School Principals, 54, 1970, pp. 27-40.

*"For those who are interested in installing and operating CAI systems, we caution that they should believe neither those who argue that the cost is very slight nor those who counsel that the cost is inordinately high. The installation and operation of CAI courses does entail substantial cost, but many aspects of standard instruction also are expensive."*

# Computer-Assisted Instruction

PATRICK SUPPES
MAX JERMAN

THE number of applications of modern computer technology has increased steadily since the first commercial computer began operation in the Census Bureau in 1951 (2)*, and none is more exciting than the application of computer technology to education and, in particular, to instruction.

Leaders in education and industry cite several educational requirements that make computer-assisted instruction (CAI) inevitable. Among the most prominent are: (a) the current emphasis on individualizing instruction, (b) the increasing amount of new information to be learned, (c) the shortage of qualified teachers, and (d) the growing need for periodic upgrading of one's education throughout life.

The question of whether CAI will play an increasing role in education is no longer debated. Rather, the question is "When will CAI begin to play a more prominent role?" The state of the art or CAI is the subject of this paper in terms of both available programs and available hardware. We begin our discussion by considering some of the types of curriculum programs now in use.

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* References are listed on page 40.

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### *Types of Curriculum Programs*

**Drill and practice.** Instruction provided by a drill-and-practice program is supplementary to the regular curriculum taught by the classroom teacher. A drill-and-practice program may be under partial control of the classroom teacher; that is, the sequence of topics studied by students may be specified in advance by the teacher. Concepts are first introduced in class, and students later review and practice fundamental skills on an individualized basis at instructional terminals.

The drill-and-practice approach lends itself readily to many subject areas in both elementary and secondary schools, and provides an opportunity for teachers to be creative in introducing and developing new concepts in class. Teachers, however, are not able to provide immediate feedback to 30 or more students as they work through a set of exercises. The computer *is* capable of presenting individualized lesson material of appropriate complexity to a number of students almost simultaneously, in addition to providing immediate feedback and correction. Further, a report on each student's performance is furnished the teacher as an aid in evaluating student progress.

The structure of a drill-and-practice program that includes branching, evaluation, and review is quite complex. For example, in the Stanford drill-and-practice program in elementary mathematics, the content of the year's work at each grade level is divided into 30 concept blocks. Each block contains lessons for seven days' work. The lessons are arranged sequentially in blocks coordinated with the development of mathematical concepts introduced by popular text series. Adapting this program to any given text usually requires no more than reordering the blocks in the required sequence. Blocks from other grade levels may be inserted in the sequence for either rapid or slow learners. It is not unusual for each class to work on a different sequence of blocks.

The first day's lesson of each block is a pretest which serves to identify the achievement level for each student on each concept. On the following day, based on his pretest performance, the student is automatically assigned one of five lessons each at a different level of difficulty. The student's performance is computed automatically after each lesson in terms of percent correct, and the student is given a lesson of greater difficulty, the same difficulty, or of lesser difficulty the following day. The level of lesson difficulty assigned each student is a function of his own performance on the previous lesson. A post-test is given on the seventh and last day of each drill block. In Figure 1, each darkened circle represents a lesson. Level 1 is the most remedial in nature, and level 5 the most difficult. The average student is expected to work at level 3.

Essentially, what happens is that students are given a pretest on each concept, such as addition and substraction, and, based on individual scores, are then assigned to one of five mathematics groups, each working at a different level of difficulty. The students are reassigned automatically to appropriate difficulty-level groups at the end of each lesson. In addition, students are given individual review lessons (noted "r" in Figure 1) selected from the block in which they had the lowest post-test score. Each student may be reviewing a different concept, again at one of five levels of difficulty as determined by his post-test score. Following four days of review, the student is given a review test (noted "t" in Figure 1). The review test score that replaces the previous post-test score determines whether review lessons will be selected from this concept block in the future. The daily lesson in the regular concept block constitutes approximately 70 percent of each day's work; the remaining 30 percent is individual review. Thus, each student periodically reviews his weakest area throughout the year.

Individualized instruction is provided by arranging the sequence of concept blocks, adjusting the sequence as needed, selecting blocks from different grade levels for use by a given

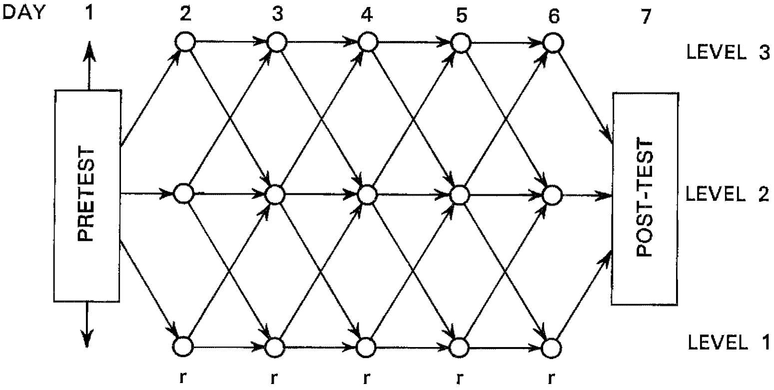

Figure 1 Branching structure followed in constructing sets of exercises for concept blocks.

class, and providing lessons automatically at five levels of difficulty for each student. Students may work through material as rapidly as they desire simply by taking more than one lesson each day. They may catch up following an absence in the same way. Poor students, as well as students of high ability, can have successful experiences because the difficulty level can be adjusted to their individual needs. In addition, students are reinforced immediately following each response.

Drill-and-practice programs in the areas of elementary mathematics, elementary reading, spelling, and language arts are available from commercial organizations or from university centers.

**Tutorial.** The tutorial instructional program assumes the burden of instruction. All, or nearly all, necessary information is programed into the instructional sequence. Provisions for remedial help or skipping ahead are often built into programs of this kind. Most CAI programs developed to date are tutorial and were designed either as special supplementary units or as full-course sequences. Teachers incorporate tutorial units at appropriate points in the curriculum sequence in much the same way as they would programed texts. Tutorial sequences, however, are usually prepared for schools that have the highest pupil-teacher ratio or for special content areas where expertise is not readily available.

Hickey (1) cites 310 available CAI programs from various centers in the United States. Upon examination of the ENTELEK file, which describes the programs, one is struck by the fact that most programs listed are less than an hour in length. Many are available only to a select audience near the computer center.

Some of the programs available for use in schools are Stanford's 3-year logic-algebra program, a college-level Russian language program, and a beginning reading program for grades 1 to 3. Florida State University has produced a college-level physics course which is offered for credit. A science program for seventh-, eighth-, and ninth-grade students is also being field tested. Students in the program at Florida State combine laboratory work with work on instructional terminals. The University of Illinois, University of Texas, State University of New York, and other places have similar projects in several subject matters underway.

A somewhat different approach to tutorial instruction is the program in which the student is a player in a game-type situation designed to develop an ability to deal realistically with problematic situations that face him in the game. In this approach, the student learns from experience the consequences of his decisions rather than from direct instruction. In perhaps the best known of these game programs, the student assumes the role of priest-king of a Sumarian city-state of 3,500 B.C. (5) The program is available on a limited basis only.

Problem-solving programs also are included under the tutorial heading, since it is possible for students to learn course content at the instructional terminals. In this instance, the classroom teacher directs student interactions and aids in planning and program preparation. Many of these programs are designed to teach students to solve mathematical problems using the computer as a tool. Students learn and use languages such as ALGOL, FORTRAN, BASIC or APL. The course of instruction consists of a sequence of graded exercises drawn from such fields as physics, engineering, and economics.

A description of all the various tutorial programs is beyond the scope of this paper. The reader is referred to the ENTELEK publications for descriptions of other available programs.

Now we turn to a brief consideration of some instructional terminals.

## *Terminal Configurations*

Before discussing the terminal hardware itself, one ought to list criteria for evaluating a given system. In order of importance these criteria are: (a) content of curriculum, (b) level of student population, (c) ease of operation, (d) efficiency of operation, (e) reliability, and (f) capacity for data retrieval.

Decisions concerning the subject content and the student population should be made before considering hardware. What is it that needs to be taught to whom? Administrators, often pressured to be innovative, take whatever is available instead of making a selection on the basis of need. Good programs can produce excellent results when they are used as they were intended with a needy population.

Terminals should be easy for students to operate, efficient in terms of response time, and reliable; that is, not subject to frequent breakdowns. The student should not have to follow an elaborate procedure to operate the terminal; rather, he should be faced only with the instructional problem. Response time should be low. Our experience indicates that the system should respond in a mean time of ½ second after the student presses a key or touches a screen. Response times longer than 2 seconds result in loss of motivation and lower learning rates.

The system also should provide feedback to the teacher or administrator on student performance. Daily or weekly reports on each student's performance aid in the overall evaluation of progress and permit teachers to help students in specialized areas.

**Simple configurations.** Currently, the simplest configuration for an instructional terminal is a teletype machine or electric typewriter connected by telephone line to a computer. Many drill-and-practice and tutorial programs run on systems with student terminals of this type. Instructions and lesson material are typed to the student under computer control.

Another simple terminal device is a telephone with touch pad. Under computer control, lesson materials are given to the student over the telephone, and the student responds by using the keys on the touch pad. An arithmetic program for elementary-school children has been successfully tested in New York City. The computer required to produce the digitized audio used in this program is not a simple device, but the student terminal is. Student responses for each of these configurations are handled by the system's central computer. Branching decisions and adjustments are handled automatically as the student responds. Detailed information can be available to teachers at the end of each day's run.

**Intermediate configurations.** In addition to a teletype or typewriter, student stations may include a slide projector, a tape recorder, or both. Many systems which have these devices operating simultaneously under computer control have been less than satisfactory for at least two reasons. First, slide projectors and tape recorders are subject to frequent breakdown. Second, in spite of the anticipated advantages of visual and auditory capabilities, many programs run on these systems failed to show better results. This is not to say that we are not in favor of visual or auditory displays—we are. It should be kept in mind, however, that the curriculum produces whatever learning takes place, not the hardware.

**Complex configurations.** Student terminals in this category consist of a cathode-ray tube (CRT), with audio or film display, or light pen, or any combination of these features. Under computer control, a wide variety of stimuli may be presented. Students respond by using the keyboard or by pressing the light pen to the face of the CRT at the appropriate location.

A wide variety of curriculum materials may be presented on a configuration of this type. Its versatility lends itself to the presentation of curriculum content appropriate to students of all ages. The complex configuration, however, is subject to the same sort of reliability problems as the previous configurations, and it is the most expensive of the terminal configurations.

### *CAI versus Programed Instruction*

Programed instruction is an attempt to individualize instruction in a limited way. There are programs that emphasize the benefits and advantages inherent in greater remedial branching through adaptation of programs to accommodate individual difficulties and differences. Examination of the structure of many programed texts reveals that for students who make few or no errors, the program is essentially linear in nature. It is not surprising that about all that can be claimed for programed instruction is that students learn approximately as much as students learn from regular classroom instruction in somewhat less time. The entire content of the course is contained in the linear main line. This is not to say that this is bad; however, it does not make sufficient allowance for individual differences either in terms of student background or achievement level. The instructional sequence is not truly individualized, since stimulus items are not dependent upon student responses. Many small frames in programs often are redundant to the point of boredom and fail to require the thought and knowledge of results at the level required for effective learning. Reinforcement is not truly immediate in programed materials, since students must check answers by moving masks or turning pages. Neither are hints easily available for students having difficulty. Evaluation is difficult since a teacher must check each response to see where errors were made if a student's performance was less than expected on some criterion test.

Computer-assisted instruction, on the other hand, does provide for immediate reinforcement and correction as the student works through a lesson. In the Stanford arithmetic program, for example, students who type an incorrect character are stopped within 1/10 second and told "No, try again." The idea is to correct the error as it occurs, often before the student has even completed the whole answer. Once the student corrects his answer, he completes the exercise from that point on. A large number of hints may be stored in computer memory; an appropriate set is available at certain points in the program. Students who type "H" for "help" or "hint" receive a clue on how to proceed.

Branching is handled automatically in a variety of ways by the computer without the student's being aware that he is being channeled into a different sequence. Students simply respond to the item presented and, according to their performance, the computer automatically selects and presents the next stimulus item or set of items.

There is considerable discussion in the current literature about the development of CAI programs which take into account a variety of personality, aptitude, and achievement variables when selecting appropriate curriculum items. None of these programs is in operation to our knowledge. The existing programs select material on the basis of achievement only. Perhaps this is as it should be, since our experience indicates that the best predictor for a student's future success is his immediate past performance. Keeping records is, of course, one of the things a computer does well. Students are programed into new curriculum material on the basis of immediate past performance, and reports of student performance are given periodically to teachers.

One of the greater advantages of CAI is the approximation to dialogue possible in such a highly responsive environment. The student is more involved in solving even a simple arithmetic problem step-by-step, for which he receives reinforcement on each character, than in solving a problem using pencil and paper and checking the answer. A description of two such programs follows.

## *New Curriculum Programs*

**The strands program.** The objectives of this program are: (a) to provide supplementary, individualized instruction in elementary and secondary mathematics on a daily basis at a level of difficulty appropriate to each student's level of achievement; (b) to allow each student to accelerate in every concept area in which he demonstrates proficiency; (c) to provide remedial help for each student in each concept area as needed while continuing to provide a degree of success which remedial students often need; and (d) to provide each teacher with a weekly detailed profile report of each student's position in each concept area.

A strand is a series of problems of the same operational type (e.g., counting and place value, addition, subtraction, fractions) arranged sequentially in equivalence classes according to their relative difficulty and running across the entire six years of elementary-school mathematics and beyond. Table 1 shows the 15 strands in the program. The strands approach provides perhaps the highest degree of individualization to date because each student's lesson is prepared for him daily by the computer, the lessons are presented as mixed drills at a level of difficulty in each concept determined by the student's prior performance in each concept, and the student moves up each strand at his own pace.

**Advancement.** Although a student may be working in several strands simultaneously, he begins each new strand with the class of lowest difficulty or at a grade level determined in advance by standardized achievement test scores. Each day's lesson consists of a distribution of problems from three different classes in each strand. One third of each lesson contains problems from the student's grade-level class, the second third is selected from the next higher class, and the last third from the next lower class for

TABLE 1

Strands in the Arithmetic Program

| Strand | Description |
|---|---|
| 1 | Counting and place value |
| 2 | Vertical addition |
| 3 | Horizontal addition |
| 4 | Vertical subtraction |
| 5 | Horizontal subtraction |
| 6 | Equations |
| 7 | Horizontal multiplication |
| 8 | Vertical multiplication |
| 9 | Fractions |
| 10 | Division |
| 11 | Large numbers and units of measure, time, money, linear measure, dozen, liquid measure, weight, Roman numerals, metric measure |
| 12 | Decimals |
| 13 | CAD laws |
| 14 | Negative numbers |
| 15 | Problem-solving |

review. Thus, the lesson contains problems from the class just below the student's grade level, problems at grade level, and problems from the next higher grade level. Branching decisions are made on the basis of student performance on each set of six to twelve problems in each strand. The exact criterion varies across strands and grade level.

A student can work through the material at his own pace by taking more than one lesson each day. He can catch up in the same way following an absence. Working at a level suited to his ability, the poorer student, as well as the student of high ability, has successful experiences. Further, the immediate reinforcement the student receives after each response is one of the more positive features of the entire CAI program.

**Assignment of new strands.** The choice of strands to which a student is assigned rests with the computer-assisted instruction program. After the initial grade placement at the beginning of the school year, a new strand is added for each student when his average grade-placement score reaches the grade-placement level of the lowest difficulty class of the next strand.

When several strands are being worked on simultaneously, the computer selects problems from each strand for each lesson as described above. The remainder of the problems for any given lesson is selected from the strands in which the individual student is weakest. For example, if Figure 2 represents a student's grade placement in each strand, the program is so constructed that the student will receive problems from strands 1 to 5, followed by a review of the strands for which he had the lowest grade placement; in this example, strands 1 and 3. Thus, the student is assured of an opportunity to advance in each strand and also is given more practice in individual areas of weakness.

Other strands include the commutative, associative, and distributive laws of arithmetic and integers. Problem-solving and algebra strands are also in preparation.

**Dialogue.** At Stanford we are just beginning to develop dialogue programs. These programs aim at a much richer interaction between the student and the computer program. In principle, the objective of a dialogue program is to achieve an interaction similar to that between a talkative student and a talkative tutor. However, it does not take much reflection to realize that we do not understand in any clear scientific fashion the nature of dia-

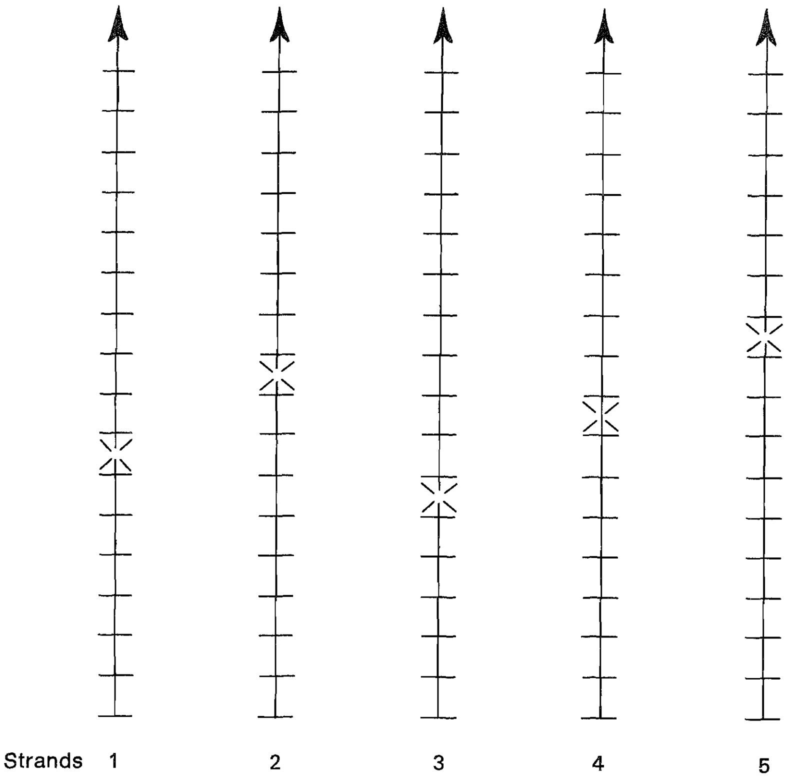

Figure 2 Sample student profile.

logues. When each of us engages in a conversation, we are not aware of the principles we use in responding to previous statements in the conversation, how we process these statements, how we select from them the content on which to concentrate for additional remarks, etc.

In some areas of curriculum, nevertheless, it is possible to develop explicit dialogue programs. As might be expected, mathematics is the easiest and most obvious area in which to begin. Our first dialogue programs try to scan the student's work and to offer comment on the deficiencies in what he has done thus far when he asks for it. The programs also ask him leading questions about what he is trying to do, and how he plans to accomplish both final and intermediate ends. We should like to emphasize that we believe it will be some time before operational dialogue programs will be in widespread use in schools. The investigation of such CAI programs is an important area of research and should be pursued intensively at the research level before implementing them in schools.

### *The Role of Government and Industry*

Most of the work in computer-assisted instruction thus far has been funded by various projects sponsored by the federal government. This probably will continue to be the pattern over the next two or three years. Yet the success of CAI in a broad operational sense will depend upon these efforts' becoming a part of local and state school budgets. Hardware and software costs are just beginning to reach the level at which individual school systems can hope to pay for limited facilities out of their own budgets. CAI efforts in secondary-school computer programing and related data-processing topics will perhaps be one of the earliest areas of concentration, especially in terms of the use of local and state funds.

It is also apparent that at the community college and four-year college level considerable funds probably will be expended by state and local funding agencies in order to implement programs that are large in number, but that require a technically well-qualified teaching staff. It seems a reasonable prediction that CAI will be an especially useful tool for basic and remedial courses in mathematics and English in two-year and four-year colleges over the next decade.

As it has in most other instances of educational innovation, much of the initiative will necessarily come from educational institutions. The role of industry, however, is particularly important in the field of computer-assisted instruction because the sophisticated equipment is manufactured and marketed by industry, and educational institutions will be dependent upon industry to provide, at the very least, technical knowhow in operating and maintaining computer systems.

As might be expected, a number of firms are interested in CAI and will continue to contribute toward its development. On the one hand, we have large computer manufacturers like IBM, RCA, and Honeywell. On the other hand, we have small software firms interested in the programing and curriculum aspects of CAI. These firms run from traditional publishers like Harcourt, Brace

& World to special software firms such as Bolt, Beranek and Newman in Massachusetts, and Computer Curriculum Corporation in Palo Alto, California. A large number of additional firms have some peripheral interest in computer-assisted instruction. As the market develops, it can be anticipated that industry will devote more attention to CAI. Undoubtedly, publishers will expend greater effort than they now do in the development of CAI courses and curriculum, as they sense the growth of a sizable market that will make commercially feasible a substantial investment in curriculum development.

In a very general way, the role of industry in CAI should be similar to the role of publishers in the production and marketing of textbooks. Yet, because of the sophistication of the technology and the requirements for operating and maintaining computer systems, as opposed to the simpler matter of placing books in a school, the relations and areas of responsibility between industry and educational institutions will have to be closer and more carefully thought out than they have been in the case of publishing.

### *Concluding Remarks*

In this article we have attempted to give a sense of current activities in computer-assisted instruction and to project at least in a modest way some of the future directions. We have not delved into many important details nor even into some central topics. For example, we have not attempted to survey the work undertaken in evaluating CAI programs or what is an appropriate methodology of evaluation. For a report of some fairly extensive evaluation results, the reader is referred to Suppes and Morningstar (4). For a detailed discussion of the first stages of developing a CAI program, and the sorts of attitudes encountered by teachers, students and parents, the reader is referred to Suppes, Jerman, and Brian (3).

On the vexing subject of CAI economics, we do not think the appropriate analyses have yet been published. One of the difficulties is that projections too often are based on the technology of last year or the year before, and in a field that is changing as rapidly as that of computers, it is difficult to prepare sound economic cost forecasts that can be depended upon to be reliable and accurate over the next few years. For those who are interested in installing and operating CAI systems, we caution that they should believe neither those who argue that the cost is very slight nor those who counsel that the cost is inordinately high. The installation and operation of CAI courses does entail substantial cost, but many aspects of standard instruction also are expensive. In areas like that of computer programing it is simply the case that many secondary schools are not able to find qualified teaching personnel. The offering of computer programing courses in a CAI context may be the only feasible alternative. For example, as the national need for languages such as Russian, Chinese, and Japanese increases over the next decade, the only hope for offering them on a widespread basis at a sufficiently high quality will be through the use of CAI courses. Finally, we believe that much of the remedial work in mathematics and English in the present high-school curriculum can be made more attractive and more efficient by placing it in a CAI context. Again, the cost of these programs will not be negligible, but the increased gains in student performance and achievement will, we would predict, offset the costs.

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