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ABSTRACT

Intended as an overview of the nature and use of computers in schools, this document describes the history and development of computers generally and of computer-assisted instruction (CAI) specifically. Included is information on several CAI systems currently in operation including (1) Programmed Logic for Automatic Teaching Operations (PLATO), (2) Time-Shared Interactive Computer-Controlled Information Television (TICCIT), (3) the LOGO programing language for mathematics instruction, and (4) Program for Learning in Accordance with Needs (PLAN). Comments are also provided on current capabilities and future directions of both administrative data processing and CAI in American Schools. (DGC)

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THE COMPUTER IN THE SCHOOL

Justine Baker

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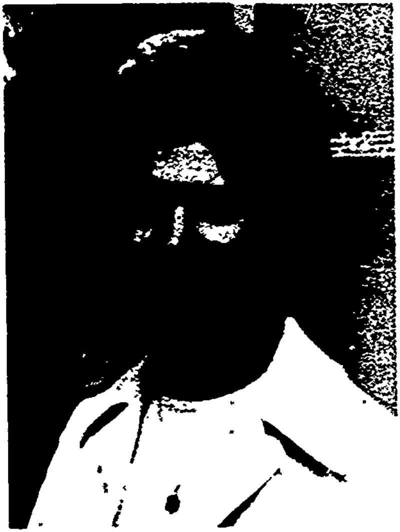

JUSTINE C. BAKER

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THE COMPUTER IN THE SCHOOL

By Justine C. Baker

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AN INTRODUCTION

At the Artificial Intelligence Lab at Massachusetts Institute of Technology two wide-eyed elementary school youngsters are sitting on the floor watching a turtle trace a geometric pattern around them. The turtle, which is a see-through, semi-spherical device containing internal electronic components and wires, is journeying under the control of a computer program written by the children.

In an elementary school in Salt Lake City, Utah, four young teachers are in the school's computer room. Two are ready to submit their pupils' mark-sense cards to a card reader connected to a remote computer system. The other two are reading results from a typewriter, under control of the same computer, which has outputted the progress of their individualized instruction classes.

A group of five Los Angeles high school students are enthusiastically engaged in preparing articles for a bimonthly newspaper called *Computer Club News*. Two of the teen-agers are writing about a new computer game they developed; the others are writing about novel results they encountered in a simulation exercise on rocketry.

About 7 a.m. on a school morning a calm principal in Detroit uses a touch-tone phone to enter coded data concerning a substitute teacher request. The phone he is using, however, is a very special telephone. It is part of an IBM computer system called TAPS—Teacher Audio Placement System. The computer on the other end of the line does a fantastically speedy search of people available for the job. Within a second the principal hears

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the directory number of a well-qualified substitute. All he has to do is dial that number and complete the transaction.

An amazed board of education member from a school district in Cook County, Illinois, examines computer print-out sheets of a full bus-route schedule for commuting youngsters in his district. These sheets, given to him by a bus company official, show grids on which are plotted bus routes for all schools in his district. What is amazing is that the computer, programmed by bus company personnel, delivers a schedule which maximizes utilization of vehicles and drivers and minimizes unproductive trip time. Every possible school, road, and weather condition which might affect the schedules has been included in the computer program. The net result is improved service to students and schools. All this and more as well—the computer has even reduced the time required to develop the route schedules from months to hours!

A perplexed-looking community college student in Alexandria, Virginia decides to press the ADVICE key on the learner control keyboard of a terminal connected to a minicomputer system. Instantaneously a bright, full-color display appears on the screen of a television receiver, which is also part of that terminal. The clue provided in the display is sufficient to help the young lady complete a memo she is preparing for an individualized instruction course in English composition. She leaves her work in her instructor's mailbox. The instructor will subsequently evaluate her skills in writing and return her paper. In the meantime the coed will return to her computer teacher the next day and continue her studies in English.

A third-year medical student is working at the console of a minicomputer in a pharmacology laboratory. He has to decide how many cubic centimeters of a new drug should be administered to a diabetic patient. Although the patient is not physically present in the laboratory, a simulation program under computer control shows his medical history with data pertinent to solving the problem. The young man studies this information as it appears on a television mounted in the computer cabinet. After completing his calculations, the medical student inputs his results to the computer by way of a typewriter-like keyboard also in the cabinet. The computer checks his arithmetic and outputs an eval-

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uation on the video screen. In this way the medical student can get an idea about his expertise in treatment.

These glimpses of the role computers play in schools today could be extended These excerpts are enough to show that computers have widespread applications in the world of education, and more will be said about specific uses of computers in schools in a later section of this book.

As technological researchers design more sophisticated hardware, or electronic components for computers. educational researchers will develop software, or programs for these machines. Their innovations will be tested in classrooms throughout the country This perpetual research and development cycle shows no signs of coming to a halt even with our current inflationary economy.

Since there are indications that computer uses in schools will increase in both type and number, it may be worthwhile to help the reader gain an appreciation for these machines and their programs by offering a summary of how these machines were invented and how these systems were implemented in schools in America

Computers are high-speed, electronic data processing machines Since data can be given to a machine in continuous or discrete form, there are two kinds of computers for accepting such information Analog computers measure continuous data; digital computers count discrete data. There is also a third subset of computers called hybrid computers. These machines combine the best characteristics of both digital and analog machines. The word computers in this book should be understood to mean *digital* computers.

HOW WERE COMPUTERS INVENTED?

Counting, a prerequisite skill in all mathematics, has always fascinated mankind. While our earliest ancestors counted objects by the method of making one-to-one correspondences between their fingers and the objects, people gradually developed more sophisticated aids to calculation. Physical techniques in counting advanced to mechanical aids, then to electromechanical calculating devices, and finally to electronic calculators and digital computers.

Evolution of Early Counting Devices in Society

Egyptian merchants developed simple sand calculators thousands of years ago. Each calculator consisted of three handmade indentations in the sand and a collection of pebbles. From right to left each indentation or groove marked place value according to the decimal system. When ten pebbles filled the right-hand groove, they were replaced by one pebble in the center groove. When ten pebbles filled the center groove, they were replaced by one pebble in the left-hand groove. Answers could then be read quickly by counting pebbles in the grooves. Addition and subtraction could also be performed with these sand calculators.

Other illustrations of purely mechanical (that is, hand-operated) counting devices used thousands of years ago are: the Chinese abacus, the Japanese soroban, and the Roman counting board. All three devices counted by means of the decimal system.

In both the abacus and the soroban, a wooden frame, partitioned into two compartments by means of a horizontal strip of wood, held beads strung on rods. Upper- and lower-level beads were assigned face value according to the rule: five for upper-level beads, one for lower-level beads. Rod-bead columns were assigned place value in increasing powers of ten from right to left. While the Chinese model contained two upper-level and five lower-level beads per column, the Japanese model contained one upper-level and four lower-level beads per column. To designate numbers, upper-level beads had to be pushed down to the horizontal partitioner, and lower-level beads had to be pushed up to the partitioner. Numbers could be added and subtracted by means of these instruments. The Chinese are still known to use the abacus in their daily business transactions.

The Roman counting board resembled both the Egyptian sand calculator and the Japanese soroban. The board consisted of grooves filled with small stones called calculi. Shorter grooves were notched in the top section, while longer grooves were notched in the bottom section. The operation of this device was very similar to that of the soroban.

The Era of Geniuses

The next group of mechanical calculator inventions occurred in Europe in the 1600s. Wilhelm Schickard in 1623 invented a machine to perform the four fundamental operations on numbers. The device was never used, however, because it was destroyed by a fire even before it was fully constructed. In 1642 Blaise Pascal invented a ratchet-gear calculator resembling a rectangular box with eight dials and corresponding windows mounted on the top. Inside a series of intermeshed gears controlled column-wide carry operations. Only additions and subtractions could be performed on that device, however.

Then in 1694, Gottfried Wilhelm Leibniz invented the Leibniz wheel, which was capable of performing all four fundamental operations. Leibniz was one of the first geniuses to recognize the need for calculating aids. He felt that men were wasting hours in the slavery of tedious hand calculations while they could be engaged in creating new knowledge. The Leibniz machine was his answer to the slavery problem; the branch of mathematics known as calculus was his answer to the development of new knowledge.

The 1700s were relatively unproductive with respect to innovations in calculating instruments, but in 1804 the first breakthrough in automatic programming was made. Joseph Marie Jacquard invented a device which could be attached to a weaving loom. His device utilized a series of connected punched cards to control complex patterns in the process of weaving. Jacquard's attachment to the loom amounted to programming the machine according to some pattern desired by the user.

Later, in the early 1820s, Charles Babbage, convinced that men must be freed from the drudgery of repetitive calculations, designed a machine called the Difference Engine which was supposed to calculate and print logarithmic and astronomical tables.

Babbage was a great thinker and well ahead of his time period. In 1833 while his Difference Engine was still in the developmental stage, he envisioned from this machine and from the Jacquard loom cards a machine which could have been the first general purpose computer—the Analytical Engine.

The Analytical Engine, according to its designer, was to be steam powered and to consist of two basic units: a store (memory) and a mill (arithmetic processor). Punched cards were to be used to control the operations of the machine and to supply data to be used in operations. An input unit and an output section which would print results of calculations were also part of the planned Analytical Engine. Babbage even included in his design a decision-making capacity for the machine and a card library of programs which could be run on the machine at any time with data changes as needed for solutions to problems.

Parts of the Analytical Engine were produced. The complete machine, like the Difference Engine, was never manufactured. What is important about the Analytical Engine was its influence on the first computers made in the United States in the 1940s. Also Babbage's library storage ideas are used today in computer systems. Vast libraries of programs (routines) and parts of programs (subroutines) are stored on reels of magnetic tape, magnetic drums, magnetic disks, and keypunch cards. Users can obtain the programs and insert their own data. In this way time need not be spent in reproducing already effective programs.

Before going on to the large-scale first generation computers, another important invention should be mentioned. Dr. Herman Hollerith, an employee of the Census Office of the United States Department of the Interior, designed and built electromechanical tabulating equipment including a card punch and a card sorter to process more rapidly the results of the 1890 census. He also designed cards the size of the dollar bill. At 288 locations on these cards, holes could be punched according to his own code-information scheme. His equipment and the 1890 census were most successful. The present keypunch cards, which date back to the 1930s, are modifications of Hollerith's ideas.

Hollerith's ideas also opened up avenues of thought and subsequent design of simple punch-card accounting machines which were popular in this country in the early 1900s. None of these instruments, however, were fast enough for scientific use.

In 1936 an Englishman named Alan M. Turing, who came to the United States to study logic at Princeton University, wrote a remarkable paper concerning the theory of computation. In his work Turing discussed a hypothetical machine that was equipped with a read-write head and a finite alphabet of symbols, each of which was arranged on a square of an infinite tape. The machine was capable of solving mathematical problems according to algorithms. An algorithm can be considered a set of rules which precisely define a sequence of operations. The importance of the Turing machine, however, was its role as an abstract model for the practical computer.

Finally, in 1944, a machine considered to be the first large-scale automatic digital computer—the Harvard-IBM Mark I was completed. Electromechanical in nature, the Mark I incorporated features of Charles Babbage's Analytical Engine. Originally designed to solve differential equations, the machine could perform all kinds of arithmetic operations. Also called the Automatic Sequence Controlled Calculator, the Mark I was the fastest machine of its time. As soon as it received its program by means of a roll of punched paper tape, it processed data until it achieved results. In three-tenths of a second the Mark I could process 23-digit additions and subtractions. The nonlinear operations took slightly longer, about 6 seconds for multiplying two 23-digit numbers and about 12 seconds for division. Answers were outputted on punched cards or on paper processed by electric typewriters.

About the same time that the Mark I was being built, another machine was in the designing and developmental stage. This machine was operable in December, 1945, and was completed in 1946. It was ENIAC, Electronic Numerical Integrator and Computer, considered to be the first electronic digital computer.

The machine was developed under a contract given to the people at the Moore School of Electrical Engineering at the University of Pennsylvania by the Ordnance Department of the U.S. War Department, which was interested in the production of voluminous calculations for firing and bombing tables crucial to ballistics research during World War II. No machine at that time was considered fast enough to take on that job. A new computer had to be built, and it was—at the University of Pennsylvania.

ENIAC was an enormous machine: 100 feet long, 10 feet high, and 3 feet deep. It contained 18,000 vacuum tubes, 70,000 resistors, 10,000 capacitors, and 6,000 switches. It was programmed by plugboards wired from outside the computer. The arithmetic system was performed in base 10 rather than base 2. An addition or subtraction with 10-digit numbers took 1/5000 of a second; multiplication, 3/1000 of a second; division, 3/100 of a second.

The prototype for many of today's computers was developed in mid-1945 in a paper written by the late, great mathematician, Dr. John von Neumann, who joined the ENIAC group at Penn. That computer, EDVAC, Electronic Discrete Variable Computer, was a stored program machine capable of performing arithmetic on base 2 numbers at rates counted in microseconds. A microsecond is one millionth of a second. EDVAC was to operate in a serial mode, that is, it was to inspect and execute one instruction at a time. ENIAC, on the other hand, performed many operations simultaneously in a parallel mode. EDVAC's input-output medium was to be extremely fast operating magnetic tape. Eventually the machine was built at Penn but not until many years later.

After World War II the computer industry developed rapidly throughout the United States and other parts of the world. The second electronic digital computer was BINAC, Binary Automatic Computer, completed in 1950 and similar in design to EDVAC. Still another computer, called UNIVAC, Universal Automatic Computer, became operational in 1951.

By the 1950s all major universities and machine manufacturers such as IBM were engaged in the design and development of these remarkable digital computers. It should be noted that one great American institution, Massachusetts Institute of Technology, now a leading school with respect to digital computers, was preoccupied with analog computers for more than a decade beginning around 1927. The late Dr. Vannevar Bush designed and built in the mid-1930s, a machine called the Differential Analyzer which served as the archetype for modern analog computers.

In summary, several important factors can be traced to the construction of high-speed digital computers. These are the need to overcome societal problems such as laborious calculations met in daily life, the advances in scientific technology culminating in the electronic elements used in ENIAC, and the concatenation of ideas of great thinkers toward the design and development of such astonishing machines. An interesting and provocative in-depth account of the development of computers from the standpoint of human achievement can be found in Herman H. Goldstine's book, *The Computer from Pascal to von Neumann* Dr. Goldstine, a mathematician, was part of the team of experts who developed ENIAC. After World War II he went to the renowned Institute for Advanced Study in Princeton where he helped Dr. von Neumann build another digital computer.

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HOW WERE COMPUTERS IMPLEMENTED IN AMERICAN SCHOOLS?

The Influence of Mathematics and Psychology

That mathematics was the subject that sparked the invention of the first electronic digital computer can be seen from the foregoing discussion. ENIAC was invented for the purpose of solving mathematical problems.

While arithmetic-logic circuits performed the operations of addition, subtraction, multiplication, and division, computer circuitry also allowed decision-making procedures. Numbers were compared with respect to relative magnitude and with respect to zero, that is, positive, negative, or zero. Also computer designers built more procedures into the arithmetic unit besides the four fundamental operations and the comparison of data. Exponentiations, root extractions, and the processes of collation, merging, matching, and sorting were also performed. The arithmetic-logic unit, then, was characterized by its versatility in processing information.

At the same time computers were being developed to do more than calculate mathematical problems, B. F. Skinner of Harvard in 1954 revived and further developed the idea of automatic self-instruction. Dr. Skinner invented teaching machines that were based on the principle of programmed instruction. A program appearing on tape in the window of a mechanical machine was presented to the student. This reinforcement-theory program was based on the following sequence. a sentence or two of information, a question (stimulus) on that information, the student's answer (response) written on the tape, and an immediate reply to that answer (correct/incorrect). The student was to advance serially through the material in this fashion until the topic was completed.

Skinner's ideas influenced other educators who began writing programs for teaching machines. Soon other teachers developed programmed textbooks which incorporated similar ideas. A time of learning by self-instruction had begun.

Finally, in the late 1950s a very interesting psychological experiment took place at the IBM Research Center. Scientists used an IBM 650 computer connected to a typewriter terminal as a dynamic Skinnerian teaching machine. A program on binary arithmetic was stored in the computer. Students, acting as subjects in the experiment, interacted with the computer by typing in answers to problems presented in typewritten form by the computer. There was a constant dialog between the computer and the student throughout the lesson. The way had been paved for self-instruction via the computer. Likewise, the seed of an idea—time sharing—had been planted.

The next section traces the brief histories and underlying concepts of several major computer projects in American schools. The presentations, however, are given according to the kind of project rather than by strict chronological order.

A Sampling of the History of Computers in Schools

While vanguard computers were designed and built in universities in the 1950s, these machines were not installed in the kindergarten through twelfth grade school systems until the 1960s One reason for the late appearance of computers in K-12 schools was the absence of relatively easy-to-use programming languages. FORTRAN, designed by John Backus and Irving Ziller of IBM, was the most popular of the early compiler languages but was not available to the public until 1957. Before that time computer users had to write complicated programs in coded formats, many of which consisted of 0's and 1's exclusively. These were called machine language programs. Somewhat easier to read and write were assembly language programs. Even these were not simple by any means. While assembly language programs permitted some symbolic and mnemonic coding, usually multiple steps were needed to direct the machine to perform an operation. Obviously, then, the possibility of introducing students to the problem-solving wonders of computers had to be postponed until a language such as FORTRAN was developed.

The FORTRAN language, called an automatic programming language, allows the programmer to think in terms of the procedures needed to solve a problem. Statements containing words in English or words resembling English words are written to direct the machine to perform operations. The stored compiler program translates each statement into as many substatements as required to direct the machine to complete the problem.

One of the first electronic computers in a K-12 school system was ABEL in the Montgomery County, Maryland Public School District. ABEL, a general purpose, stored program computer with magnetic drum and relay architecture, was given in 1951 by its original owner, the U.S. Navy, to the George Washington University in Washington, D.C. In 1962 or 1963, the people at George Washington gave ABEL to the recently built Albert Einstein High School. Unfortunately, ABEL was not operational when it arrived at Einstein. A number of high school students tried to make ABEL work, but had no success. The staff at Einstein High School, however, did not let this computer failure sour their attitudes toward computers. Several years later, in 1968, they began work on an impressive project involving computer-assisted instruction. The computer system developed in Montgomery County included the use of a time-sharing network of visual-display terminals connected to a large IBM computer. The computer helped students in solving problems, and in learning lessons; it helped teachers in monitoring the progress of their pupils.

The first major computer-assisted instruction project was begun in 1960 under the guidance of Dr. Donald Bitzer at the University of Illinois. Dr. Bitzer invented and developed a teaching system called PLATO, Programmed Logic for Automatic Teaching Operation. Originally designed to add the dimension of automation by way of a computer to the somewhat dull individualized instruction materials in existence, PLATO spread from providing instruction at the college level to the secondary school level and then to the elementary school level.

In 1961 the first teaching attempt in higher education was made by PLATO. In 1965 the first complete college course was given, solely by the PLATO syste . That course was in library science Then in 1968 the time-sharing mode of CAI was added to the PLATO system. In the same year student terminals were equipped with recently developed plasma display panels rather than the more expensive cathode-ray tubes. By 1969 the first remote station was in operation at Springfield High School in Springfield, Illinois, ninety miles from Urbana where the large central computer of the PLATO network was housed.

The PLATO system has undergone four developmental phases from PLATO I in 1960 to the current PLATO IV. The idea behind the project is to introduce many teachers and their students to the educational marvels of dynamic individualized instruction presented by a computer-based system. Each PLATO IV terminal consists of a keyset for communication between the user and the computer and a display for showing graphic information and photographic color slides. Attachments include audio systems, tape recorders, touch panels, film projectors, and electronic equipment for research. Most pieces of equipment are under computer control. Even laboratory apparatus for experiments are provided in the PLATO package.

By use of an easy-to-understand TUTOR language, teachers with no previous experience with computers could design lessons for their students. Any teaching style is acceptable. The computer is even programmed to monitor and evaluate student performance. Lessons can be revised and edited on-line (from terminal to computer), by any teacher at any time. Due to the appeal of such an attractive educational system, courses ranging from astronomy to veterinary medicine are available. All levels of instruction are likewise available—from elementary school to graduate school. Simulation studies, game playing, and science experiments are also part of PLATO.

By far the most extensive computer-based system in this country, the PLATO goal is to connect 4,096 student terminals by means of telephone lines to the large central Control Data Corporation 6000 series computer system. In March of 1974, there were 450 terminals in the PLATO network.

A major objective of the University of Illinois project is to make computer-based education economically possible. Around 1972 an estimated cost, based on optimum use of the PLATO system with the inclusion of computer costs, communication lines, terminal equipment, and the development of instructional materials, was between 50 cents and 75 cents per student per terminal hour. By the time the full 4,096 terminal network is operable, Dr. Bitzer hopes to have costs reduced below 50 cents. A cost of 10 cents per student per terminal hour in the near future is not unrealistic

While high school and college students in the early 1960s were becoming acquainted with computers, either by actual contact or by reading about these great machines, elementary school youngsters were also being made aware of computers. By the end of 1963, Patrick Suppes, educator and mathematician at Stanford University, introduced six fourth-grade students to their first lessons in elementary mathematical logic The youngsters had access to an apparatus consisting of a cathode-ray tube attached to a typewriter keyboard In addition to this equipment an optical-display device for showing pages from a book and a light pen for making interactive contact with the screen and thereby with the lesson stored in the computer were available at each of the six student stations. All stations were located in the same room with the medium-sized Digital Equipment Corporation PDP-1 computer at the Institute for Mathematical Studies in the Social Sciences at Stanford.

During the 1964-65 school year, CAI activities at Stanford under the direction of Dr. Suppes progressed very well. First- and fourth-grade mathematics materials were also programmed for youngsters in neighboring schools. Even kindergarten children were introduced to first-grade math lessons by means of the Stanford computer.

In the spring of 1965, several terminals were placed in a fourth-grade classroom at the Grant School in the Cupertino Union School District of California. These terminals were teletype machines connected to the Stanford computer by means of telephone lines. Forty-one children received daily drill-and-practice arithmetic lessons by this arrangement. Computerized instruction in the elementary school had begun.

In subsequent years the Stanford CAI endeavors spread both geographically and academically (subject-wise). Remote computer terminals connected to Stanford's computer were installed in schools in Iowa, Kentucky, Mississippi, Ohio, Washington, Tennessee, Washington, D C , and Texas, as well as in California. Tutorial and drill-and-practice programs in mathematics, reading, logic and algebra, problem solving, computer programming, first- and second-year Russian, language arts, and even CAI for deaf students were added to the Stanford repertory. The Russian courses have been offered at Stanford for credit and have been proved successful. It should be noted that special equipment such as teletype machines with Cyrillic (Russian) alphabet keyboards and audio tapes with earphones are needed for this language course.

Another highlight of the Stanford program was the development during the 1968-69 school year of a technique called digitized audio, which was used in a computer-based reading program for first, second, and third graders.

By the spring of 1970, the Institute for Mathematical Studies in the Social Sciences added another historical first—the distribution of CAI by a communication satellite. By means of a low-cost ground station at Stanford, a demonstration which proved CAI to be feasible for isolated rural students as well as city students was conducted.

In 1970 a new approach to computer-assisted instruction was initiated at the Institute for Computer Uses in Education at Brigham Young University under the direction of Dr. C. Victor Bunderson Designers and developers from two other institutions, the University of Texas and the MITRE Corporation, joined forces with the Brigham Young group to make TICCIT a meaningful system TICCIT is an acronym for Time-shared Interactive Computer-Controlled Information Television.

The philosophy of the TICCIT project is to plant academically successful and economically feasible CAI systems in American schools and to change the role of the classroom teacher to that of tutor-advisor, diagnostician, and problem solver. Having experience from previous CAI projects as guides, the TICCIT people set up shop in Provo, Utah. They decided to implement their system in community colleges because these schools are relatively new in American education, are not bound by tradition, and should be receptive to innovation.

Two community colleges have been given contracts to test the

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TICCIT systems. During 1974-1976 installation, demonstration. and evaluation of the project will be underway. The Educational Testing Service of Princeton, New Jersey, will make a thorough evaluation of costs and effectiveness of hardware and software. The two community colleges involved with TICCIT are Phoenix College, Phoenix, Arizona, and the Alexandria Campus of the Northern Virginia Community College.

The TICCIT system uses a pair of Data General Nova 800 series minicomputers with 128 terminals for time-sharing facilities. The entire system is self-contained. That is, a college could purchase the system and distribute the terminals in classrooms, dormitories, and neighboring houses on campus. Each student terminal consists of color TV displays with sound. Full-color sound movies are also part of the TICCIT package. Programs in mathematics and in English aimed at the community college level have been written by teams of subject-matter experts, psychologists, and computer technologists. This software is part of the TICCIT system. A projected commercial cost which includes hardware, CAI programs, and equipment maintenance is less than one dollar per student contact hour.

Around 1970, Seymour Papert at the Artificial Intelligence Laboratory at M I T., created a computer-based environment which future educational historians may regard as one of the most novel and intriguing in twentieth-century education.

Before discussing Papert's work, a note about artificial intelligence is in order "Artificial intelligence is concerned with thinking about thinking in general," Papert once said. Since problem solving (mathematical and nonmathematical) involves intelligent thought, computers which solve problems have artificial intelligence Therefore, in-depth research into the nature of human thought patterns should lead to better ways to construct and program computers. Under the umbrella of artificial intelligence, research is being conducted on processing sensory data, especially visual images and speech sounds, developing sophisticated information storage and retrieval systems; and processing natural languages. Teams of professors and students are engaged in artificial intelligence research at two great centers—M.I.T. and Stanford Also, Dr. Herbert Simon of Carnegie-Mellon University and Dr. Ruzena Bajcsy of the University of Pennsylvania are

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among others doing quality work in a rapidly growing field. The ultimate aim of researchers in AI is to build machines which will function in ways typical of intelligent human beings.

Dr. Papert's laboratory, also called MATHLAND, is filled with cybernetic toys such as turtles, puppets, and music boxes which are under computer control. Elementary school youngsters can go into the laboratory, type commands at a computer terminal keyboard, make puppets dance, make music boxes play tunes, and make turtle devices walk and trace pictures. The computer language they use is called LOGO which was developed at M.I.T. to teach mathematics rather than programming.

The idea behind the project is that children can best learn a subject by involvement—especially if that involvement is amusing and hence makes a lasting impression. While the LOGO project is enormous, one simple illustration should serve to clarify the turtle concept.

Given the following set of cardinality five: a child with knowledge of LOGO, a computer, a teletype machine (terminal), a large flat surface (paper), and a box-like apparatus (equipped with a pen) on wheels called a turtle—a new topic in mathematics called turtle geometry can be demonstrated. By typing the following instructions, a youngster could make the turtle draw a rectangle.

PROGRAM	EXPLANATION
TO RECTANGLE	definition of a procedure
1 FORWARD 20	an advance of 20 units
2 LEFT 90	a 90° rotation about its central axis
3 FORWARD 50	an advance of 50 units
4 LEFT 90	a 90° rotation about its central axis
5 FORWARD 20	an advance of 20 units
6 LEFT 90	a 90° rotation about its central axis
7 FORWARD 50	an advance of 50 units—back to starting point
END	completes definition

As soon as the computer reads the END statement, it types back: RECTANGLE DEFINED. The child then types:

PENDOWN
RECTANGLE

With these instructions the computer controls the turtle as it "walks" around in its defined rectangular path and at the same time sketches a picture of where it has been.

The work of Drs. Seymour Papert, Marvin Minsky, and company was so successful that portable MATHLANDS with supertoys and computers have recently spread to elementary school classrooms in New England and even abroad to England. In fact, there is a company called General Turtle, Incorporated, which manufactures the complete line of M.I.T. toys.

A large-scale and well-received computer-managed instruction project called PLAN, short for Program for Learning in Accordance with Needs, was developed in 1967 by the Westinghouse Learning Corporation, the American Institutes for Research, and 13 cooperating school districts. The PLAN system functions as an aid to the busy teacher who is conducting individualized instruction classes. PLAN materials include sets of lesson plans (teaching-learning units) complete with behavioral objectives for elementary, high school, and community college language arts, mathematics, science, social studies, and career education courses.

The PLAN program of computer-managed instruction is typical of CMI systems in which the computer is used to support individualized instruction through daily record keeping of pupils' performances and appraisals of their learning capabilities. All data (answers) related to placement and criterion-referenced tests are marked in pencil on special computer cards by the pupils. At the end of the day the teacher places these cards in a card reader (input device) connected by a communication line to a large, time-sharing system computer at the PLAN Iowa headquarters. Sometime during the late afternoon or evening, the computer which is under the control of a specially prepared assessment program types back a print-out sheet by means of a typewriter-like terminal (output device) located near the card reader at the school. The next morning the teacher retrieves this information and schedules each student's lesson according to the suggestions made by the computer.

Although this cycle is typical throughout the school year, it need not be rigidly followed. The creative teacher is free to teach students in small or large groups as the need arises. Also the teacher may make use of an intrinsic flexibility in CMI. That is, the teacher may assign students any materials, such as a variety of texts and audiovisual aids to help them master the behavioral objectives in the program (Behavioral objectives relate to behaviors which should be demonstrated upon completion of a teaching-learning sequence.)

Since the inception of the PLAN program, various research studies conducted by independent agencies have shown that PLAN students make greater gains than control students in both cognitive and affective psychological domains. These results represent a major thrust for computer-managed instruction

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THE VARIETY OF USES OF COMPUTERS IN SCHOOLS

Basically, computers are used in two ways in educational institutions. Transactional usage applies to administrative duties, while instructional usage relates to educational programs.

With respect to administrative applications, computers are used as record keepers. Auxiliary storage media such as magnetic tapes and magnetic disks can be packed with information concerning students, faculty, and nonprofessional personnel in a school. Authorized personnel can make use of retrieval programs to obtain this information when requested.

It is not uncommon, especially in large schools, for students to receive their reports, complete with grades and attendance records, on pocket-size computer print-out sheets. Also class schedules are processed by computers and student rosters are print-out sheets.

Sophisticated programs have been written which utilize the services of computers to tabulate financial reports and to make business decisions. Computers are even used to manage the resources in school libraries and keep track of incoming and outgoing books. These systems include the identification of borrowers by the use of student identification cards that are fed into a card reader under computer control. In the future the familiar card catalogs in libraries will be replaced by computer-produced book listings.

Instructional uses for computers are diversified and have been multiplying over the years, sparked by the creative imaginations of educators in the computer field. Problem solving, the oldest educational computer use, applies the machine to processing

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mathematical, computational, and logical problems. The computer lends itself especially well to problems which have repetitive patterns such as finding roots of equations in the complex number system, checking the convergence and divergence of series problems in calculus, and finding standard deviations of samples in statistics.

Computer-assisted instruction (CAI) uses the computer for tutorial instruction which sometimes involves drill and practice lessons. Performance monitoring and record keeping can also be included in CAI applications. Some educators use the term CAI, however, in a more comprehensive role, designating CAI any educational activity presented or supported by a computer. Such activities include simulations, game playing, and even computer-managed instruction.

Computer-managed instruction (CMI) involves the computer as a teacher's aide, usually for the purpose of individualized instruction. Jobs performed by the computer in CMI are test grading, record keeping, and diagnostic reporting. Monitoring activities in which the student is not directly involved with the computer are characteristic of CMI. Recall the PLAN program described in the previous section.

There are CMI programs which allow the student to test himself directly at the computer terminal. The computer presents the questions, the student replies with the answers; the stored program keeps track of right and wrong answers.

Since all student responses are recorded on secondary storage magnetic media, student progress can be checked by teachers and administrators. Therefore, CMI makes possible accountability studies in which educators can compare the advantages or disadvantages of the computer to more traditional forms of education, for example, the lecture-discussion method.

Simulation involves experiments in which a system characterized by mathematical equations is supplied to the computer, which, according to its program, makes decisions on that information. In other words the computer acts as a model for a physical event, a laboratory experiment, or a natural process.

Simulations can be drawn from ecology, space travel, business, political science, social science, physics, chemistry, and biology. Among the many simulation programs that can be

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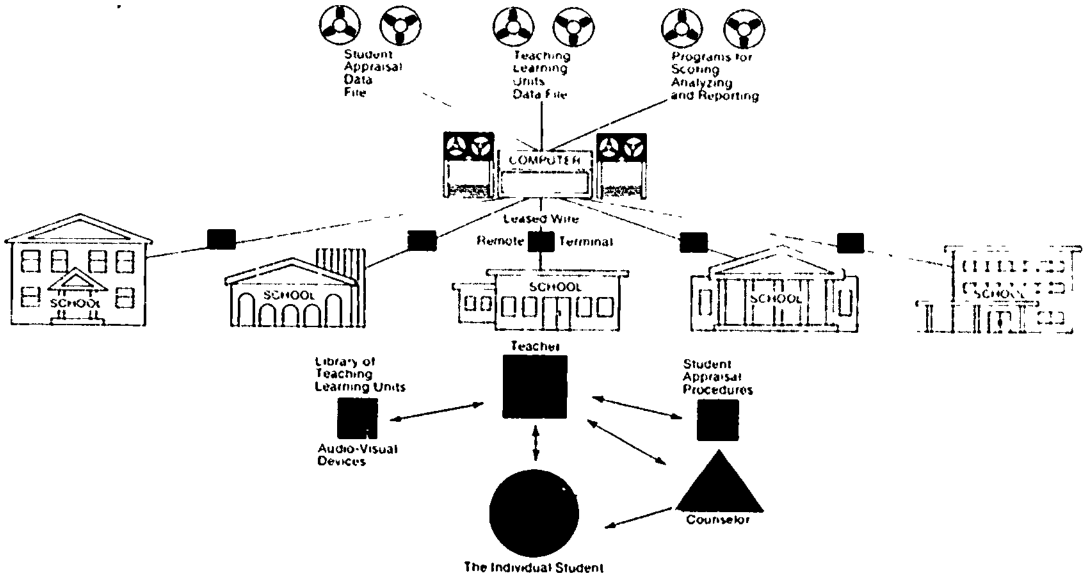
Figure 1—Schematic Representation of a System for Computer-Managed Instruction.



SOURCE: "Computer-Managed Instruction," Brudner, H. J., *Science*, Vol. 162, p. 973, Fig. 2, 29 November 1968.
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THE COMPUTER FOR BUSINESS EDUCATION High school students prepare for careers in data processing This IBM system/3 computer also performs administrative work for the school district Photo courtesy IBM

THE COMPUTER MONITORS STUDENT PERFORMANCE A computer will score and analyze the students' answers Individual and relative grade rank will then be made available to teachers and parents. Photo courtesy IBM

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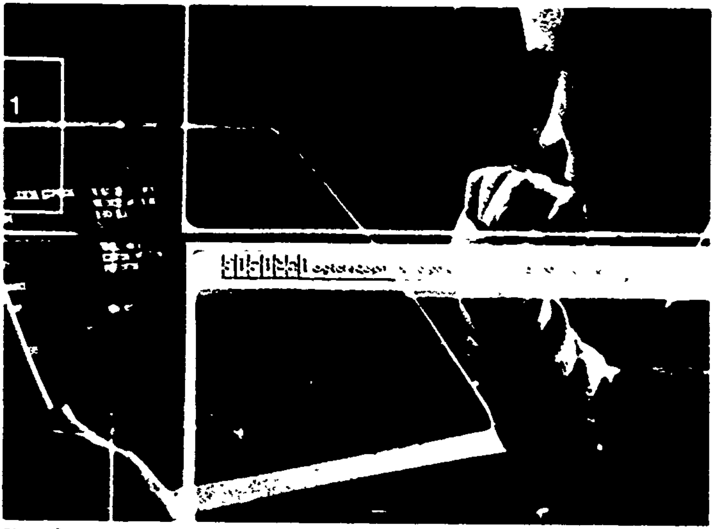

THE COMPUTER AS A GUIDANCE COUNSELOR A program appearing on the screen of a terminal connected to the minicomputer can be used to help a student plan his vocational aspirations Photo courtesy Digital Equipment Corporation

THE COMPUTER AS A SECURITY GUARD ON CAMPUS Indiana University uses a small IBM computer to "read" badges and make decisions about whether individuals may or may not enter buildings In the case of authorized persons, the system unlocks the door and records [illegible] time and the individual's badge number Photo courtesy IBM written are those which determine whether a stream is polluted, a rocket will reach the moon, or a new business will survive. Advantages of using computer simulated experiments, especially in science laboratories, are protection of students from physically dangerous experiments and saving of money, for expensive lab equipment need not be purchased.

Game playing programs can be written for computers which will react with students until a win, loss, or draw outcome is achieved. Research is currently being conducted, especially in the field of artificial intelligence, on the improvement of programs for playing checkers and chess. Since a complete game program for a complicated game like chess involves, from a human standpoint, an infinite number of legitimate moves, it is possible for computer experts to build computer-learning techniques into the program to enhance the machine's chance of winning. The computer can "learn" and adjust its program according to moves made against it by the human player. While games are entertaining and challenging for the student, they are formidable in a context such as that just described.

There are game programs for poker, tic-tac-toe, lunar landings, football, go, nim, Tower of Hanoi, and many more. Games may be played by students against each other or by students against the computer. One of the most exciting applications of the computer is its ability to motivate students to constructive thinking through games.

Computer science, which includes studies in computer system maintenance, operation, and technology as well as computer literacy (awareness) and programming, is an area of exceptional value for the school. If there is to be computer education for all children in society, as some educators foresee, teachers in computer science departments, especially in secondary schools, would be called on to disseminate knowledge about computers to all students according to their individual interests.

Finally, a more recent use of computers in schools is for guidance. Students can interact with computers programmed to elicit vocational preferences. With other guidance programs, high school students can decide what colleges they might attend. Alternate decisions for problems confronting teen-agers today, such as drug abuse, can also be written into guidance programs.

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The reader should keep in mind that different computer languages exist for different applications. A survey conducted around 1969 showed the number of existing computer languages to be about 120. Since then more languages have been developed both by computer companies and by educators, so that today there exists a plethora of computer languages.

Foremost among them are. FORTRAN (Formula Translator), ALGOL (Algorithmic Language), COBOL, (Common Business Oriented Language), and PL/1 (Programming Language 1), all of which are used primarily for problem solving and simulations. BASIC (Beginner's All-Purpose Symbolic Instruction Code) and APL (A Programming Language) are popular time-sharing languages used for problem solving, simulations, and games. QUICKTRAN, the time-sharing adaptation of FORTRAN, is a problem-solving language.

SNOBOL, a symbol-manipulation language, and LISP (List Processor) are used in artificial intelligence research. SIMSCRIPT, an event-oriented language, is used for writing simulation programs; while IBM's COURSEWRITER, along with other languages such as PLANIT and LYRIC, are dialog program generators or authoring languages used in CAI software packages. Another interesting language called GRAIL (Graphic Input Language) allows graphic interaction with the screen by means of a stylus.

To make use of computers, teachers and students need not, however, overburden themselves in an effort to learn many computer languages. A working knowledge of even a subset of some of these languages is sufficient to make the "electronic slave" perform monumental tasks. Some school districts employ programming experts who code computer-assisted instruction programs into computer languages and thereby implement the software successfully into the system.

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THE FUTURE OF COMPUTERS

What Advances in Computer Technology Can Be Expected?

Probably the aspect of the computer that most fascinates people is the machine's speed. Present-day computers are so fast that their speeds are now measured in nanoseconds. A nanosecond is one thousandth of a millionth of a second, or one billionth of a second. Some speeds are even measured in picoseconds. A picosecond is one thousandth of a nanosecond.

An example of the incredible speed of a modern computer appeared in a film made in 1968 for IBM. In the picture a styrofoam cup containing coffee, which has been accidentally pushed from a table, is shown on its way to the floor. Accompanying this frame are the following remarks:

> Within the half second it takes this spilled coffee to reach the floor, a fairly large computer, given information in magnetic form, could—
>
> (1) Debit 2000 checks to 300 different bank accounts, and
> (2) examine the electrocardiograms of 100 patients and alert a physician to possible trouble, and
> (3) score 150,000 answers on 3000 examinations and evaluate the effectiveness of the questions, and
> (4) figure the payroll for a company with a thousand employees, and a few other chores.

The thirty-year history of computer technology shows a trend of speeds approaching that of light, which is the upper limit of computer speed. While we can expect to have faster computers, we might also expect technology to advance the minicomputer to the size of a notebook.

In a book called *The Emerging Technology*, Roger Levien of the Rand Corporation has listed several developments he believes will be available in the late 1970s and 1980s. Among these is the conversion of ordinary electric typewriters to interactive computer terminals by means of integrated-circuit attachments. Also the development of cable television (CATV) could bring computing into the home. Inquiries concerning educational matters or personal information could be typed on the home typewriter which is wired to a large time-sharing computer. Answers would appear in seconds on that same typewriter, just as they do for school youngsters working at computer terminals. The television screen, too, would be used for display of questions and answers. In this case, a keyset attachment without paper or a screen-contact medium would be necessary.

In a book entitled *Design of Man-Computer Dialogues*, James Martin, who works for the IBM Systems Research Institute, feels that natural language dialog between the computer and the user may not be available for a long time because computers have difficulty in understanding different accents, tones of voice, and ambiguous words in our language. He believes, however, that if much more money were spent in research on usable voice input technology, there would be some 200 million telephones in the world acting as computer terminals as a result of this research.

With the uses of computers in society increasing and the costs of computer services decreasing, computer technology is bound to increase in use and in importance. The number of computers in the United States is expected to double from the present 160,000 to 320,000 by 1980, according to some experts.

It is the author's opinion that the time will come, perhaps in the 1980s, when the predictions of these experts will be realized. Even now the MITRE Corporation is developing techniques to deliver CAI to the home by way of a cable television system.

In the future, curriculum experts and teachers can prepare half-hour to hour-long audio-video, color tapes for all school subjects from kindergarten to college use. Students who have missed school or who have difficulty in learning will be able to communicate with computer systems which store these instructional programs in a library of subject packages, each of which will

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be divided into learning modules. To illustrate, in mathematics there could be hundreds of these modules covering instructional units such as finding square roots, adding signed numbers in algebra, construction of proofs on congruent triangles in plane geometry, and finding the sums of infinite series in calculus. The computer has the potential to tap the abundant resources of television—all to the benefit of society.

With regard to future vocal dialog between a student and the computer, it is the author's belief that during the 1980s students throughout the country will be able to communicate with computers by means of touch-tone phones fitted with overlays to aid in programming. In this way the home telephone will serve as a computer terminal. Limited vocabulary will permit the student to state verbally the type of problems he wants solved, telephone buttons will provide programming input, and the computer will offer vocal suggestions, again in a limited vocabulary, and state the answer to the problem.

The above idea is an extension of two different computer concepts. The first is the ELIZA M.I.T project which has used a limited vocabulary for nonvocal natural language conversation between a person and the computer. The second involves an experiment conducted in a New York City high school in 1966 by IBM. Touch-tone phones were added to dial phones in the homes of participating students. The students then used the services of an IBM 1620 second generation computer as a desk calculator to do homework problems. Answers to problems as well as corrections of keyboard errors were given to the student by the computer in a clear human voice prerecorded and stored in the computer program.

The ultimate extension of computers talking in a free-style manner, that is, as people converse on the telephone, is a long way off. Nonetheless, companies such as Bell Telephone Laboratories and IBM are working toward vocal dialog goals. The General Electric Company has developed a computer based on the DEACON (Direct English Access to CONtrol) project, which operates by voice input and responds by voice output. Also possible breakthroughs in easier-to-use programming languages and in artificial intelligence research may lead, perhaps by the end of the present century, to natural language dialog.

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Although a computer talking in its own synthetic voice, complete with a machine accent might seem as fantastic as a "Star Trek" episode, talking computers with flexible CAI lessons for school students are a distinct possibility. For the not-too-distant future, however, it seems reasonable to visualize students carrying all their supplies from class to class in handy computer notebooks and using the services of home typewriters, phones, and TV sets to enhance their learning capabilities.

Could a Major School System Operate Effectively Without a Computer?

The answer is no. If a major school system is defined as a large city district or a consolidated suburban district with at least 10,000 students and 1,000 or more employees, multiple data bases and sub-bases are necessary for datamation activities.

The answer to the information organization problem, especially in large school districts is a computer system operating under the direction of a team of system analysts, programming specialists, and maintenance workers. A glimpse of the total spectrum of the administrative duties performed by a large computer system can be shown by reference to a major city school district such as Philadelphia. Anthony D'Alonzo, director of the Division of Data Processing, has organized the entire system on six major data bases. Data bases exist for pupil, personnel, facilities, financial, curriculum, and inventory and property records.

Each data base is subdivided into sub-bases. For example, the pupil data base involves information on student schedules, rosters, class lists for teachers, pupil enrollment projections, referral and withdrawal reports, and other student-related items. The personnel data base relates to employees of the school district. Payroll, position and pay grade, teacher certification and other files are included in this base. Under the curriculum base are subjects of information concerning library orders, textbook requisitions, and audiovisual aids.

The system operates essentially as follows: Computer programmers write algorithms for each of the multiple functions within the system. All pertinent data is combined in the specific

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programs. Programs are then keypunched on cards which are fed to the card reader From there the information is transmitted to the central processing unit, which processes the program and stores the output on magnetic tapes and magnetic disks. Since information in coded form can be literally packed on magnetic tapes and magnetic disks. the space problem for records is satisfied The tapes resemble cassette tapes, the disks resemble phonograph records. There are also machines which process programs directly onto magnetic tape, bypassing the card approach.

When information from these bases is needed, data division personnel select the proper tapes or disks and run these through auxiliary machines within the computer system. The desired information is quickly accessed by retrieval programs and a wealth of services, such as the processing of reports to students and the composition of paychecks for teachers, is generated by the computer.

Many people are needed in this system of revision of data, analysis of programs, and comparisons between files. Systems engineers and maintenance checkers work in the data processing group to oversee smooth operations and productive computer runs.

The Philadelphia School District embraces some 274,000 students, 41,000 employees, and 500 buildings. The operating budget for the 1974-75 school year is $479.6 million. School systems of this size and universities need the services of computers to cope with their large volumes of transactions. A harmonious interrelationship between creative-thinking people and the computer, which supplies its super speed, massive yet compact storage capacities, and accurate information processing, is a necessity to achieve the effective operation of the over-all system.

Should School Systems Incorporate Computers and Computer Courses into the Curriculum?

The answer is yes. Although a few years ago investigators found negative attitudes among some administrators concerning the adaptation of computers for instructional purposes in schools, the evidence for introducing these machines in schools is impressive.

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A year-long study in 1969 of computers in secondary schools found that in most schools computers were introduced for instructional purposes by members of mathematics departments. While math teachers found uses for computers within their discipline, teachers in other departments were reluctant to employ the services of the computer and offered resistance to their usage. At the same time in some schools math teachers were influential in promoting computer usage in other departments.

Among the factors contributing to negative attitudes were: teachers in nonmathematical disciplines did not know how to use computers in their courses; teachers felt threatened by computers because students, being highly impressed by computers, have been known to learn more about the machine than their teachers know about it, and tradition-bound curricula in many schools deter innovation.

Another survey, conducted around 1971, was more comprehensive in that attitudes of people in all phases of education from elementary schools to professional schools were sampled. Results showed that negative attitudes toward CAI (used in the general sense) were based on the high cost of computer systems and the related problem of accountability in relation to cost effectiveness, fear of change, especially when coupled with a highly complex instrument—the computer; ignorance about the potentials of the computer; the fear of teachers that the computer will rob them of the affection of their students; and fear by teachers that the computer will replace them. A suggestion offered in that report to combat some of these apprehensions was the development of CAI courses in teacher training institutions.

On the positive side there is so much that can be done with computers in schools. Creative teachers and students are designing their own programs and getting much enjoyment from the experience. Computer science and computer awareness is spreading from school to school. One computer manufacturer, Digital Equipment Corporation—called the IBM of interactive computer manufacturers—sponsors a group called DECUS, the DEC users. Educational ideas and programs are exchanged by DECUS members. Organizations such as the National Council of Teachers of Mathematics, the Mathematical Association of America, and the

International Federation for Information Processing are concerned with computer usage in schools and have been influential in introducing the computer into the school curriculum.

Computer uses are as numerous as existing programs allow. Many fine software packages are available from computer companies, universities, and schools. Also creative teachers and students make up their own games and simulation activities. The computer is a tool to be used. It will remain idle until activated by a person who has found some use for the machine.

A new kind of school community is evolving. teachers working with students and computers, a good model of which can be found in the Montgomery County, Maryland, schools, where a computer-assisted instruction project named REFLECT began in 1968.

Since computer-assisted and computer-managed instruction proved successful in Montgomery County, when the Title III ESEA grant for REFLECT expired, school administrators continued computer-based instruction under state and local funding. What is important in Montgomery County is that administrators, teachers, and computer personnel together harmoniously developed a working system in which students could learn and grow intellectually with the help of the computer.

As early as 1967, the President's Science Advisory Committee said since the computer was such a valuable and versatile tool in society, students attending schools in the 1970s who have not been exposed to knowledge about computers will be poorly prepared for the world of the 1980s and 1990s. It is the author's feeling as well as the belief of many other educators that although most school students will not be computer technologists, the influence of the computer on future jobs is so important that students should be made aware of the computer—what it is and what it does. Computer awareness courses should be part of every curriculum in every school. If the school cannot afford a computer, there is enough good literature available to teach students about the merits and societal affectations of the computer.

Minicomputers are popular today and some are available for as little as a few thousand dollars. Time-sharing terminals may be connected to these small computers and an interactive mode of computing could be established for problem-solving, CAI, gaming, simulation, and other computer activities. Administrators would do well to check with computer manufacturers with regard to available hardware prices and software packages.

If the general objectives of education are to develop the mind, body, and personality of our students so that they will be able to fully understand their world, make positive personal contributions to society, and live satisfying lives, then they should know about the computer. The computer with its attributes of speed in problem solving, virtually endless storage and retrieval capacity for enormous numbers of facts, its system of logical ordering of information, ability to make critical decisions, and ability to manage real-time systems such as space rockets and oil refineries should be part of the curriculum. It is time for administrators and educators to bring the computer into the school for the benefit of students.

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