

facts and the selection of predetermined actions on the basis of those facts. This a computer can do beautifully.

In scheduling civil service examinations, for example, our computer makes "decisions" of this kind by the thousands. Why should the time of a man or woman be devoted to such work with less accuracy and little satisfaction? We have other work for men and for women, in which they can do a far better job using the huge data resources of the computers. This work involves decisions on personnel planning, the matching of men and jobs, the forecasting of manpower needs, and the important decisions of career-planning.

For proper decisions in these areas we must have integrated information systems. This will require the use of information across departmental boundaries. It is here that current efforts to standardize symbols and codes will pay dividends. Direct tape-to-tape feeding of data from one department to another may become common. These systems will mesh well with developing plans for an executive-level staffing program which will be designed to locate the best possible man for any given top-level assignment, no matter where in government he may be serving.

The computer's ability to search its perfect memory and pick out records of individuals with specific characteristics has been applied in the search for candidates for Presidential appointments. A computerized file containing the names and employment data of some 25,000 persons, all considered likely prospects for federal appointive positions, is searched electronically. This talent bank, with its automated retrieval system, broadens the field of consideration for the President in critical decisions of leadership selection.

Throughout the government, one of the great responsibilities is to provide true equality of opportunity in employment. To know where we have failed to provide it, where we have succeeded, and how best to plan, we need a multitude of data. Through head-counts we know only that a certain number of Negroes, for instance, were on the rolls in certain grades at a certain time in the past, and now we can count that there are fewer or more. But these data do not reveal whether the people in certain jobs came from lower jobs or from outside the government. They do not assist us in recommending training or evaluating it. They fail to give us the management information required to do a conscientious job in creating conditions that will make a reality of equal opportunity.

To obtain additional and more accurate information, a new effort has been initiated in this area. By means of a voluntary racial designation prepared by

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## PLUG-IN INSTRUCTION

**Computers, harnessed to teaching machines and television, promise a new era in universal public education.**

By PATRICK SUPPES

**C**ONTRARY to the expectations of many, the computer may make classroom teaching more, rather than less, an individual affair. And in doing so it will facilitate learning at a speed and depth of understanding that now seem impossible to achieve.

The theme of individualizing instruction is very old in education. Psychologists long ago documented the fact that individuals differ in their abilities, rates of learning, and even in their general approaches to learning. And educators have concluded that, ideally, the most effective teaching is that which is tailored to the needs and abilities of each individual. But the costs of providing individual instruction in a society committed to universal education are prohibitive. Meanwhile, administrators and teachers continue to struggle with the problem by such means as grouping

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students with roughly similar abilities, and following the concepts of the ungraded classroom and of team teaching.

Surprising as it may seem, the burgeoning technology of computers may offer one of the best means of providing individual instruction at reasonable cost. A handful of experiments throughout the country already are exploring the varied possibilities of this new type of individualized instructional technology.

Computer-based teaching systems, designed to aid the teacher in the individualization process, consist of a variety of student operated instructional devices. These learning machines are not to be confused with the large class of so-called "teaching machines" of recent years—frequently identified with the educational process of programmed learning. Typically, these mechanical devices dispense instructional material in a fixed sequence of small, easy-to-take steps of one or two sentences, usually followed by a question. All students traverse the same sequence regardless of differences in background and aptitude. With computer-based teaching devices, however, the student will study

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**Working at a teletype keyboard, this fifth-grader types out the answer to a problem sent by telephone line from Stanford University. The teletype booth is placed in a corner of the school classroom, and each youngster spends about five minutes a day working on a drill at one of five levels of complexity. As each child works through a drill, the computer records his total time, correct or incorrect answers, percentage of problems correct to date, and the total time in the program.**



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sequence that is tailored to his individual needs. This flexible system will differ from the non-computerized teaching machine in responsiveness to different learning problems, both as they occur or as they have been anticipated on the basis of previous experience with a student.

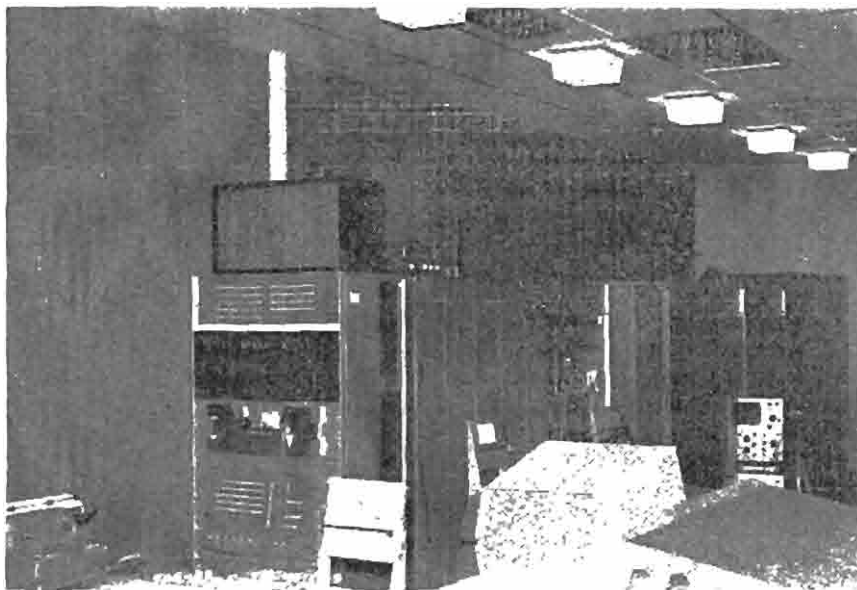
Basically, and most importantly, the computerized system enables the teacher and the researcher to learn about individual students as they are in the process of learning. As a matter of design, the more the machines are used the better tools they will become for instruction. This is because the computer stores and analyzes mountains of learning data amassed while students study with the machines. Automatic curriculum evaluation and modification are only two examples of resultant improvements.

The heart of the new learning machine is the electronic high-speed computer or information processor. The computer functions strictly according to detailed instructions written by a human programmer. This is how it works.

The information needed to perform the task and procedures to be followed are called the program, and are usually entered into the machine on its typewriter keyboard. The program is translated into electronic impulses and often stored on a magnetic tape similar to that in a tape recorder. The control unit of the computer performs the work specified by the program, and the resulting information is transferred to an output device that prints messages on pages, punches holes on special cards, or displays a visual image on a television screen.

The student station, or console, is connected to the computer by coaxial cable or by telephone lines over a distance. It consists of a television-type screen, a light-pen, a typewriter keyboard, and often earphones and microphone as well. Photographs, words, drawings, tables, or equations are lighted up on the television tube; micro-filmed pages or sections of pages can also be enlarged and displayed on a similar screen. When sound is important, as in learning Russian pronunciation or analyzing musical phrases, information is received through earphones. Or, for question-and-answer drill, the student may sit before a teletype machine, which types out messages to which he replies by typing back.

At his console, the student may respond to questions by asking questions of his own, or "talking to" the computer, in two ways: 1) on the typewriter keyboard below the television tube, he may type his responses in ordinary English or whatever is appropriate to the subject being learned—for example, Spanish



**This medium-sized computer, the PDP-1, controls an entire individualized learning system. Connected to it by coaxial cable are classroom devices such as a television screen, light-pen, typewriter keyboard, microphone, and earphones.**

phrases, numbers, or letters of symbolic logic; 2) he may use the light-pen, a device resembling a pocket flashlight, to point to some part of the visual display—for instance, the correct answer in a multiple-choice question. When the light-pen is touched to the screen, the exact point of contact is automatically transferred to the computer's memory. In this way, also, incorrect material may be erased by tracing the light-pen over a section of the image. A revised display will appear on the tube.

The light-pen is particularly useful for young children who can make only limited use of the typewriter; also, because it is silent, it may be used in the traditional classroom, where a typewriter without acoustical insulation would be disruptive. A similarly flexible and convenient device for student response is the electronic tablet, resembling an opaque slate, on which the student may also write or draw with a light-pen.

The important technological advance that makes a computer-based teaching system practical is "time sharing," whereby the immense capacity and speed of the computer allow many students, working independently in different locations, to use a single computer at the same time with little delay in computer response to individual commands, questions, or answers. At the present stage of development, between thirty and forty students, or a like number of classrooms, each working at a different task, can use the computer simultaneously. This time-sharing capability puts the entire potential of the computer at the service of the individual learner, and assures the maximum, and therefore the most economical, use of each machine.

The computer-based teaching components can be arranged in a number of ways, varying from a single typewriter station in an elementary school classroom to a fully automated college classroom containing ten or more self-instructional consoles. Such installations exist today in a few universities across the nation. Indications are that the elementary school child could productively spend as little as fifteen minutes a day at a console, while the secondary school student might work in two thirty-minute sessions, one in the morning and one in the afternoon. A college student might take an entire course of instruction in a learning cubicle conveniently housed in his dormitory. The nature of the subject matter is the chief determinant of machine components and the length of time spent at the consoles. There is already a good deal of evidence that students at all age levels gradually come to feel as much at home with this sort of equipment as they do with an ordinary television set.

Ideally, computer-assisted instruction may be applied at three levels of interaction between student and computer program. These are at present in various stages of development, so far as practical use is concerned:

► **DRILL-AND-PRACTICE SYSTEMS.** Mainly a supplement to the regular curriculum taught by a teacher, this is by far the most viable application of the technology in an applied school setting today. In the case of elementary-school mathematics, for example there is abundant evidence from both pedagogical and psychological studies that students need a great deal of practice in arithmetic skills before a reasonable level of mastery is attained. Students

need corresponding practice in the standard applications of arithmetic and, more generally, in developing what is sometimes called a good "number sense." The computer system at this level can relieve the instructor of a considerable burden, and at the same time provide practice work for each student at his own pace and level of complexity.

But the important difference between this and traditional teaching methods is that with teaching machines the instructor can cater to the needs of each student: each can receive problems that will challenge him, whereas with traditional textbook assignments, no differentiation can be made. It is a straightforward matter to program the computer to offer exercises of various degrees of difficulty, and to select each student's level according to his past performance. Some computer systems have been programmed to generate practice problems guided only by a general rule provided by the text author, who is thus spared the time-consuming effort of preparing every exercise.

► **TUTORIAL SYSTEMS.** In contrast to the drill-and-practice systems, the tutorial system takes over the main responsibility for developing skill in the use of a given concept. In the teaching of elementary Russian at the college level, for instance, it could be the responsibility of a tutorial system to offer a complete body of curriculum material on the recognition of sounds and the unfamiliar forms of the Russian alphabet. While more difficult to develop than drill-and-practice exercises, computer-ready tutorial programs have been prepared in a variety of subject areas such as foreign languages, mathematics, logic, and some units in the general sciences.

Whether one is concerned with college-level Russian or first-grade arithmetic, it is possible with this approach to approximate the relationship a tutor would have with a student. Above all, it is possible to analyze each student's comprehension in greater depth and detail than are usually possible for a teacher with a classroom of thirty. An important point is that in the tutorial program every effort is made to avoid an initial experience of failure. The program also has enough flexibility to avoid boring the bright child.

The instructional mode in a tutorial system will permit freely constructed responses on the part of the student, as in the illustration of a program in mathematical logic. The student is permitted to make any valid inference about the data presented to him by the machine; the main function of the tutorial program is to assess the validity of the inference he makes. The relative wisdom of the step he takes is not indicated until he has made a serious effort to find the

correct proof of a theorem. As is usual in proofs of mathematical theorems, different students will find different proofs; the computer program will accept any proof that is valid. When students do not succeed in finding a proof, the program gives them hints.

It should be evident from these examples that skill-subjects such as reading, mathematics, and elementary foreign languages can be handled most easily and are best understood in this environment. Indeed, tutorial systems can carry the main burden of teaching skill-subjects, and widespread application would lead to a radical revision of the organization of teaching, because a rather large part of all instruction is at the elementary-skill level. For this reason, it is common to ask, what will be the teacher's task if these elementary skills are taught in a tutorial fashion by computer-based terminals? The most important point to be made in this connection is that no tutorial program for computers in the near future will be adequate to handle every type of problem that arises in learning. It will be the teacher's responsibility to move to the much more challenging and important task of trouble-shooting: of helping children who aren't proceeding successfully through the tutorial program.

► **DIALOGUE SYSTEMS.** Dialogue systems allow the student to conduct a genuine dialogue with the computer. They exist now only as elementary prototypes; their successful development to any depth and subtlety will demand the solution of some relatively difficult technical problems.

To illustrate one central problem, suppose that in a program on American history the student types in the question, "Why did Booth kill Lincoln?" Or a more complicated question, such as, "What was the role of the railroad in the economic development of the Mississippi Basin in the nineteenth century?" It is very difficult to write programs that will deal with freely constructed questions of such complexity.

The situation is by no means hopeless, however. In curriculum areas taught for a considerable time, with reasonably sharp focus of subject matter, it is possible to provide a fairly thorough analysis of the types of questions that will be asked. In these subject areas, we can make considerable progress toward the recognition of the question by the computer program. The central intellectual problem at the moment is not that of storing enough information to give answers. Rather, it is to recognize from the standpoint of the program precisely what question has been asked.

A second central problem arises in working with elementary school children for whom it is essential to be able

to "input" a question on a typewriter. However, they can ask or answer a question in a fairly complex way if their speech can be recognized by a computer program. The problem of speech recognition simply adds another dimension to recognition of sentence meaning.

Presently there is considerable research on how computers can be made to deal with natural-language material in ways equivalent to humans' dealing with the same material. The approaches are taken on at least three different levels: 1) syntactic (dealing with the structural patterns of sentences); 2) semantic (dealing with the meaning of words, word groups, sentences, paragraphs, and whole documents); and 3) pragmatic (dealing with factors such as the occurrence of names of people or chemical compounds, the frequencies of words, and the presence of clue-words such as "summary").

Whether the computer system used to individualize instruction is a fairly thin drill-and-practice system or a very rich dialogue system, a number of problems still remain to be solved. Some have to do with how curriculum materials should be organized. Because of the complexities of organization, the only hope would seem to lie in the development of an adequate body of fundamental theory about the learning and retention capacities of students. Until that time, individualized instruction with computers must proceed on the same basis of practical judgment and pedagogical intuition that we use in arranging curriculum materials in ordinary classroom settings.

One of the most difficult tasks is to know how to organize computer programs so that they can make use of unexpected student responses as a good tutor would. But perhaps the foremost problem of the near future concerns the preparation of course materials. Who is going to do it? When? Work now underway is far from adequate. A second near-future problem concerns the careful test and evaluation of this innovation in a way that will be reliable and not boomerang and bring about a premature demise.

Other important questions are rooted in the more distant future. One of these concerns the teacher's role if learning machines are adopted on a large scale. Will the motivation and the requirements for what constitutes a good teacher change radically?

In spite of such formidable questions, one can say for the first time since universal education became a major objective of our society that individualized instruction at a deep level is now feasible. The eventual advance in the level of education that could result from achievement of this goal lies beyond imagination.