reduced cost, including a minimal registration fee). Key lectures could be webcast and played at an individual's convenience. 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 of the Q&A period run as a newsgroup.

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 on the economics of old-journal digitization, such as JSTOR, a digital conversion 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 licensing the contents of JSTOR, at a price that is incremental to the cost of the paper-based journal.

Commercial publishers, however, are not inclined to sell only the electronic version at a lower cost and give up current income levels with the standard subscription package. Because 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 $400 per year for an active researcher. This usage-metered pricing 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 MS and PhD dissertations. But 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 papers available for a limited period of time. In 1999, the National Institute of Health proposed using 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.

In the competition for leading papers, however, faculty are circumspect about submitting articles to a new journal without a track record, whether it is electronic or not. 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 thirty 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. Computer companies, however, 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.

As a coauthor 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 on-line 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. One electronic textbook under development that bears watching is on molecular modeling (see http://flory.utk.edu).

CONCLUDING REMARKS

I have attempted to paint a picture of how universities will be undergoing change during the next ten to twenty 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 two hundred 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 explore various options and to be proactive in carrying out experiments and innovation, rather than merely hoping these external forces will go away.

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REFERENCES

1. Negroponte, N., *Being Digital,* Knopf, New York, NY (1995)
2. Dolence, M.G., and D.M. Norris, *Transforming Higher Education,* Society of College and University Planning, Ann Arbor, MI (1995)
3. Duderstadt, J.J., "Can Colleges and Universities Survive in the Information Age?" pp. 1-25 in *Dancing with the Devil,* Educause/Jossey-Bass Publishers, San Francisco, CA (1999)
4. Dertzoukis, G., *What Will Be,* Harpers, New York, NY (1998)
5. Wilson, J., "Distance Learning for Continuous Education," *Educom Review,* **32**(2), 12, March-April (1997)
6. Bothun, G.D., "Distance Education: Effective Learning or Content-Free Credits?" *Cause-Effect,* **21**(2), 28 (1998)
7. Petre, M., L. Carswell, B. Price, and P. Thomas, "Innovations in Large-Scale Supported Distance Teaching: Transformation for the Internet, Not Just Translation," *J. Eng. Ed.,* p. 423, October (1998)
8. Poindexter, S.E., and B.S. Heck, "Using the Web in Your Courses: What Can You Do? What Should You Do?" *IEEE Control Systems,* p. 83, February (1999)
9. Wilkinson, S.L., "The Electronic Frontier," *C&EN,* p. 38, June (1999) ❒