Chapter 2

COMPUTER TECHNOLOGY IN EDUCATION AND ASSESSMENT

2.

COMPUTER TECHNOLOGY IN EDUCATION AND ASSESSMENT

This chapter presents an overview of computer technology and its uses in education and assessment. First, the definition and context of such computer uses are discussed, followed by a description of the types of educational computer systems that have evolved.

THE TECHNOLOGY

Description

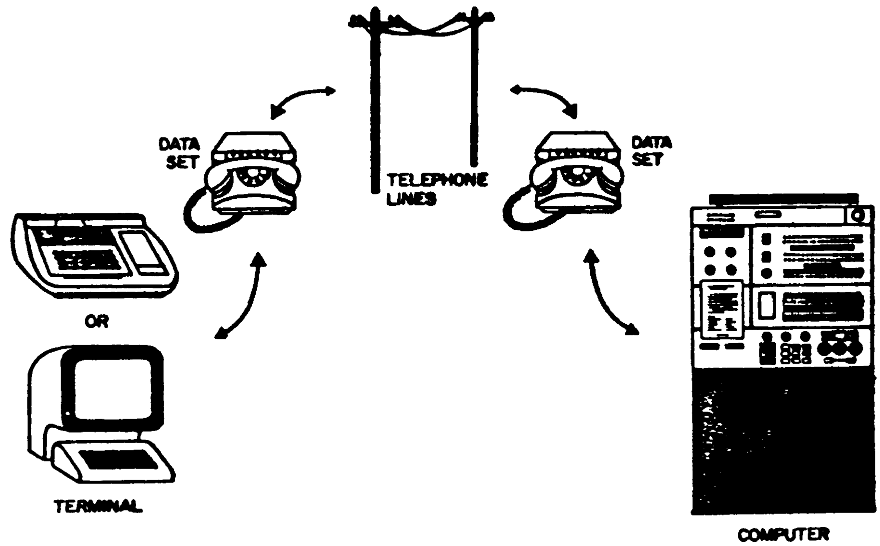
The use of computers in education and assessment, often called computer-based education (CBE), involves a process by which an individual uses a typewriter-like device, a *terminal*, to communicate 'with a computer. Information is transmitted into and out of the computer through the terminal by means of a typed page or a special television screen. Other forms of communication with the computer (e. g., voice) are available only on a limited basis in very restricted settings. The terminal is connected by a *communication link*, such as a cable, microwave, or telephone, to a computer that may be distantly located. The computer receives, stores, retrieves, processes, and outputs data. The terminal, computer, and the communication links are called *hardware*.

An educator or evaluator uses a simplified computer programing language, called an *authoring language*, to translate learning materials into *programs* that direct the activities of the computer hardware. Computer programs are generally labeled *software;* the subsets of programs that serve as the instructional materials are given the specific name *courseware*. Records of individual performance and additional education and assessment programs are stored in the computer or in storage hardware such as tapes and disks; storage hardware are called *auxiliary memories*. Taken together, hardware and software comprise a system that allows the user to interact with educational or evaluative materials stored inside the computer.

Figure 1 portrays a sample interactive hardware configuration. The terminal and a small computer may be combined with sufficient auxiliary memory to create a self-contained system, or they may be part of a larger system tied by a communication link to a distant computer. Figures 2 and 3 portray sample interactive computer systems in the medical education and assessment context.

The most suitable configuration of hardware and software for CBE depends on the desired features of the instruction or assessment program. The choice of systems is influenced primarily by the availability of equipment at an institution or by the desire to use specific courseware. Alternative systems vary, for example, in speed, reliability, ease of programing, ease of use, operating costs, initial costs, capabilities, availability of courseware, and number of simultaneous users permitted by the equipment. Differences in equipment and in software make courseware transfer from one institution to another less

Figure 1.—Sample Interactive Computer Configuration



SOURCE. The Ohio State University College of Medicine

than a routine activity. Smaller machines require a lower capital investment and have lower operating costs, but they generally can accommodate fewer simultaneous users and may have limited capabilities. Larger machines require a higher capital investment and are more expensive to operate, but they provide more capabilities and permit larger numbers of simultaneous users.

There is no consensus on explicit definitions of the descriptors "small" and "large;" rather, these are subjective terms. However, three general categories of computers that reflect these terms are commonly used: microprocessors, minicomputers, and large-scale computers. These three categories are described briefly below.

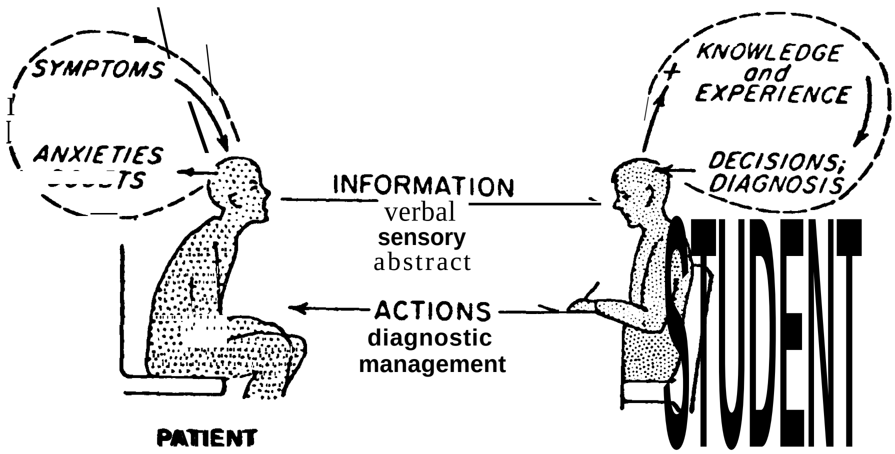
Microprocessors are the smallest of computers. They can be used as stand-alone machines that have a terminal "built-in" and, therefore, require no communication links. They also can be used as sophisticated terminals that are linked to a larger computer. They generally serve only one user at a time and have limited storage and processing capabilities. Their greatest advantage is low cost; their greatest disadvantage is the paucity of existing courseware suitable for use on a microprocessor.

Minicomputers are the middle category of computers. They have more software and courseware because they are generally easier to program than microprocessors. They can execute instructional programs that are almost as complex as those in large-scale computers. Minicomputers, however, cannot serve as many simultaneous users as the larger machines and are more costly than microprocessors.

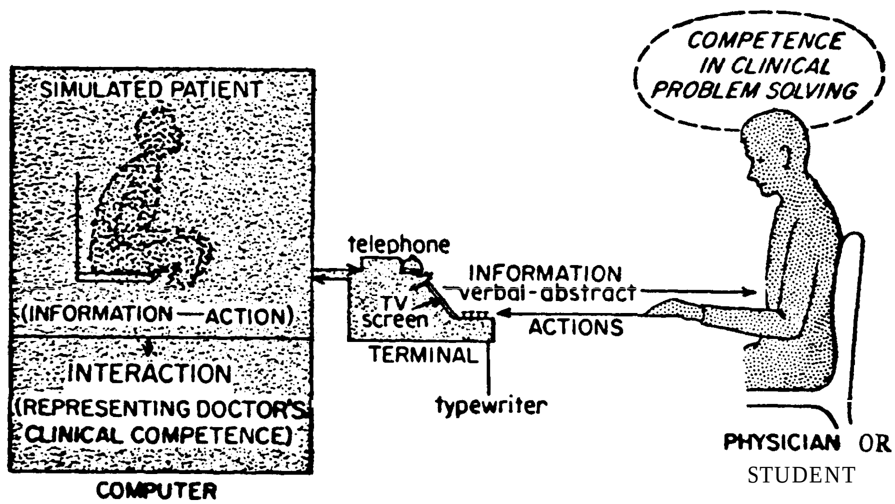
Large-scale computers are the most costly and powerful computers. A typical large-scale system can support hundreds of simultaneous users and the most complex software and courseware. Clusters of terminals linked to the large system can be used for specialized training or other functions.

From the standpoint of user access, computers are generally categorized in the following four ways: single user systems; small-scale, time-sharing systems; large-scale, time-sharing systems; and networking,

Figure 2.2.—Sample Interactive Computerized System in Which the Computer Simulates the Patient



Live Clinical Interaction

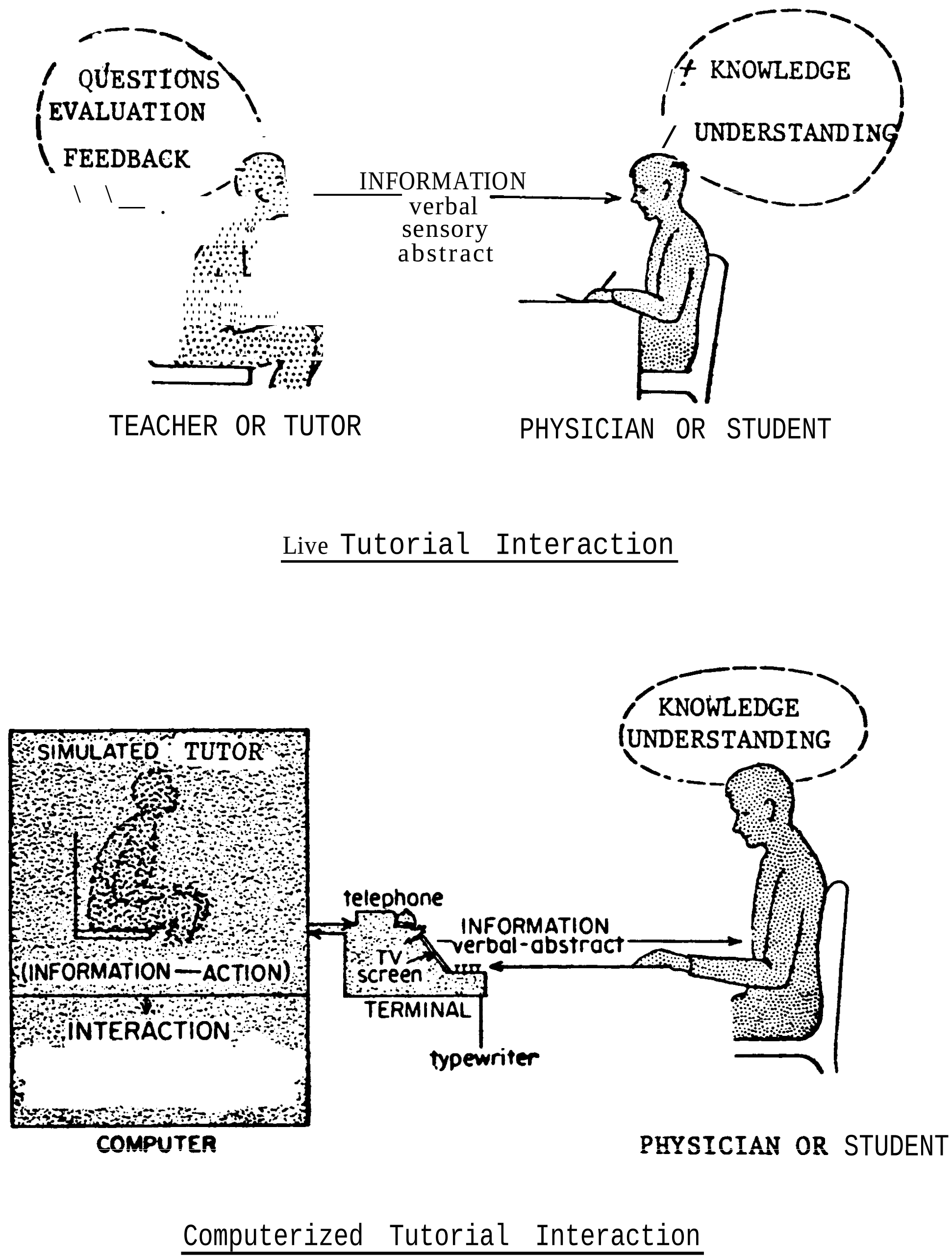


Computerized Clinical Interaction

Adapted from figures 1 and 2, p xiii, Toward the *Measurement of Competence in Medicine,* John R. Senior, 1976

Single user systems exist in the grey *zone* between the "home/hobby" computer market and the less sophisticated segment of the "office" computer market. In this category, the terminal and a microprocessor or minicomputer are combined with sufficient auxiliary memory to create a self-contained system that does not require linkage to a larger computer. Since the auxiliary memory is usually a flexible diskette that has limited storage capacity, a rather small number of programs or courses can be used at any one time; the complexity of such programs and courses also may be restricted by storage limita-

Figure 3.—Sample Interactive Computerized System in Which the Computer Acts as the Teacher/Tutor



Adapted from figures 1 and 2, p xiii, *Toward the Measurement of Competence m Medlcme,* **John R Senior, 1976**

tions. The lack of standardization in the manufacture of small computers increases the difficulties of transferring courseware from one type of single user system to another type. Several computer languages are available, including special purpose educational languages (Gerhold and Kheriaty, 1978). The initial cost for such systems is usually less than $10,000. * The costs for hardware operation and maintenance also are low. The degree of user control is high; computer professionals usually are not required to program or maintain the system.

Small-scale, time-sharing systems include microprocessor- or minicomputer-based machines that support from 1 to 16 simultaneous users (Tidball, 1978 b). No clear distinctions exist between this category of use and the previous one except in the number of users able to interact simultaneously with the computer. Because of these systems' larger auxiliary memory capabilities, it is possible for many programs and courses to be continuously and simultaneously available for use. These systems are flexible, require relatively low initial costs, and include central program libraries. Programing and maintenance for such systems generally require special expertise. Initial costs for these systems range from $10,000 to $100,000. The cost of additional terminals is highly variable, ranging from $1,000 to over $10,000 apiece, depending on the degree of independent "intelligence" desired by the user.

Large-scale, time-sharing systems are, for the most part, dedicated only partially to education and assessment because the full capacity of the minicomputer or large-scale computer is not required for such uses. In a hospital, for example, excess computing capacity may be used to support the medical information and hospital payroll systems. The initial costs for these systems range from $100,000 to over $1 million, although the costs for one terminal's use of the system are typically less than $600 per year (Ohio State University, 1977).

However, some large-scale, time-sharing systems are used exclusively for one purpose, such as education and assessment. Thus, their hardware, courseware, and communication links are used optimally for one activity (Hunter et al., 1975; Trends in Computer-Assisted Instruction, 1978). This optimization can result in operating efficiencies and reduced costs in systems that are extensively used. The costs of such systems are still relatively high because efforts have, and continue to be, directed at developing greater capabilities, not at reducing costs. For example, highly sophisticated graphics, touch panels, microfiche, voice recognition, and audio response capabilities increase costs. As mentioned earlier, a typical large-scale system can support hundreds of simultaneous users and may provide sophisticated instruction for large training programs.

IBM offers systems that include education and assessment programs as only part of their design. Examples of systems designed exclusively for education are time-shared interactive computer-controlled information television (TICCIT) and programed logic for automated teaching operation (PLATO). Both TICCIT and PLATO have had extensive funding support from the Federal Government. PLATO was started in 1959 at the University of Illinois (Seidel and Rubin, 1975) and continues to be developed by that institution. The TICCIT system began with a small amount of internal funding at the MITRE Corporation in 1968 (Nuthmann, 1978) and is being developed currently at Brigham Young University. In 1972, the National Science Foundation added millions of dollars of support for completing and field-testing both systems (Stetten, 1972). Results of evaluations of the implementation of both systems have been mixed. Development of additional courseware and more experience in privately supported use are required before conclusions can be reached regarding the efficacy and costs of these systems.

PLATO is now being marketed commercially by Control Data Corporation, and TICCIT, by Hazeltine Corporation. The purchase price of TICCIT is approximately

*All figures in this chapter, unless indicated, reflect only computer hardware costs. Communication links, software, and courseware are all additional costs.

$750,000 for 128 terminals (approximately $6,000 per terminal); PLATO costs $6,000 to $20,000 per terminal, depending on the size of the computer supporting the system and the number of terminals connected. A limited number of each system has been sold to date.

Networking, the final category of use, involves computer-based learning materials, developed at one site, that are shared with other institutions through a network of interfacing computers and leased telephone lines. The networking approach can be significantly cheaper since it does not generally require as many support staff at the user site nor faculty expertise to develop CBE materials. Other advantages in joining a network include access either to a central computer with a large library of tested courses, or to multiple computers with libraries of courses; economies of scale; the availability of technical and educational network specialists for particular computer applications that an individual institution or user could not afford; wider exposure, and hence, better quality of courseware; greatly reduced capital investments; expenditures only for computer services used; and opportunities for communication with a community of users. The network user has access to a library of existing CBE courses, written in different computer languages by one or more authors, without the costs of conversion, installation, and maintenance of all software. The major disadvantages to networking are the lack of control over computer resources and courseware and the continuing costs for long-distance communications access to the host computer(s).

The development of distributed networks will further opportunities for use of both single user and time-sharing systems and minimize the disadvantages of networking. In a distributed network, an entire computer program can be "down-loaded" from a small-or large-scale, time-sharing system to a single user system. It can be used by the single user system without connection to the network until an updated version is desired, user data need to be transferred, or other functions are desired that require linkage to the program library or host computer(s).

Trends

Several trends are evident in the future of computers that will affect the availability and costs of CBE:

The number of computers will continue to rise. The number of computers in the United States has risen from 1 in 1944, to 12 in 1950, to 6,000 in 1960, and to 50,000 general purpose computers in 1975. These figures do not include the almost unquantifiable number of microprocessors that are in use. Added to the 40,000 computers in use around the world, the total value of all computers exceeds $35 billion (Molnar, 1975). The percentage of the U.S. gross national product spent on computer usage will increase from 2.1 percent in 1979 to 8.3 percent in 1985; per capita expenditures for computing will rise from $101 to $670 in the same period (Nyborg et al., 1977). It is estimated that by 1980 every hospital with 200 or more beds will have a computer, and most homes and private offices will have access to a computer of some type (Collen, 1974).

The costs of computing will continue to decrease dramatically. The most important impetus for the dramatic reductions in the costs of computing is improved performance of electronic circuitry, which can now move electronic impulses from one circuit to the next in one-trillionth of a second (Branscomb, 1979). Silicon and integrated-circuit technology provides the basis for these advances, although new technologies, such as liquid helium, are in development and may result in further advances. Such circuits are packed closely together to enhance speed of transfer; they also account for the continued reduction in the size of computers.

The size of computers will continue to decrease dramatically. The computing power of a machine that filled a large room 25 years ago is now contained in a machine that can be held in one's hand. "An individual integrated circuit on a chip perhaps a one-quarter-inch square now can embrace more electronic elements than the most complete piece of electronic equipment that could be built in 1950" (Noyce, 1977). The microprocessors or personal computers of today, which cost as little as $300 to $500, have larger computing capacities than those of the first computers, are 20 times faster, and are much more reliable. Some predict that personal computers the size of an average dictionary will be available within the next 5 to 7 years at less than the cost of one of today's handheld calculators. These future devices will have more computational power than all but the largest of today's machines (U.S. Congress, 1978).

Input and output terminals or mechanisms will become increasingly sophisticated. Typewriter-like terminals, touch panels, and light pen technologies now are used for learner input in interactive educational computing. Printed pages or visual screens are the most commonly used means for the computer to output its messages. Currently, terminals can incorporate slides, soundtracks, microfiche, and similar technologies in the learner-computer dialog. In some cases, these auxiliary technologies are user-controlled and in others, they are computer-controlled. Voice recognition for input and voice synthesis for output are in early stages of use. Research is being conducted to explore the use of thought waves or electronic brain impulses to interact with the computer (Fields, 1979).

Costs of software and courseware development will continue to rise. In light of all the hardware advances and the decreases in their costs, the development of software and courseware that take advantage of the capabilities of the machine represents the most serious future problem regarding the use of computers. Currently, costs for courseware design and development are much more expensive than hardware costs. The gap between hardware and software costs will continue to widen as labor costs increase and hardware costs decrease.

Author time required to create truly sophisticated CBE materials cannot be underestimated. Table 1 shows the increasing time requirements for courseware development as the complexity of the courseware increases from simple linear tutorial questions to linear tutorials with a variety of feedback options, to linear tutorials with branching within questions, to linear tutorials with branching between questions, to fully individ-

Table 1—Computer-Based Education Course Development

	Instructional Programmer						
Type of CBE	Initial author effort	Author interaction	Coding and debugging	Author review and revision	Additional review	Course documentary	Total develop. time
Linear.	25	5	10	10	5	5	50
Linear with options.	30	5	10	15	5	5	70
Linear/within question branching	**40**	10	**30**	**20**	**5**	10	115
Linear/between question branching	80	**30**	**50**	**40**	**10**	15	215
Individualized	100		100	**50**	40	20	330
Simulations.	3-1o	(4-6:)'	72-124	2-1o	7-14	5-6	94-1 70"

NOTE: Average development times in hours for 1 hour of terminal Interact Ion or one case
"Time for generation of a case—this time is somewhat less due to an automatic authoring aid
SOURCE: The Ohio State University, College of Medicine, 1976.

ualized tutorial development, and to simulations. Times for courseware development and maintenance range from 50 to over 300 hours; costs range from $1,000 to $15,000 per hour of courseware developed (Ohio State University, 1976).

Communication costs will continue to be high. Costs per hour of use depend on the usable life of the course, the computer and communications hardware configuration, the volume of use, and the degree of support services provided. Communication costs account for over 50 percent of hourly costs in most networks (Forman et al., 1978). Other costs, such as those for user services, user training, billing, research, and development, must also be considered. When all cost components are included, expenditures per student hour for CBE systems use vary greatly. One national network charges from $4 to $15 per hour (Tidball, 1978a).

Personal computing will rapidly accelerate, posing new opportunities and problems. The lower costs and smaller sizes of computers have led to their widespread use for hobby and entertainment purposes. In the near future, the use of microprocessors for personal needs will be as commonplace as the use of handheld calculators. Individuals, families, schools, and businesses all will have terminals containing powerful microprocessors that can be used for a wide variety of functions, including education and assessment. The development and availability of software and courseware will not keep pace with the increasing availability of hardware. Creativity and careful planning will be necessary to fully realize the capabilities offered by the linkage of emerging technologies, such as video discs, with microprocessor technologies. Microprocessor-based computer systems serve not only as stand-alone systems but also as linked systems. Microprocessor systems can be linked to “view data” systems such as the British Post Office System; this system offers stock market status information, consumer reports, bibliographic indexes, electronic financial transactions, and mail-order catalogs (Institute of the Future, 1979). Home- and office-based education (especially continuing education) will be available as a result of linking microprocessor systems with extensive data bases.

COMPUTER-BASED EDUCATION

Methods

Specifying the knowledge to be obtained, the skills to be learned, and the standards of acceptable performance is a prerequisite of any education and assessment system. Educators refer to the specification of measurable knowledge and skills as behavioral objectives. Ideally, then, instruction should be designed to teach objectives; tests should be developed to measure attainment of objectives; and administrative mechanisms should be developed to monitor, record, and manage activities in the educational process. CBE methods are similarly divided into three categories to reflect the three components of the educational process: computer-assisted instruction, computer-assisted testing, and computer-managed instruction.

Computer-assisted instruction (CAI) involves the computer in the presentation of instructional material. The computer is combined with other media, such as lectures, films, and labs, in the instructional process and is used ideally for those aspects of the teaching/learning process that can benefit most from CAI capabilities.

Computer-assisted testing (CAT) can be *on-line,* when the test is generated by the computer and administered at a terminal connected to a computer, or *off-line,* when the test is administered manually by paper and pencil. The computer can support testing in any of the following ways: (a) store and retrieve banks of test items, allowing for efficient generation of numerous alternate tests; (b) administer tests; (c) score and print results of tests; (d) maintain testing records for purposes of test validation and/or student diagnosis and prescription; and (e) catalog and reference instructional materials relating to specified knowledge and skills.

Test items can be selected for presentation according to either a set of rules, statistically determined prior to testing, or the individual's responses to items in the current testing situation. Both testing mechanisms take less time to complete than traditional tests, prevent redundancy in test items, provide consistency and standardization for the entire target audience, provide equivalent alternative versions of tests, and allow for more precise measurement of achievement and ability. Learners are not retested on previously mastered knowledge and, hence, receive only those test items that are necessary. The reliability and validity of the tailored tests are comparable to those of traditional tests containing twice as many items (Weiss, 1976; Be jar et al., 1976; Patience, 1977), and immediate information regarding the correctness of the response given after each item can alleviate test anxiety (Weiss, 1976). Automatic maintenance and availability of performance records assist in test validations and in the recognition of gaps in learner knowledge; such gaps may be overlooked in conventional testing because an adequate overall grade may mask important specific deficiencies (Kimberlin, 1973). Generally, the response of test-takers to all types of computer-assisted and tailored testing is positive.

Computer-managed instruction (CMI) manages the learning process by assessing the student's level of skill and knowledge through testing, by maintaining records of student progress through a course or within individual sections of a course, and by prescribing the next step a student should take in his/her studies (Seidel and Stolorow, 1975). CMI can route a student forward to the next section or back to remedial sections, give tests, and direct the learner to written materials, faculty consultation, or CAI courses. CMI can coordinate both the computerized and noncomputerized portions of the entire instructional process.

Strategies

CBE employs a variety of educational approaches or strategies, including drill and practice, tutorials, simulations and games, and inquiry. These strategies have been used for both individual and group-oriented education. The use of CBE by groups is relatively new (Bergin et al., 1978a & b).

Drill and practice exercises require the user to complete a series of exercises, for example, balancing equations in acid-base calculations, that relate to a particular area of knowledge. The computer can use random number generators or complex algorithms to create an almost endless set of exercises of any given difficulty level that are specifically tailored to the needs of the individual learner.

Tutorials are instructional situations in which the learner interacts with computer programs that model a teacher, Such tutorials are designed to meet the individual needs of each student by allowing "instructors" to be continuously present and, therefore, responsive to specific learner needs. Student feedback, remediation, as well as testing and recordkeeping, can be accomplished by a computer instead of by a human instructor. Tutorial programs allow problem solving, question answering, and other similar capabilities. "Intelligent tutors" that are built into these systems offer the student hints, track student errors, and present alternatives to identify overlooked or misunderstood information. A schematic drawing of a tutorial CBE item is shown in figure 4.

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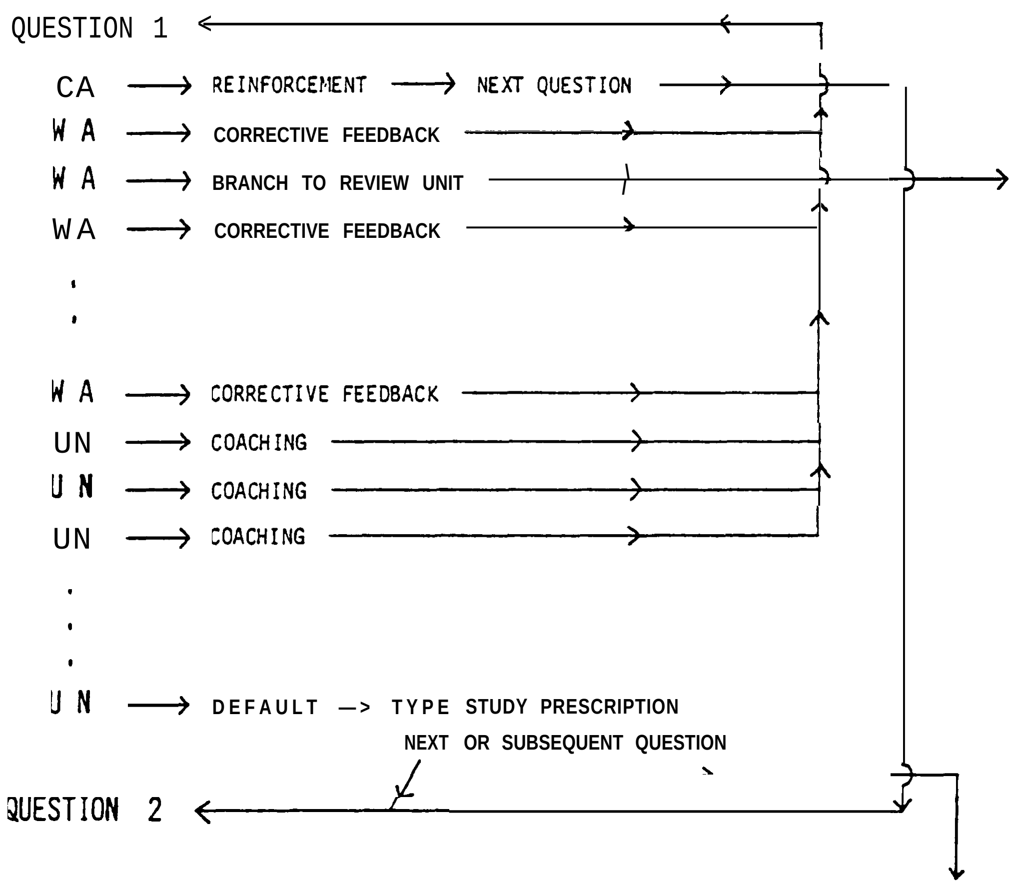
Figure 4.—Schematic of a Tutorial Computer-Based Education Question



KEY: CA = CORRECT ANSWER
WA = WRONG ANSWER
UN = UNANTICIPATED RESPONSE

Simulation and games are instructional strategies that allow participation in a situation closely resembling an actual experience. The sophistication of the computer allows for generation and use of simulation rules and enables complex simulated decisionmaking by the student in accordance with these rules. Simulations permit students to perform "dangerous" and "critical" tasks. They also telescope real-world time, abstract essential task elements from a potentially confusing total environment, and expose the user to a wider variety of environmental variations. For example, flight simulators have been used in aviation since 1939. Real flight accommodates only 6 practice landings per hour; flight simulations allow 30, and can be conducted despite airport traffic, unfavorable weather, and initial pilot inexperience without risk to personnel or equipment (Orlansky and

String, 1977). Through 1981, the total Department of Defense investment for flight simulators will approach $2 billion (Allen, 1976). Aircraft control, submarine control, navigation, automobile control, medical diagnosis and treatment, business management, population and ecology studies, and dozens of other complex situations also have been simulated for the purposes of training and testing both individuals and groups. The skills developed through simulations transfer well to on-the-job performance (Puig, 1976).

Since the 1950's, there have been efforts to construct computer programs that simulate human thought processes through *artificial* intelligence. Research groups at Bolt, Baranek, and Newman; Stanford University; and the Massachusetts Institute of Technology have developed programs to teach logic, symbolic integration, and automatic critiquing of student achievement. Using artificial intelligence, the computer program itself tries to simulate a human tutor (Papert, 1975; Brown et al., 1977). Recent work in this area includes the "sophisticated instructional environment" (SOPHIE), which is being used by the Navy to teach electronic troubleshooting. This program creates a "reactive" situation in which the student learns by experimenting with his/her own ideas (Brown, 1975). Currently, the major source of financial support for artificial intelligence development is the Department of Defense, although small projects have been funded by the National Institute for Education and the National Science Foundation (U.S. Congress, 1978).

Computerized games create a cooperative or competitive environment in which the student interacts with real or artificial participants to achieve specified goals. Simulation and games are often used together as instructional tools for teaching problem-solving skills. In electronic troubleshooting, for example, partners can introduce faults into a simulated machine and the "winner" both diagnoses his/her problem and provides a solution first. Data requested from the computer by either player may be helpful to both.

Inquiry permits the learner or user to address questions to the computer. To process the questions and provide answers, the computer uses key words and stored responses. For example, the computer could be queried as to contra-indications for drugs or serve as a "consultant" for the diagnosis and management of patient problems. This use differs from artificial intelligence because queries are compared to specific answers rather than being interpreted according to a general rule or algorithm.

Funding

During the past 20 years, CBE development and testing have been supported by Federal, State, and local governments; educational institutions; private foundations; the military; large industrial firms; the computer industry; and, to a lesser extent, the publishing industry (Tennyson, 1977). Table 2 shows the results of a 1974 study of expenditures by developers for CBE programs in all subject areas.

More recent data on funding for health-related CBE projects between 1968 and 1978 show three primary funding sources: the Federal Government, private medical foundations, and medical boards. Their combined support totaled over $9 million (Association of American Medical Colleges, 1979). Among the Federal agencies, the National Center for Health Services Research, the National Library of Medicine, and the Bureau of Health Manpower provided over $5.4 million. Almost .50 percent of these Federal funds went for direct support to medical school programs that were developing, using, or evaluating CBE; over 35 percent was directed to improve the cost-effectiveness of computers in

Table 2.—A Sample Spread of Computer-Based Education Funding and Development Sources as of 1974

Categories of developers	Percent of CBE programs developed as of 1974*
National Science Foundation.	300/o
Colleges and universities	29
Military ., ...	10
U.S. Office of Education	9
Private sector	9
Public schools	8
National Institutes of Health , ...	1.8
Other Federal agencies.	1.8
Other—foundation	
State agencies	
Community colleges	1.4
Professional societies.	
Total, ...	1000/0

"IS somewhat Inflated since It Includes learnlng *about* computers (e g , comput. er science and programming) as well as learning wlth computersd (e g , CBE)
SOURCE Human Resources Research Organizatlon, 1974

cost-effectiveness of computers in health education; and the remainder was dedicated to projects designed to educate physicians in the use of computers.

Among private medical foundations, the National Fund for Medical Education, the Robert Wood Johnson Foundation, the Kellogg Foundation, and the Merck Foundation have expended over $2 million on a wide variety of CBE projects. Medical boards, such as the National Board of Medical Examiners, the American Board of Internal Medicine, and the American College of Physicians, jointly spent almost $2 million in the development of CBE materials for the assessment of physician competence.

Federal funding levels for CBE research and development have decreased in recent years (U.S. Congress 1978). This reduction is due partially to the inability of CBE researchers to document initial claims of large cost decreases and proficiency increases in education and training as a result of CBE use. In many situations where CBE proved useful, State, local, or private support was used to replace Federal money (Montgomery County Public Schools, Ohio State University, etc.).

Limitations and Capabilities

Computer-based education is most frequently applied to test knowledge and skills in areas in which correct responses do not involve an affective component, such as attitudes or preferences. In situations where an evaluator must observe the performance of certain skills (e. g., surgery), assessment by computer is ineffective, if not impossible. Additionally, required individual and organizational changes often inhibit effective CBE introduction, diffusion, and utilization (Casburgue, 1978). Despite these and other limitations, CBE can be an improvement over more conventional educational and evaluative methods. Table 3 summarizes the results of 32 studies that are recent and representative samples of the many CBE evaluation studies. The findings of these studies are summarized below.

Savings in learner time to complete a course of study were shown in the great majority of the studies, with as much as 50-percent savings in training and testing time. The reorganization of instruction to an objectives-based form, a prerequisite for CBE use, can itself cause significant learner timesaving.

Table 3.—Thirty-two Studies of Computerized Simulations and Testing

	Source	Time saved	Cost saved	Greater efficiency	Improved skills	Provision of training not previously available
S	Abernathy and McBride, 1978 . . . . •	+	+	+	+	+
S	Allen, 1976	+	+	+	+	+
T	Bejar et al., 1977	+	0	+	+	+
s	Bentz, 1975	+	–	+	+	+
s	Brown et al., 1977	+	0	+	+	+
s	Brown, 1977. ....., ...	+	0	+	+	+
T	Brown and Weiss, 1977	+	+	+	+	+
s	Buchanan, 1978	+	+	+	+	+
s	Ellis, 1978	+		+	–	+
s	Gregory, 1975.......,..	+		+	+	+
T	Guerra et al. 1977. . . .	+	0	+	+	+
T	Hansen et al.,1974.	+	+	+	+	+
s	Johnson, 1976..	0	0	0	+	+
T	Lippey and Partos, 1976.	+	0	+	0	+
T	McLain and Wessels,1975. . . .	+	0	+	+	+
s	Misselt and Call-Himwich, 1978 . . .	–	–	–	–	–
s	Mockovak et al.,1974, ...	+		+	+	(conventional – superior)
s	Orlansky and String, 1977	+	+	+	+	+
s	Puig,1976					
	Tanks	0	+	0	0	–
	Aircraft carrier.	+	0	+	+	+
	Weapons trainer. ., ...	+	+	+	+	–
	Airtraffic controller	+	0	+	+	–
	Automobile	0	+	+	+	–
	Airborne Ecosystem.	+	+	–	+	–
s	Roberts, 1977	+	+	+	+	+
T	Sealy,1975.	+	0	+	0	+
T	Vale, 1977	+	+	+	+	+
s	Willey,1975					
	Dartmouth	+	0	+	+	+
	Ohio State	+		+	–	+
	University of Wisconsin. .	0	–	+	+	+
	University of Illinois	+	0	+	+	+
	University of Michigan ...,	+	+	+	+	+
	Totals.	+ = 27	13	~8	26	25
		– = 1	7	2	3	7
		0 = 4	12	2	3	0

Key S = simulation
T = testing
\+ = positive results
– = no slgnificant difference
O = no results

SOURCE Human Resources Research Organization 1978

Cost savings findings were mixed. These findings reinforce the need for further studies in this area. One such study could examine linking particular educational needs with the use of different media. For example, instructor provision of tutorial sessions for three or four students may be more cost-effective than CBE sessions of the same material largely because of the high developmental cost-to-use ratio for CBE. If there is a need for frequent repetition of the sessions over an extended period of time, however, CBE may be more cost-effective. Examples of cost savings are evident in the computer-based simulations of the University of Michigan's Psychology Department; these simulations are carried out at one-half the cost per student hour ($7 versus $14) of live experimentation (Willey, 1975). IBM also realized cost savings from CBE use. IBM's Field Engineering

Division has used CBE since 1964. As a consequence, the number of their education centers decreased from 17 to 3, and the costs of training were reduced by 60 percent (Long, 1978).

Greater efficiency in learner functioning was demonstrated in the majority of these studies. Learners showed greater achievement per unit of time spent because they could proceed at their own pace, receive continuous feedback on their individual performance, take tests at appropriate points, and discuss materials presented with their peers. Tests could be tailored to precisely assess the individual's performance, not only by giving a score, but also by identifying any gaps in knowledge. Since clerical chores of grading and remediation are part of most CBE programs, the efficient use of instructor time also increased.

Improved skills were shown in 80 percent of the studies in such diverse areas as flying and flight maintenance, merchant marine and submarine operations, personal interviewing, business forecasting, and on-the-job performance of telephone servicepersons (Puig, 1976; Roberts, 1977).

Provision of training not previously available was characteristic of the large majority of the studies analyzed. Simulation for training purposes is a prime example of this uniqueness: simulation can provide practice of many kinds that only years of experience could previously have provided. For example, weather, traffic, time, maintenance, and fuel costs make training of airline pilots or tanker captains in real craft impractical (Puig, 1976); and financial, political, and physical phenomena cannot be adjusted for training purposes.