ROLE AND IMPACT OF COMPUTERS IN ENGINEERING EDUCATION

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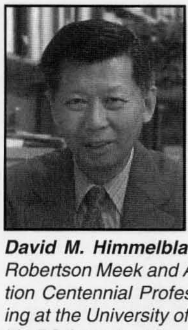
After three-and-one-half decades of development, the computing environment is now highly interconnected. Networks proliferate between computers, laboratories, buildings, campuses, and across continents. Computer use is integrated into many chemical engineering courses to aid teaching, learning, and communication. Many pioneers' dreams have now become a reality.

CURRENT STATUS

The Computing Environment • When the university is in session, the chances are that lights are on in the Computer Teaching Laboratory, its computers are running, and students are using them in various ways, some of which their older brothers or sisters could not have done just a few years ago. These days, the Laboratory is easily the most-used facility in the chemical engineering department. System crash is now a rare event. The Laboratory's opening hours are dictated only by security and maintenance considerations and there is no full-time staff associated with the facility. It is user-serviced with a half-time teaching assistant acting as a Laboratory manager, with policy guidance and planning provided by a faculty director. For fourteen hours a day during the week and eight hours on Saturdays and Sundays the micros slave tirelessly at the friendly commands of users. The micros are connected in a local area network (LAN) served by a file server, printers, and other peripherals. The LAN is linked to the campus fiber optic backbone, and through it to the Internet worldwide.[2]

Access to the information superhighway is the most significant step forward in the empowerment of faculty and students and has already taken place on many campuses. Give or take a few details such as the type of hardware and software or the physical dimensions of the laboratory and the size of the student population, the environment described above reflects the computing and information processing environment currently existing in many universities and, in particular, in the chemical engineering departments.

Impact of Computers on ChE Education • This paper is concerned with the present status of engineering education, with specifics taken primarily from chemical engineering. How have computers affected the learning and the teaching of engineering? The use of computers has now been integrated into most of our undergraduate courses, beginning with material balances and stoichiometry (analysis of chemical process systems), thermodynamics, equilibrium separations, continuing with process dynamics and control, process design, process optimization, and chemical engineering laboratory, and ending with electives such as statistics in process modeling. Significant changes have already taken place in the content, learning, and teaching of these subjects. For example, linearization and Laplace transformations play a ubiquitous role in classical process control. In the days before computers, we spent much time on inverse transformations and in the preparation of Bode and Nyquist diagrams in stability analysis. Now, with Program CC, we simply input the appropriate polynomials in the numerator and denominator of the transfer function in the Laplace domain, and then let the computer do the tedious work. Parametric studies are easy to carry out. Understanding and insight, which used to take a long time to develop, are now



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[2] *In this simplified description we have omitted a few hardware and software details.*

acquired rapidly and enthusiastically. Similarly, TK-Solver and Lotus 1-2-3 take a lot of drudgery and mystery out of balances and stoichiometry. With flowsheet simulators and property libraries, the dual role of thermodynamics in process analysis and in property estimation becomes very much easier to teach and to explain. In statistics, by using Monte Carlo simulation, the instructor can readily demonstrate and verify, for instance, the Central Limit Theorem and can display plots in vivid color graphics in dimensions which "will cross a rabbi's eyes" (*Fiddler On the Roof*).

The result of all this is that by using computers, one can cover more territory and tackle more realistic problems in less time. Because of the availability of these new tools and techniques, it is possible to begin experimenting with new pedagogy[1-3] which, in time, may profoundly change the ways students learn and instructors teach these subjects. This is particularly true with subjects involving many elements, complex structures, and closely knit relationships (such as systems engineering) that would be difficult to demonstrate experimentally. With computer simulation we can now reproduce precisely controlled "misbehavior" to study its impact on every aspect of the system.

Communication and Productivity Tools • Equally remarkable are advances that have taken place in communication and personal productivity tools. With only a modicum of formal instruction, students can acquire serviceable skills in word processing, graphics, desktop publishing, database, and E-mail, and with spell checkers there is no excuse for misspelled words. By making it "fun" to prepare texts and illustrations, not only do the reports and illustrations look more professional, but in due course they also improve in substance and style. With universal access to computer networks, anyone can send a message or be reached by E-mail without having to play phone-tag.* Through remote access, instructors can just as easily review class records and assign homework problems as they can conduct an electronic dialog with colleagues at other locations—all without leaving the physical environment of home or office. Last but not least, by greatly simplifying the protocol, distribution, and delivery, E-mail lowers the threshold of communication and shrinks the physical and psychological distances of an organization, be it a corporation, a government, or an university.

To appreciate the profound and pervasive changes that are taking place in information technology in general, and computers in particular, we need only look back at the path of progress that has led us to the present state of development.

** As we were revising this manuscript in October of 1994, an all-electronic conference was taking place on Internet, breaking new ground in communication. As participants of the first International Chemometrics Internet Conference (InCINC'94), the authors could ask and answer questions and conduct technical discussions on papers in five simultaneous sessions, while proceeding with our daily business in the background mode. We were quite conscious of being witnesses to an historic event.*

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HIGHLIGHTS OF THE PAST

By most reckoning, we are in the fourth decade of computer applications, even though there may not be an exact point of origin. The first two decades were dominated by mainframes and minis. In chemical engineering, much of the initial programming efforts were directed at replacing repetitive calculations. Taking 1958 as our reference point, the establishment of FORTRAN as the universal high-level programming language for quantitative computation must rank among the foremost achievements of that first decade.

By the second decade, LP (Linear Programming) and, more specifically, codes based on the Simplex Method, had become the single largest user of computer time in the process industries. Time sharing, on line terminals, and flowsheeting programs were some of the other notable developments of that decade.

The year 1978 heralded the introduction of the first commercial-scale microcomputer, the Apple II, followed three years later by the IBM PC and the mass marketing of software (word processors, spreadsheets, and databases) that fueled the revolution of microcomputers.

By 1990 personal computers (PCs, clones, Apples, and Macintoshes) became the second most common tool of communication—second only to the telephone. It is notable that E-mail and networking did not gain popularity until well into the third decade.

One of the most remarkable characteristics of the computer industry is the continual improvement in performance in relation to price which has been sustained for over three decades. Figures 1 and 2[4] (next page) show that the price of computing has dropped by one-half every two to three years ever since computers were marketed commercially. A present-day $3,000 PC is comparable in computing speed to a million-dollar mainframe a decade ago. If progress in the rest of the economy had matched progress in the computer sector, a Cadillac would cost $4.98, while ten minutes' work of labor would buy a year's worth of groceries![4]

What Has Already Happened, or Is Happening • One important impact of the changing price/performance ratio is improved user-friendliness. In the early 1980s, a word processor ran on a 64 KB memory microcomputer, by the mid-1980s it required 640 KB of memory, and now, in 1995, no respectable application software requires less than several megabytes of memory. But with this extravagance in memory requirement came a much more fault-tolerant and user-friendly interface, and the same "look and feel" (under Windows, for example), that makes the task of assimilation much less formidable for lay users. In fact, previous emphasis on learning to program in FORTRAN and similar high-level languages has diminished since Matlab, MathCad, Polymath, Mathematica and their ilk have enhanced their capabilities and relieved users of the need to program—raising anew the question whether it is necessary to teach programming to students other than computer engineering and computer science majors.

With ever-improving computing capabilities and methods of solution, the bottleneck in process analysis is once again the quality and fidelity of the models suitable for different applications. Some attention is already being directed to applications typically ignored by educators, such as modeling less structured, fuzzy problems and applications involving noisy and correlated data.

Cheap information storage and improved means of transmission and distribution have already changed the *modus operandi* of traditional institutions such as libraries and publishing houses. Journal abstracts and even articles are sold on compact disks that can be searched at will at nominal cost, and with an E-mail address and access to databases a student can download information just as easily as he can send an electronic file to a friend.

Textbook have changed substantially. Readers are expected to have access to a computer to solve exercise problems. Disks containing pertinent software are commonly found inserts in the backs of books. The technology exists today to customize, assemble, and electronically deliver textbooks for each student, but it may take time to resolve all the copyright issues and to provide suitable marketing mechanisms. How to provide teaching material for engineering courses will almost certainly be a major issue in the next decade, and the opportunities for innovation will be limited only by our imagination.

One important impact of computers on engineering education has been to broaden the access to teaching and learning styles. In a few instances, computer-aided learning has completely replaced the lecture-recitation format for learning, but in most universities changes have occurred in a more limited way over a period of many years as the role of computers in education became better appreciated by the faculty. Such changes are often caused more by the influx of young faculty members who have hands-on knowledge in using computers than by the action of accreditation or university guidelines. So retooling of tenured faculty may well be one limiting factor in introducing new information technology in our pedagogy. Nonetheless, the rate of technological innovation will continue to be rapid, and equipment will become technologically obsolete when it is still in good mechanical condition. Short life cycles in computing technology will continue to be a fact of life. To stay in the competition, schools must have plans and funding to rejuvenate programs and facilities. Those with foresight to anticipate will have a competitive advantage.

Curriculum revamping will surely be needed at some point, since we cannot go on adding new material to the existing courses without deleting other topics. This will create opportunities for experimenting with new pedagogy, which may in turn make our profession more accessible to a wider range of candidates, thereby contributing to retooling of the national workforce.

Historically, the path to progress is strewn with expensive wreckage. A megabuck investment does not ensure that a project will succeed, and today's success is no guarantee for tomorrow. An example of innovative educational software is the PLATO system, which reportedly cost CDC hundreds of

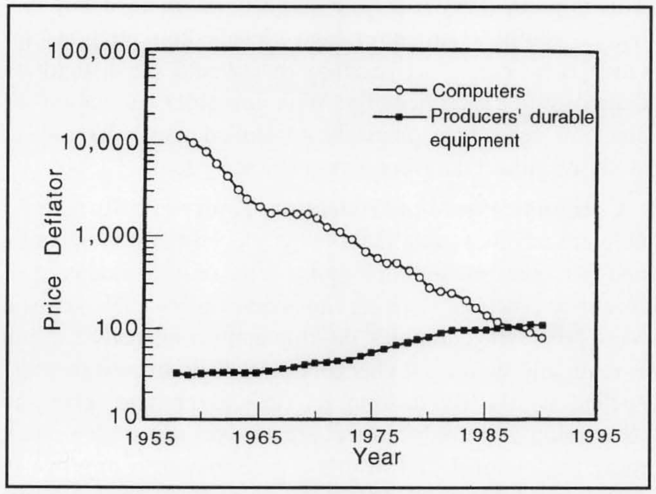

Figure 1. *The cost of computing has declined substantially relative to other capital purchases (based on data from U.S. Department of Commerce, Survey of Current Business, 1990). Figure reprinted with permission from Comm. ACM,* ***36****(12), 67, Dec (1993)*

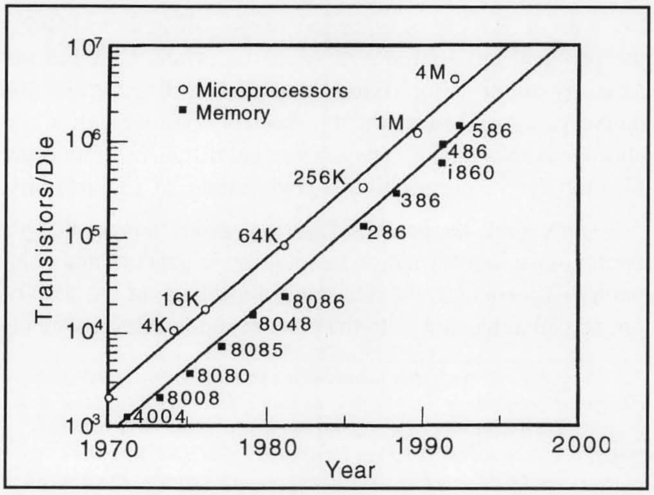

Figure 2. *Microchip performance has shown uninterrupted exponential growth (data provided by Intel.) Figure reprinted with permission from Comm ACM,* ***36****(12), 67, Dec (1993)*

millions of dollars in the 1970s but which has left no lasting imprint on engineering education today. The IBM multitasking operating system for PCs, OS/2, has been reported to cost one billion dollars to develop and has produced perhaps one hundred million dollars in revenue. With respect to hardware, in the 1970s IBM crushed RCA, Xerox, Honeywell, and GE, and compelled those companies to take large write-offs. In the parallel computing field, more recently both Kendall Square and Thinking Machines have declared bankruptcy.

However, we did learn some valuable lessons. Most potential users cannot visualize how to use unfamiliar technology in large mental steps. If the context of the new technology is sufficiently dissimilar to the current context, rejection is likely. Thus, quantum leaps often fail where incremental changes may succeed. Another lesson for developers of new computing technology is to focus on the relevance to educational needs and not be carried away by the clever, exciting, or imaginative technology. Changing curriculum solely to take advantage of computing technology is usually a waste of resources.

THE FUTURE

What might we predict about the future? On the hardware side, commercial technology already available includes 1280x1024 pixel graphics, 21 inch color monitors, 90 MHz clocks, 150 MIPS computing speed, 10 GB hard drives, and 1200 dpi printers. In the near future we expect Intel to continue maintaining its remarkable 44-month product cycle. High-speed transmission and vast databases are expected to make greater impact on education. Subject to usage monitoring and accounting, software at one site may be exploited by students at another site at little cost, making it unnecessary and unattractive to reinvent the wheel. Further integration of software and textbooks will eventually lead to multimedia teaching material.

An education built on sound fundamentals and in-depth understanding is still the best strategy to allow one's knowledge base to evolve and grow with changing times.

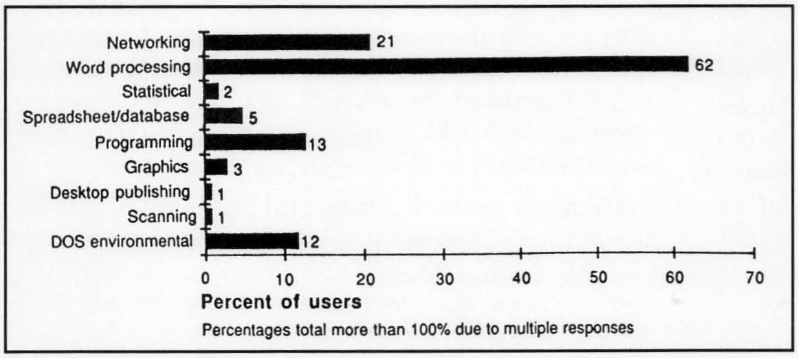

Figure 3. *Types of Software and use in computer labs. [Graphic by Steve Alspach; reprinted with permission from NU Information Systems and Technology, Northwestern University, Evanston, IL, News and Views,* ***2****(3), Spring (1993)]*

While hands-on practical experience is indispensable to engineers, one must avoid overspecialization. Paraphrased in another way,[5] kilobit education is dangerous in a world of gigabyte technology.

On the other hand, history also shows that the momentum generated by a real winner can carry development a long way. FORTRAN, LP, word processor, and E-mail are some examples. Word processing was probably the single largest application that spearheaded the commercialization of personal computers. Figure 3 shows that it continues to be the dominant application of campus microcomputer users even today.[6]

Compared with the earlier decades when IBM accounted for three of every four computers sold, we now have a global market for buyers and sellers of information technology in addition to vast capital and financial institutions, trained manpower, and many potential winners. A list of promising developments includes networks, optical and parallel computers, CD ROMs, satellite broadcasting and reception, personalized portable phones and pagers, notebook computers, and high-definition television. The potential for information technology mergers which will further enhance the use of computers in engineering education is very large and very likely.* How engineering education can continue to make use of these rapid changes remains a challenge. It is our responsibility to take advantage of these changes in engineering education to shape engineers who shape the future.

We are almost at the dawn of the 21st century. Looking back along the pathway leading to the present makes us realize how far we have traveled in a journey that was propelled by just a few key inventions. How many more wonders lie ahead of us to be discovered, invented, and applied to engineering education in the coming decades? The possibilities are truly exhilarating and exciting.

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** Mergers are taking place even as we write. Novell and Word Perfect have just announced a new alliance to compete with Microsoft which is teaming up with McCaw to form Teledesic, a global communication network linked by 840 satellites.*