The Computer as a Tool for Learning

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Experimenters from the beginning recognized the advantages computers might offer in medical education. Several medical schools have gained experience in such programs in automated instruction. Television images and graphic display combined with computer control and user interaction are effective for teaching problem solving. The National Board of Medical Examiners has developed patient-case simulation for examining clinical skills, and the National Library of Medicine has experimented with combining media. Advances from the field of artificial intelligence and the availability of increasingly powerful microcomputers at lower cost will aid further development. Computers will likely affect existing educational methods, adding new capabilities to laboratory exercises, to self-assessment and to continuing education.

(Starkweather JA: The computer as a tool for learning, *In* Medical informatics [Special Issue]. West J Med 1986 Dec; 145:864-868)

Computers have improved remarkably in both availability and capability, and their use in medical education is increasing. Computer programs not only provide assistance for learning facts and their relationships, but they have become useful tools for the learning of decision making and problem solving. It is likely that computer-based educational methods will continue to evolve and play a significant role in the overall development of future medical education methods.

The Development of Educational Assistance

The application of computers to education has a history of more than 20 years. It was preceded by the promotion of simpler teaching machines.[1] In 1959 a computer was reported being used as a teaching machine, but it was considered to be economically unsound.[2] Work on the application of computers to teaching continued, nevertheless, in technologic companies such as IBM,[3] Bolt, Beranek and Newman[4] and Systems Development Corporation.[5] At the University of Illinois (Urbana, Ill), learning stations were developed that linked students or curriculum authors to a central computer. By 1967 a survey listed 240 publications concerning computer-assisted instruction that had appeared between 1959 and 1967 and 20 centers in the United States where digital computers were dedicated for instructional systems.[6]

In the late 1960s, it was possible to place a student in communication with a large-scale computer for about the cost of using an individual tutor. It was imagined that costs would decrease, and there was considerable optimism in the business world that prompted a number of companies with computer facilities to join with publishing houses to develop computer-based materials. An example of this optimism was reflected in the August 1, 1968, issue of *Forbes* magazine (vol 102, p 44) in which its reporter predicted that computer-assisted instruction would become big business, bigger than textiles, rubber or paper:

> But the sharpest rate of gain (in educational expenditures) is almost certainly going to be in spending for machines and programs to enable teachers to teach more effectively and efficiently. At present, total spending in this area is only about $2 billion a year, most of it in textbooks. That $2 billion could easily swell to $10 billion within the next six years, with old-fashioned textbooks getting a smaller and smaller proportion.

In writing about the application of computers to medical education at about that time, I emphasized a need to teach clinical skills as well as necessary facts.[7] I was not alone in the belief that computers could provide practice in the skills of inquiry and problem solving. Others wrote of the need to give students practice in these skills and how computers could provide the means: they had the capacity to analyze and respond to relatively unconstrained input from a student; they gave rapid access to extensive information storage and retrieval, and they could give potentially unlimited competence in the field of instruction through access to the collected insight, experience and creativity of a large number of teachers.

The reputation of computer-assisted instruction, however, suffered ill effects from overpromotion similar to that which had occurred with programmed instruction using booklets, multiple-choice filmstrips, branching books and so forth. The former principal of a school where many new methods were tried wrote that "programmed learning has

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been oversold, overrated, overpriced and underproductive."[8] The materials were promoted long before carefully developed programs were designed to match the needs of particular students. Improvements in computer capability and reductions in cost have occurred much more rapidly than programming systems developed for education. The potential for computer use is perhaps more evident than ever, but applications that involve changes in long-established educational methods are slow to occur.

A good case can be made for the belief that instructional objectives should be stated not only in terms of information to be learned, but also in terms of observable behavior that can be expected from a student at the completion of a sequence of study. During the course of learning, students should be in a position to practice the behavior they are trying to master. Even though this seems to be a platitude, an example of contrasting approaches would be medical students who are asked to give a list of signs and symptoms associated with a disease rather than getting practice in attempting to solve a diagnostic problem on the basis of presented symptoms. Interactive instruction can allow students to practice behavior that is closer to their eventual goal.

Applying the Computer to Medical Education

Using a computer as an aid to learning holds a special appeal to those who have experimented with computers and who have also been involved in the education of physicians and other health care professionals. For example, a special interest group for health care educators was formed in the early years within the Association for the Development of Computer-based Instructional Systems and it has continued to be an active element. The potential seemed clear—that it would be possible to create problem situations for medical students that would be realistic clinical experiences. Such clinical exercises could pose diagnostic problems and confront students with the necessity to communicate in an interview situation, and the exercises could be reliably repeated for more than one student. The report, "Physicians for the 21st Century,"[9] commonly referred to as the GPEP report (for General Professional Education of the Physician), was a recent reiteration of earlier statements made by others along the same lines. It described the proliferation of factual knowledge within each specialty discipline and how this leads to rote learning and a lack of necessary integration and synthesis. It urged medical school faculties to reduce the dependency on lectures as the principal method of teaching and to increase activities that provide students with more opportunities for independent learning and for problem solving.

There is, nevertheless, a general resistance to change from the traditional methods by medical school faculty members. Interacting with a computer and self-pacing have not been clearly shown to be more effective than the usual teaching methods in terms of student performance. Faculty are also often reluctant to use programs developed at other schools. The result is the occasional, scattered use of computer-based materials introduced as optional adjuncts to existing courses.

Uses for Automated Instruction

Because introducing computer-based methods is likely to be incremental, the following may be some appropriate criteria for identifying situations in which automated instruction will be best suited. First, automated instruction is particularly useful where it is necessary to teach complex and sequential decision-making processes. Second, it is particularly useful where discriminations among complex stimuli must be learned. Third, it is useful where there is a large proportion of people who need to acquire information at times when they cannot be taught as part of a large group of learners.

Many aspects of medical education seem to have these characteristics. Not only do medical students require instruction at irregular times related to specialized schedules in various services and departments, but students, interns, residents and other staff are faced with rapidly growing knowledge and changing techniques that they must master. Computer-based methods can provide experiences with cases not often seen or with procedures that would be dangerous if actual patients were used. Other advantages are that students can control access to instruction to meet their own needs and pace, the learning can be private without risk to a student's self-esteem and realistic simulations can create an engrossing context in which learning is both enjoyable and motivating.

In spite of the expected benefits of computer-based learning and its general acceptance by students, studies of student achievements have not shown an advantage. This may be due to the difficulty of measuring the effectiveness of teaching and comparing teaching methods, or it may be due to the primitive nature of person-computer communication that has so far been available. Many computer-based curriculum materials produced to date can be characterized as programmed instruction that could as easily be presented in the form of a low-cost book. Because of the additional time and effort required to convert such sequences into computer programs, such programs are not cost-effective.

There are now new possibilities that use the increasing graphic capability of computers and their interaction with other media. Until recently, the application of various technologies to instructional activity has proceeded almost entirely along separate lines described by the names of the separate audiovisual media—movies, slides, books, programmed instructional material and television. These have been used most often by those who specialize in one or another of these media. We are now seeing some integrated combinations of television and computers, however, with the computer providing users with adaptive effectiveness.

Major Existing Projects

The PLATO System

One of the largest organized collections of computer-based educational programs is the PLATO system, begun more than 20 years ago at the University of Illinois and later available from Control Data Corporation.[10] It was from the beginning an ambitious project, one combining high-resolution graphics on a specially designed plasma display terminal and the projection of images on the same display from a random-access microfiche projector. Terminals connect to a centrally located large computer by leased telephone lines. There is now also a version that can operate many of the same programs on a free-standing microcomputer. The programs are written in an authoring language called TUTOR that, like other specialized computer languages such as MUMPS and PILOT, simplifies the process of developing lessons. The PLATO system grew to contain lessons for many subjects at all levels of education. More than 400 lessons have been developed at different medical schools and collected in the system. They differ widely in approach, some operating in a testing mode, some providing tutorial exercises and drill of factual information and some running simulations that model a portion of the real world.

Ohio State University College of Medicine's System

Another large project that has provided services to medical schools is a library of instructional programs and related data bases developed at Ohio State University College of Medicine (Columbus, Ohio).[11] This project provides on-line access to computer-assisted instruction in most areas of health professions study and is probably the largest single collection of such coursework. It supports users from other medical centers in all parts of the country by the Health Education Network. This network, which developed as an experiment in shared computer-assisted instruction with support of the Lister Hill National Center for Biomedical Communications of the National Library of Medicine, has now operated on a commercial basis for more than ten years.

The medical school at Ohio State University has been an innovator in experimenting with independent study using computer-based materials that parallels the normal course of study. The curriculum covers introductory physiology, biochemistry, pathophysiology and therapeutics using modules that contain learning objectives, reading assignments, small group laboratory and conference sessions and computer-based testing. Volunteer groups of students have used these materials, and their progress compares favorably with classmates taking the traditional curriculum.

Computer-Aided Simulations of the Clinical Encounter

One of the most advanced portions of the aids to independent study available from Ohio State University are Computer-Aided Simulations of the Clinical Encounter (CASE). These originated at the University of Illinois College of Medicine (Chicago)[12] and were later moved to Ohio and the Health Education Network. A user assumes the role of physician and makes free-text inquiries of the simulated patient via a keyboard to develop diagnosis and management of the case.

Simulation Programs at Massachusetts General Hospital

Simulation of a somewhat different sort is shown in an extensive series of clinical management simulations at Massachusetts General Hospital (Boston).[13] Some of the simulations are of a physiologic system or process, such as electrolyte balance and its reactions to therapy. Some are diagnostic problems to be solved in which the simulation is a matrix of probabilities that medical findings such as history, physical examination information and laboratory results are associated with specific diagnoses. In other simulation exercises, the condition of an imagined patient changes in response to decisions of the student. These simulations, written in the MUMPS programming language, have been available to other medical centers by dial networks. Some of them have now been adapted for operation on microcomputers and are available for purchase from a commercial publisher. Currently available topics in this format are managing hypertensive emergencies, digitalis therapy, the treatment of arrhythmias, arterial blood gas measurement and cardiopulmonary resuscitation training.

Computer-Based Examination

The National Board of Medical Examiners, working with the American Board of Internal Medicine, has developed a computer-based examination called CBX that is a complex patient-case simulation requiring diagnosis and case management. It is an examining system that models reactions to drugs, interventions by the physician being tested, the passage of time and the constantly changing interactions between these variables. Pictorial slides or microfiche accompany the text information.

Useful learning materials can now be produced using videodisk technology without a separate computer. This is possible because a videodisk player contains a microprocessor that can control the choice of visual display. It responds to control sequences recorded on one of the two available audiotape tracks and in reaction to a user's responses with a keypad. Examples are videodisks on the management of trauma and neurologic disorders, produced at the University of Washington School of Medicine (Seattle), and a tutorial on nosocomial infections such as bacteremia[14] and surgical infections,[15] distributed by Miles Pharmaceuticals.

TIME

Adding a microcomputer along with videodisk images and sound allows more complex interactions and more realistic simulations. The same videodisk can be used in an instructional or testing mode with a change in the controlling computer program. An experimental system called Technological Innovations in Medical Education (TIME) has been developed at the Lister Hill Center of the National Library of Medicine.[16] A student user reacts to dramatic portrayals of a patient's medical and social conditions and is expected to do so without prompting. The microcomputer is trained to recognize a user's voice with a selected vocabulary so that a student makes uncued, verbal interventions in the course of managing a case. Other experimenters have developed similar portrayals of medical problems and emergencies requiring decisions that must be made in real time as one interacts with the program. Such simulations can be highly realistic and motivating. While there is yet no comprehensive catalogue of instructional software and very little interchange of materials from one institution to another, in a recent summary an attempt was made to cover all simulation programs that provide practice in clinical case management.[17] The result of a national survey, this catalogue lists nearly 100 interactive programs that deal with strategies of patient care. It provides information about developers and distributors, system requirements for operation and suggested audiences.

Other Systems

From experiments in artificial intelligence, systems have begun to be developed with expert knowledge in specific fields. They operate as consultants on diagnostic and case management problems. With minor modification of use, they have potential as self-directed learning aids. The Quick Index to Caduceus Knowledge (QUICK) is an application program built on the INTERNIST-1 knowledge base (now called Caduceus) developed at the University of Pittsburgh School of Medicine (Pittsburgh).[18]* It is an electronic textbook of medi-

*See "The INTERNIST-1/QUICK MEDICAL REFERENCE Project—Status Report" by R.A. Miller, MD, M.A. McNeil, MD, Sue M. Challinor, MD, et al, elsewhere in this issue.

cine that allows a physician to get information directly from the Caduceus knowledge base, and it can be used as a diagnostic aid or as a teaching tool. The user can obtain a profile of a disease or a differential diagnosis of presented findings. NEOMYCIN is an application of an existing expert system for teaching purposes, one that teaches how to solve diagnostic problems of infectious meningitis.[19] HEARTLAB is a program being developed at Harvard Medical School that makes use of both graphic display and sound-generating capabilities of the Apple Macintosh computer to allow students to learn variants of heart sounds in an exploratory fashion and then to test their diagnostic ability (B.P. Bergeron, MD, written communication, April 1986).

The Directions of Further Development

There will probably be a useful place for drill and practice programs and those that test for the retention of necessary facts. The direction of greater improvement, however, is in more programs that assist with decision making and problem solving and help the learning of such skills. There are a number of changes in both hardware and software technology that will make such improvement possible with what will very likely be an increasing rate of change.

Hardware capabilities continue to increase rapidly, and they already offer more possibilities for information display, the collection of responses, record keeping and adaptation to a user than have been yet applied to instructional programs. Lowered equipment cost is allowing students to have access to convenient and powerful workstations. The storage of large amounts of information is rapidly dropping in cost, and the display of information is becoming increasingly effective with higher resolution graphics and the use of color. Computer control of images from videodisks is likely to become less expensive and easier to produce. Many students will have gained experience with their personal computers, and they will be more prepared to take advantage of computer assistance. Awareness of computer possibilities is also likely to increase for physicians in practice. Instructional programs for continuing education will become available to operate on local equipment in common use. It is already clear that advantages in availability, speed, reliability, lower cost and the avoidance of data communication difficulties have prompted the migration of many programs to microcomputers as these computers have become more capable.

There is a need to produce educational software that is general enough that it can operate with different specific equipment. This seems necessary both because the hardware keeps changing and improving at a rapid rate and also because standardization to a particular configuration does not seem likely. As more students begin to have their own computers, there will be differences between student equipment and school equipment and differences in the school equipment used in different departments. Software representing a large investment, such as complex models simulating clinical conditions or large knowledge bases, needs to remain usable even as there are changes in the technology with which they are stored and accessed.

Improving Existing Methods

Perhaps it would be helpful to think of computer assistance to learning in the context of how computers may improve existing educational elements and methods. For example, computer assistance should be applied to developing better tutors, better textbooks, better laboratory exercises and even better lectures. In addition, computers should improve information access for students, both from library collections and from instructors. Electronic mail between students and between students and instructors should become an available resource.

A Tutoring Computer System

Computer systems should interact using programs that act less like a lecturer and more like a responsive tutor. As computer programs develop more inference capability in a particular problem area, we should see programs that leave the initiative to students, programs that are able to recognize common student errors and ones that can provide advice when requested. Rather than simply present information, ask questions and then branch appropriately to new information, an expert tutor program will place a student in the position of primary agent, but be ready with assistance. We foresee that it will be difficult to assess the ability of such a tutor because as programs become more complex, the problem of assessment will become one of a similar difficulty to that of evaluating human teachers.

Textbook Adjuncts

Computer systems can improve the representation of concepts by providing adjuncts to textbooks such as animated drawings and graphic displays that can be manipulated by a student. Animation can help students to visualize a sequence of events in a time-related variable. Manipulating an image, such as rotating or expanding details, will go far beyond what can be shown with a defined set of pictures in the usual text. Such materials can be catalogued and described for use in a variety of instructional programs.

Simulating Laboratory Exercises

Better laboratory exercises should result from the involvement of computers. It will be possible to simulate the elements of a laboratory so that students can carry out experiments by interacting with a computer. Such a virtual laboratory can act as a precursor and an introduction to actual laboratories, with useful prompting of students to recognize important indices and to explore their variation and effects. Some programs will provide data on the basis of an underlying model and let a student compare them with predictions from alternative theories, or compare them with data gathered from larger samples. Some will operate more in direct simulation of a model and encourage a student to change some variables and observe the effects on others.

We are likely to continue to have lectures, but they can be improved with computer assistance. Just as graphics produced by a computer are an extension of what is found in textbooks, new technology can produce large-screen graphic displays with high resolution that can go far beyond what a lecturer can produce with a blackboard. It seems feasible to expect that displays generated during a classroom presentation would be available at workstations for further use outside of class at a student's own pace of learning.

Self-Assessment and Continuing Education

In general, a steadily improving interaction between computers and students will likely increase the use of computer-based tools for medical learning. New programs will probably emphasize simulations that can assist in the learning of decision making and problem solving. In a recent review of medical information science in which computer-based education was considered,[20] the conclusion was reached that the primary implications of developments in computer-based medical education relate to continuing education and testing. Programs that can operate on a physician's own computer will have the advantages of self-directed learning and self-assessment whenever time permits. For this reason, computer-based access to self-assessment as well as instructional material has particular usefulness for continuing education. Areas of weakness or gaps in knowledge are likely to be individually different, and professionals in mid-career may be much more comfortable in exploring their own competence in private than in public.

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