COMPUTER-ASSISTED LEARNING IN ACTION

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What I have been asked to talk about today are some of the recent developments in computer-assisted instruction (CAI). I shall not be talking about the scientific problems associated with devising effective pedagogical methods, but rather about applications that have been made of CAI. I want to emphasize at the outset that there are many scientific problems to be solved in this area and that considerable progress has already been made, but such topics are technical and not easily discussed in a general talk. Further, the chairman of our symposium has been explicit in his instructions to confine my remarks to computer-assisted learning in action. Before launching into a discussion of computer-assisted learning, I should like to show you a film produced at Stanford University illustrating various aspects of CAI. Hopefully, this film will give you some acquaintance with the nature of computer-assisted learning and make my later comments more meaningful.

[The film which was shown at this point illustrated various forms of CAI under development at Stanford University. It gave special attention to a computer-based program in initial reading for children in grades 1 through 3 and presented several different types of student terminal devices and computer configurations in use at Stanford. For a review of research on CAI at Stanford University, the interested reader should consult the following references: Atkinson (1968), and Suppes, Jerman, and Brian (1968). The learning models and optimization methods that underline much of the research are discussed in Atkinson and Shiffrin (1968), Groen and Atkinson (1966), Rogers (1967), and Wilson and Atkinson (1967). Detailed descriptions of the various CAI programs developed at Stanford and a bibliography of published research are available by writing to the Institute for Mathematical Studies in the Social Sciences requesting copies of the quarterly reports entitled "Progress Report: Stanford Program in Computer-Assisted Instruction." These reports provide descriptions of the major CAI programs in use at the Institute and include instruction in mathematics and reading for the primary grades; instruction in mathematics and language arts in grades 4 through 8; college-level courses in logic, algebra, and Russian; and CAI programs in computer source languages.]

In recent years there have been rapid, and in many cases quite sophisticated, developments in the area of computer-assisted instruction. A number of factors account for these developments. One factor, of course, has been the dramatic growth of computer technology in general. Also of major importance from a psychologist's viewpoint have been the progress made in formulating viable psychological theories of the learning process, and their related impact on curriculum development. However, in my opinion, the single most important factor in the development of CAI is the potential that it offers for answering today's most pressing need in education—the individualization of instruction. Children enter school with remarkably different abilities and levels of knowledge. They work at different rates and with different degrees of accuracy and understanding. To accommodate to these individual differences is a continuing and overriding concern of our educational institutions. In the past the solution was easy because only a small part of the population was given an extended education, and those regarded as important future members of society, the children of the aristocracy, were educated primarily by private tutors. But since the turn of the century, the concern for adapting the curriculum to the ability and achievement level of each student has become a serious concern of schools dedicated to educating the future citizens of a broadly based democratic society. Today we all accept the concept that education is universal, and every forecast indicates that the number of years of education of the average citizen will continue to increase in the foreseeable future. Unfortunately, the economics of education are such that even in an affluent society we cannot afford to provide tutorial instruction for students on a broad basis. Computer-aided instruction does offer the real promise of a technique that can be used in the public schools to meet the problems of individual differences at a deeper level and in a more scientific way than as yet has been possible.

Computer-assisted instruction has grown in less than five years to a point where, during the current school year, many thousands of students ranging from elementary school to the university level are receiving a significant portion of their instruction in at least one subject area under computer control. In the Stanford project alone, approximately 4000 students are daily being processed in subjects ranging from initial reading and mathematics in the primary grades to college-level courses in Russian. Serious CAI applications are now in progress in many universities throughout the United States and also in Europe. A list of those universities that have had substantial programs under way for two or more years would include Stanford, the University of California at Irvine, the University of Texas, the University of Illinois, Florida State University, Pennsylvania State University, the University of Pittsburgh, State University of New York, Harvard University, and a very significant effort at the University of Paris.

Computer-assisted instruction was developed in university centers, but has now moved into the public schools. Philadelphia's school system was the first major one to implement a CAI project independent of university sponsorship. Philadelphia was closely followed by New York City and Waterford, Michigan, where significant projects began operation this fall. CAI projects in several other school districts are in the planning stage and will be operational sometime in the next ten-month period. Industry has also become deeply involved in the field of CAI, particularly in the design and production of integrated hardware-software systems. IBM was a pioneer in this area with the production of its CAI 1500 System which is in operation in more than 15 installations around the country. Philco-Ford entered the market with the system currently in use in the Philadelphia public schools. More recently, Instructional Systems was organized as a division of RCA. The RCA Instructional-70 System is now in operation in the New York public schools and simultaneously services 200 student terminals.

The growth of the CAI project at Stanford University is in many respects illustrative of developments in the entire field over the past several years. In

1963, we set about to develop a small tutorial system. Since there was no integrated CAI system available at that time, we assembled a system from components produced by several manufacturers: a PDP-1 computer from the Digital Equipment Corporation, a "random access" audio device from Westinghouse, cathode-ray display tubes from Philco-Ford, and film-image devices from IBM. The technical difficulties of forging a unified system out of such diverse components were enormous. However, most of the difficulties were overcome and the system was made operational in the fall of 1964. Six student stations function simultaneously, providing instruction in elementary mathematics and language arts. Elementary school students were brought to Stanford by bus and received instruction on a more-or-less daily basis.

Encouraged by our initial success, we applied to the Office of Education for a grant to develop and implement a CAI program in initial reading and mathematics for culturally disadvantaged children. It was at this point that IBM, in collaboration with the Stanford group, undertook the development of the 1500 System. After a major effort on the part of IBM and an equally significant effort by Stanford, the 1500 System was installed in an East Palo Alto school and began operation in the fall of 1967. Last June marked the end of the second year of operation of this system on which approximately 400 first-grade students received a major part of their daily instruction in reading and mathematics under computer control. The 1500 System has been classified as a tutorial system in the sense that a very rich branching logic allows real-time instructional decisions to be made regarding the material to be presented next, based on an evaluation of some subset of the student's response history. Significant gains in student achievement have been demonstrated in each of the two years of operation. One of the most surprising results was in the area of reading. As is the case for the population at large, the girls in our control group were far better in initial reading than the boys. The experimental group run on CAI showed a marked improvement over the control group, and also the difference between girls and boys was virtually washed out. Stated otherwise, CAI led to improved performance for both boys and girls, with a greater improvement for the boys, who by the end of the year were roughly at the same level of performance as the girls.

Paralleling the development of the 1500 System, a second CAI system, based on a very different design philosophy, has been developed by the Stanford group. This system is known as the Stanford Drill-and-Practice System. It utilizes a large central computer, and the student terminals are inexpensive Model 33 teletypes tied to the computer over ordinary telephone lines. There are some 500 such terminals spread around the Stanford area and also remotely located in Mississippi, Kentucky, Washington, D.C., and Iowa. Some terminals on the system are also equipped with digital audio, the audio being stored in the computer in digital form and relayed to the student over ordinary telephone lines. Although the hardware configuration of the drill-and-practice system is much simpler than that of the 1500 System, an even greater difference is found in the data management and branching structures. The drill-and-practice system does not have the real-time branching capability of the tutorial system. Individualization is primarily accomplished through an off-line update wherein the performance of each student on day N is examined overnight, and appropriate lesson material based on that performance record is selected for presentation to the student on day $N + 1$. The assumption governing the drill-and-practice programs is that basic concepts are presented and developed by the teacher in the classroom, and the computer furnishes intensified drill and practice on these previously developed concepts at a level of difficulty appropriate to each student. During the current school year, approximately 4000 students will receive daily lessons in arithmetic, initial reading, spelling, and logic.

The tutorial and the drill-and-practice procedures just described in the context of the Stanford project are by far the most prevalent modes of computer-assisted instruction. However, they are both essentially simulations of typical student-teacher interactions. Their value lies in the degree of individualization of these activities and in the increase in efficiency which can be brought about by the unique capabilities of electronic data management. Other types of applications of computers for instruction have been pursued. For example, a computer simulation program involving laboratory experiments in college chemistry has been developed at the University of Texas. This program frees the student from the time-consuming task of handling complex and sometimes dangerous equipment and allows him to concentrate on observation and the logical dynamics of analysis. Essentially the student is seated at a terminal like the one shown in the film and carries out a normal laboratory experiment in chemistry. He may mix two compounds and see the result in color on a film screen; he may then decide to centrifuge and again observe the outcome on the screen, carrying out each operation on the typewriter and following any path of permissible operations he chooses in conducting the experiment. Of course, if he makes a serious mistake, the computer will warn him of this mistake.

The ultimate CAI system is one in which the student can input free-form statements and questions which would be analyzed by the system and understood in the sense that the system would then compose and display appropriate replies. Needless to say, we are some distance from that goal at the present. However, the CAI course in logic developed at Stanford University is a step in that direction. In this program, the student is required to carry out logical derivations and algebraic proofs. The system will accept any line in the proof or derivation that does not violate the rules of logic. Thus, the student and the system can achieve a kind of free interaction at least within the confines of the language of elementary logic. The above is but a brief sampling of the variety of instructional applications of computers that are currently available. Let us now turn to some of the problems that confront workers in the field.

There are many problems in CAI concerning both hardware and computer software development that we will not have time to discuss today. However, I would like to state that in my opinion there are no major technical obstacles to the development of cost-effective CAI systems that could be in large-scale use in the next five to ten years. In this regard, the work of Professor Donald Bitzer of the School of Engineering at the University of Illinois is worth mentioning. He has been actively involved in the development of CAI for some time and has just recently made a detailed analysis of the costs involved in large-scale CAI systems. On the basis of this analysis, he has shown, using current technology, that a CAI system equipped with both audio and visual display devices can be designed to carry out instruction at less than 30 cents per student hour. At this level of cost, supplementing education with CAI may well be the most economical way of making major improvements in school learning.

A problem of a more serious nature than technical improvement or reduction of hardware costs does exist, however. It is the problem of evaluating the effectiveness of computer-assisted instruction. It should be clearly understood that evaluation of CAI programs is only partially an evaluation of equipment and the system. Primarily it involves an evaluation of the instructional program and, as such, is basically an evaluation of the program designer who is the real teacher in the CAI system. The evaluation question becomes, "To what extent does the curriculum designer provide the computer with an appropriate set of instructional materials and an adequate decision structure for branching among them?" Unfortunately, curriculum design is still more of an art than a science. However, computers are a unique instructional tool in that we can embody in their programs whatever scientific knowledge we currently possess about human learning; at the same time, they hold the promise of greatly increasing that knowledge if proper utilization is made of the response data which they can collect. In the past, psychologists interested in human learning have not shown a great deal of enthusiasm for studying the acquisition and retention processes involved in mastering a subject-matter area such as initial reading or mathematics. Instead, they have preferred to study the college student as he masters highly contrived and artificial tasks in a laboratory situation. The reason is not that the learning theorist is uninterested in more complex phenomena, but rather that he feels he cannot exercise sufficient experimental control to gain accurate and meaningful data. With a computer system this objection is no longer valid, for now subject-matter learning can be studied in the schools under conditions of greater control and with more precision in response-recording than was possible in the past, even in the psychologist's laboratory.

One of the primary aims of computer-assisted instruction is the optimization of the learning process. This is implicit in the concept of individualized instruction. A major focus of the research effort at Stanford is the development and testing of instructional strategies expressed as mathematical models. An important class of such models may be called "optimization models," since they prescribe the sequence of instructional events which will produce optimal learning within certain boundary conditions. Such optimization models are difficult to investigate in a rigorous way for complex learning procedures. The problem can be attacked, however, at the level of fairly simple learning tasks. These simple tasks do not encompass all the instructional processes of interest, even at the elementary school level, but they include enough to warrant careful investigation. We hope that analyses of these tasks will provide guidelines for the investigation of the more cognitively oriented instructional procedures.

As an example of an optimization procedure, let me refer to one used in some spelling lessons that are part of the drill-and-practice program in language arts. This is not the most elegant optimization scheme that can be presented, but it is one that is simply understood. A list of N words are to be learned. The CAI program essentially involves a series of discrete trials. On each trial, the computer selects a word to be pronounced by the audio system, the student then responds by typing the word, and the computer evaluates the student's answer. If the word is correctly spelled, the computer says correct. If the response is incorrect, the computer says incorrect and provides the correct spelling. If X trials are allocated for teaching a list of N words and if X is much greater than the N, then the problem becomes one of finding a decision rule for presenting words for test and study that will maximize the amount of learning. In general, such decision rules can be classified into two types: those that make use of the student's response history on a moment-to-moment basis to modify the flow of instructional materials, and those that do not. The resulting strategies have been termed response-sensitive and response-insensitive. The response-insensitive strategies are usually less complicated and can be completely specified in advance so that they do not require a system capable of branching during instructional sessions. The programs developed by Skinner and his associates, which Professor Hilgard referred to earlier, are examples of response-insensitive instructional strategies. In order to illustrate a response-sensitive strategy, let us assume that the learning process for the spelling task described above is adequately characterized by the one-element model of stimulus-sampling theory (Atkinson and Estes, 1963). In essence, this is a mathematical model of learning which postulates that the learning of a given item occurs roughly on an all-or-none basis. Under the assumptions of the model, the optimal strategy is initiated by presenting the N words in any order on the first N trials and a continuation of this strategy is optimal over the remaining $X - N$ trials if, and only if, it conforms to the following three rules:

Rule 1. For each item in the list, have the computer set up two counters; one, designated as the P-counter, will keep track of the number of times an item has been presented and the other, designated as the R-counter, will count the length of the most recent run of correct responses to that item. At the end of trial N, set all P-counters to 1 and all R-counters to 0.

Rule 2. On any trial, present the item whose R-count is least among the R-counts for all items. If several items are eligible, select from these the item that has the smallest P-count for presentation. If several items are still eligible under this condition, then select from this subset the item that had the slowest reaction time on its last presentation.

Rule 3. Following a trial, increase the P-counter for the item presented by 1. Also increase the R-counter for the presented item by 1 if the subject's response was correct, but reset it to 0 if his response was incorrect. Leave all other counters unchanged.

Even though these decision rules are fairly simple, they would be very difficult to implement without the aid of a computer. Data from our current experiments indicate that the above strategy is efficient at a level predicted by the theory and is far better than strategies that present the items in a predetermined order. We might also derive another potentially more useful model that fixes the achievement criterion at some specified level and produces a set of decision rules which minimize the number of trials to reach that criterion.

These are examples of extremely simple optimization strategies. Others under investigation make use of more realistic assumptions regarding the learning process and employ more powerful mathematical techniques for deriving optimal strategies. Of greater importance, they attempt to optimize performance not only within a given day's session, but also from one unit of the curriculum to the next. The development and testing of models for optimizing instruction has just begun but shows considerable promise for the future. It is not surprising that these problems have received little attention in the past. Optimization strategies that have been derived even for the simplest learning task are usually too complex to use in a school setting without the data management capabilities of a computer. Computer-aided instruction will make it possible for us to implement, on a routine basis, instructional strategies that even the most ingenious tutor could not hope to execute.

In my view, the development of effective optimization strategies and viable theories of learning will be an interactive enterprise, with advances in each area influencing the concepts and data base of the other. For far too long, psychologists studying learning have shown little interest in instructional problems, whereas educators have made only primitive and superficial applications of learning theory. Both fields would have advanced more rapidly if an appropriate exchange of ideas and problems had existed. It is my hope that prospects for CAI, as both a tool for research and a mode of instruction, will act as a catalyst for a rapid evolution of new concepts in learning theory as well as a corresponding theory of instruction.

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