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Advances in Computer-based Education

The Plato program will provide a major test of the educational and economic feasibility of this medium.

D. Alpert and D. L. Bitzer

Since its initiation in 1959, the PLATO program (*1*) at the University of Illinois has been committed to exploration of the educational possibilities and the engineering and economic problems relating to the introduction of the modern high-speed computer as an active element in the instructional process. During the past decade, numerous other groups at universities, nonprofit institutes, and industrial corporations have also begun to explore the possibility of utilizing modern computer technology for education. A widely varying array of such efforts is encompassed by the term "computer-assisted instruction" (CAI).

The setting for these activities is an overall formal educational process in which the national investment is more than $50 billion annually, a commitment which is expected to increase to well over $100 billion by 1980. Yet, despite this large national commitment, it is commonly agreed that there are vast unmet needs in education, in terms both of quantity and of quality. There are growing demands for more mass education over a larger fraction of the human life-span, and demands for more individualized instruction tailored to the specific preparation and motivation of a given student. However, these expanding educational needs have not been matched by increases in the productivity of the educational process. Rather, the costs per student at all levels and in various types of institutions have been rising so rapidly as to cause serious concern for the future (*2*).

Under these circumstances, it is not surprising that many institutions have sought to enhance educational productivity and to enrich the instructional process by the introduction of technology, especially the technology of the modern high-speed computer. The many programs in computer-assisted instruction have been based on recognition of the unique value of the computer in adapting the selection and presentation of instructional materials to the pace and style of individual students and in acquiring and processing data relating to the effectiveness of the teaching and learning processes. Nevertheless, although some of these programs have met with great enthusiasm on the part of highly qualified educators, it is fair to say that the general reaction has been mixed.

The mixed impressions about computer-assisted instruction are due in part to the wide variation in notions as to the types of systems that are feasible and the teaching strategies that are possible. Several recent assessments of the field (*3*) attest to the wide diversity of the objectives and professional specialization of such programs and to the even greater diversity of technological and educational resources available to them. At one end of the spectrum is the conception of such instruction simply as an automated version of a drill and practice lesson or a pro-

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grammed textbook; at the opposite end is visualization of a remarkably powerful new medium capable of various instructional modes which can assist the student in becoming an efficient and independent learner in many fields and at all levels of education.

Another source of confusion lies in considerations of the costs of computer-assisted instruction and in mixed perceptions as to the state-of-the-art of available CAI technology. Some proponents of such instruction initiated programs and sought financial support as long ago as 1965, on the premise that a significant operational application was feasible with the computer technology then available. Others took it for granted that the prime need was an innovative approach to the preparation of lesson materials, and that the lesson materials developed would be compatible with later systems. Many proceeded on the assumption that economically feasible follow-on systems would somehow inevitably be developed, but they had little insight or evidence concerning what might evolve and when it might happen. The widespread interest of the popular press in the potential promise of such activities heightened the expectations of educators and the general public alike, but did not provide a basis for understanding the key issues.

It was some years after the onset of such publicity that the realities of the economics of existing technology were brought home to the educational administrators and public agencies faced with decisions on broad implementation of computer-assisted instruction. This more realistic view has called for assessment of costs as well as of benefits to be derived, and more sober perspectives have emerged. For example, in a recent evaluation of the field, carried out under the aegis of Associated Universities, Inc. (*4*), the present educational validity and economic viability of CAI systems are summarized as follows.

> Although still a laboratory curiosity, the use of the computer for direct instruction has been amply demonstrated. . . . Without minimizing the differences of the many projects, their most interesting aspect is the common result. In every case, direct instruction by computer has shown substantial potential; it is effective, flexible and well received by students and faculty. But every case has also demonstrated that *such instruction is not economically viable. Resolving this conflict is the crux of useful computer assisted instruction* [italics added].

Since the economics of computer-based systems was recognized as a central issue at an early stage in the Plato program, we present here an assessment of the problems and potential of computer-assisted instruction from the perspective gained by this experience. In fact, the Plato program has for some time proceeded on the premise that the technology of the 1960's was not capable of making a significant and economically practical contribution to the nation's educational program. As early as 1964, a broad systems approach aimed at a novel and economically sound solution was set in motion. We proceeded to identify the specific systems problems in which technological innovations were called for; furthermore, as new educational ideas or teaching strategies were conceived, the design of hardware and software systems was modified to incorporate them. Although not promising immediate wide-scale utilization, this approach was in many ways far more ambitious than those built around available commercial systems in its perception of the possible role of the computer in education. To accent and characterize this approach, we have found it useful to describe our activity by a different and perhaps more appropriate term: "computer-based education." We call the laboratory in which the current effort is centered the Computer-based Education Research Laboratory (*5*). In this article, however, we use the terms "computer-assisted instruction" and "computer-based education" (CBE) interchangeably.

The Plato program has directed its efforts toward meeting two different, though related, objectives.

1) Investigation of the potential role of the computer in the instructional process. The major objective of this phase has been to examine the question, What is educationally possible?

2) Design of an economical and educationally viable system incorporating the most valuable approaches to teaching and learning developed in the above investigation.

To achieve the first objective, three successive and increasingly versatile systems (Plato I, II, and III) were designed and built. These systems were intended to explore the educational possibilities without regard to the economic constraints imposed by the technology available at the time of their completion. The initial stage of Plato III, a system utilizing a large commercial second-generation computer, was installed in late 1964 and has been in continuous use since then. A network of four associated demonstration centers was added early in 1969. Exploratory educational efforts with Plato systems have now involved experiments in at least 20 fields of study and over 100,000 student-contact hours (much of it for academic credit) in course work at the elementary, secondary, and college undergraduate and graduate levels. Among the results have been the realization of many new teaching strategies, valuable experience in different institutional environments, and an assessment of the attitudes of students, teachers, and authors of lesson materials.

The systems-design phase of the Plato program has addressed itself to the achievement of a highly flexible instructional system which could be economically justified at any educational institution. A milestone in this program was the proposal, in January 1968, of a design for Plato IV, a large-scale system which, even in a prototype version, would be justifiable in economic terms. The engineering design of Plato IV has been described elsewhere, by Bitzer and Skaperdas (*6*). Initial steps toward implementing the development of such a system at the University of Illinois have included demonstration of the technical feasibility of certain key components. Concurrently, some of these components are approaching the pilot production stage through the cooperative contributions of several industrial firms.

What Is Educationally Possible?

What is the role of the computer as an active element in the educational process? It is now widely accepted that the computer can be a valuable tool in the presentation of drill and practice routines in fields like elementary mathematics and vocabulary development. A capability for such programs was provided by the earliest and most limited system, Plato I. Plato II provided a more expanded tutorial capacity. The most important consequences of these two systems, however, were their stimulation of research and development leading to the broader capabilities of Plato III, which was designed for optimum educational versatility without specific concern for costs. In continuing full-time use as an exploratory system, Plato III has provided opportunities for developing many powerful new teaching strategies in fields as diverse as algebra and anatomy, psychology and pharmacology, languages and life sciences.

Without wanting to underrate the usefulness of computer-based systems for such rote learning situations as arithmetic drill and practice, we think it important to dispel the notion that computer-assisted instruction is limited to this type of application or is, in effect, an automated version of the Skinner teaching machine (*7*). The teaching strategies developed for Plato III are so far removed from this approach as to represent a totally different concept of the role of computer-based systems in education. To provide insight into the actual possibilities, it is important, first, to correct certain misconceptions about computer-based education. We list some of these, and give a brief commentary on each.

Misconception 1: Computer-based education is synonymous with programmed instruction. Computer-based education makes possible unprogrammed instruction or student-controlled learning by utilizing teaching strategies which differ completely from the basic tutorial logic of most programmed instruction. While of substantial value for the development of certain skills, the interchange of factual information between man and computer is only one mode whereby a teaching strategy may be incorporated into the computer. For example, the information may be stored in the machine in the form of simulated models of an actual system or device; one may simulate such widely differing systems as a biological organism (such as the human circulatory system) or an electronic circuit (such as a defective television set). Through a set of instructions stored in the computer, so-called algorithms, the computer is called upon to calculate unique responses to varying student inquiries. It is in this manner that the great computational power of a computer has been programmed to play chess with human opponents—to make appropriate moves in response to unpredicted behavior. In other teaching strategies the computer may be programmed to aid the student in the development of logical, algebraic, or geometric proofs, or to play the role of referee and scorekeeper in interactive games between humans, thus providing new insights into group or adversary behavior.

Misconception 2: Since the instructional strategy must be previously programmed in the computer, it must of necessity anticipate all conceivable student responses so as to compare them with "correct" answers stored in the machine. Teaching strategies which do not call for specified student responses are widely used and often of greater value in many fields and at many levels of instruction. For example, students studying geometry may be called upon to "draw" on the Plato graphic display a figure that has specified geometrical properties but need not be of a particular size or in any given location on the screen. In such cases, a set of algorithms in a so-called "judging routine" makes use of the computational power of the machine to assess the validity of the "answer." Other such routines have been assembled to judge open-ended verbal responses and to distinguish between conceptual errors and spelling difficulties. In a sequence for teaching algebraic proofs, the computer helps the student by pointing out or correcting arithmetical or logical errors after each statement, thus allowing the student to concentrate on the central notion of "proof."

Misconception 3: Computer-based instruction may be useful for the transfer of information but is not of value in the development of critical thinking. On the contrary, the development of comprehension calls for individual challenge or attention and is often inconsistent with the "classroom" approach. Computer-based instruction has often been found to be more effective than standard educational procedures in many learning situations that call for judgment, interpretation of complex problems, and evaluation by the student of the validity of his conjectures. In the course of some lessons, for example, the student may use the computer-based system to calculate, analyze, and display. This relieves him of much of the drudgery of "learning" and helps him develop intuition and insight. Although we view computer-based education as a way of enriching rather than replacing human involvement in the teaching process, we do not relegate computer-based education solely to routine tasks.

Misconception 4: A computer system used for computer-based education cannot be used in a time-sharing mode for conventional computer programming. The extent to which this is true is largely dependent on the size and design specifications of the system. In any multiple-access system it is necessary to set aside some reserve time, over and above the statistical "average" time of individual student usage, in order to avoid long intervals of waiting at times of peak load. In a large computer system this reserve time may be substantial. For Plato IV the reserve is to be of the order of 40 percent of the total available time, to make sure that the typical waiting time for any student is less than 0.2 second. This reserve capacity may be utilized in various ways for conventional computer programming. As many as 200 or 300 terminals could be used in a true time-sharing computational mode in concurrent operation with the remaining student terminals for purposes of computer-based instruction. Alternatively, this reserve computer time could be used for processing the educational response data from "on-line" students and could thus provide a mechanism for continuous evaluation of student progress and teaching effectiveness.

One example of a major departure from the tutorial mode of instruction is the so-called "inquiry" mode, which has proved to be of significant value in the development of critical thinking and intellectual comprehension. In this teaching strategy the student is presented with a problem statement that cannot be dealt with by a simple or multiple-choice answer; it may call for a sequential analysis or constructed response that cannot be uniquely anticipated. For example, in one of the chemistry sequences the student is asked to identify an "unknown" organic substance on the basis of any sequence of questions or "tests" he may specify. To make a valid response, the student may find it necessary to gather factual information about the substance's physical properties, to study its interaction with reagents selected by him, to "measure" and display its infrared spectrum, to interpret the data, or to calculate various reaction rates or other properties. While factual data may be stored in the form of dictionaries, tables, or other textual forms, the specific "results" of an experiment are often stored implicitly rather than explicitly. The student decides what tests he wants the computer to perform or what calculations he wants it to carry out. In a similar sequence in medical science, the student is asked to diagnose and prescribe the treatment for a patient's illness. When he proposes a treatment, the computer responds with a report of the expected effect on the simulated patient.

Obviously, we have proceeded far beyond the role of the computer as a bookkeeper, scorekeeper, and guide to selected textual material. Not only is the student helped in acquiring new information but he is aided in fitting this information into a broader context and in gaining new perspective. He may be introduced, even at a very early stage, to an investigative approach to the solution of many problems.

A major computer-based system provides a whole new capability for testing, evaluating, and model building for the learning and teaching process. Educational psychologists were among the first to recognize the potential value of this new medium for research in these areas. Several programs in educational psychology are in progress at the University of Illinois, with the Plato III system as the basic research tool. Obviously, such a system may also be utilized for evaluating specific course materials and, eventually, for measuring and increasing the effectiveness of this new medium.

Initial experiments aimed at evaluating educational effectiveness have been made at the University of Illinois and elsewhere (*8*). The data sample is altogether too limited, but the results have been encouraging. For example, a class of 20 students in a medical science course was taught for a semester entirely with the Plato system. When compared with a control group in a nationally administered test, the students taught with the Plato system were found to have scored as well in grade performance even though they had required only one-third to one-half as many student-contact hours of instruction as those taught in the conventional classroom. Subsequent measurements extending over a 26-week period indicated that the Plato group showed greater retention over that interval.

Subjective evaluation of Plato by students, teachers, and authors has been unusually positive in a wide variety of exploratory experiments. Several key features help to explain why computer-based education has aroused the enthusiasm of students and teachers alike.

1) The interactive nature of this instructional medium typically absorbs the attention and encourages the total involvement of students at all age and grade levels (see Fig. 1).

2) The student may proceed at his own pace and can exert considerable choice in the selection of alternative teaching strategies and methods of presentation.

3) The feedback of information is applied not only in the learning process but also in the teaching process; the system provides teacher or author with the means of assessing in detail the progress of the individual student, with a powerful tool for evaluation and modification of lessons, and with a mechanism for measuring overall educational effectiveness.

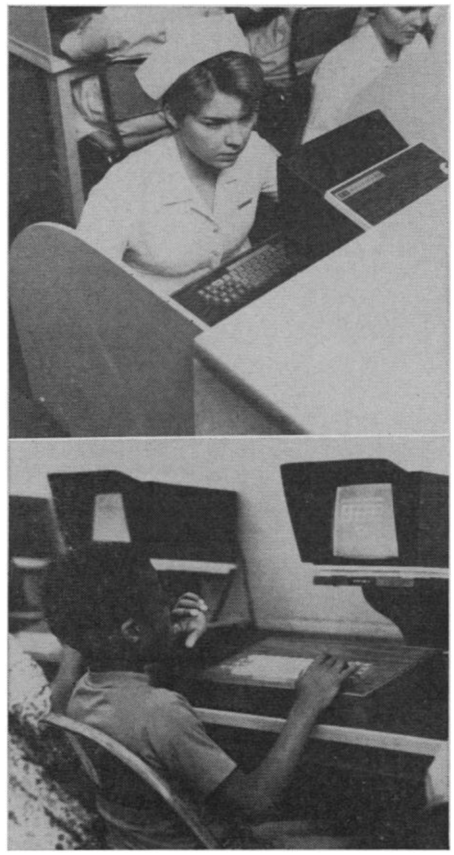

Fig. 1. Students at Mercy Hospital School of Nursing and Washington Elementary School Demonstration Centers (Plato III).

4) Lesson materials may be written or edited at a student console at any location while other consoles are being used by students. Thus, materials previously prepared elsewhere may be modified by a teacher in a participating institution (for example, a community college or a secondary or elementary school) in response to the particular needs of his own students.

We hasten to add, however, that the results attainable with any system of limited size cannot be considered definitive. We question whether a reasonable perspective can be achieved until much larger experiments can be performed. For a typical course, our data on Plato III have been limited to several hundreds of hours of student instruction. In the absence of a fully developed educational model or a widely accepted evaluative procedure, even for conventional educational methods, it is not possible from such relatively small samples to derive broad generalizations. Two conclusions seem justified: (i) that computer-based education is a plausible approach to improved individualized instruction in a very wide array of courses or subject-material areas; (ii) that the nature of educational testing and evaluation calls for, and will be radically and substantially affected by, the availability of large computer-based education systems; a valid measure of effectiveness calls for a much larger sampling of data and a longer period of comparison than has heretofore been available.

This expanded view of what is educationally possible is made feasible by several unique features of the Plato III system. First, a highly flexible software system has made it easy for educational innovators to use their intuitive notions to develop wholly new sets of teaching or testing strategies; the capacity of a large central computer makes possible a very wide variety of such teaching strategies, even in a single lesson. Second, the flexible software design has provided compatibility not only with CAI systems developed by other manufacturers and designers but also with the next generation of such machines; educational materials developed elsewhere can be readily incorporated. Third, although the software system has become increasingly sophisticated and permits an experienced author to develop very complex teaching strategies and lessons, it is not necessary for an author to become, or to be dependent on, a systems programmer. Teachers and authors can begin to prepare, edit, or modify lesson materials after a few hours of familiarization with the Tutor (*9*) language, with no previous experience. Finally, it is possible for messages to be transmitted from a given student station to any other student station; thus, teachers or authors may act as participants in the system or monitor the progress of individual students.

What is the role of computer-based instruction in the context of the conventional classroom setting? Just as the printed page or the textbook has distinctly different uses at various educational levels, we postulate different uses for computer-based education at the various stages from preschool to graduate education and beyond. At the elementary grade level, in view of the important role of teacher and pupil interactions during most of the day, it seems reasonable to anticipate that computer-based instruction will occupy a relatively small fraction (perhaps 1 hour per day) of the pupil's time. Interestingly, our experience at this level indicates a unique cooperative relationship between teacher and pupil when the individual members of the class are at their Plato consoles. The teacher is called upon only when the pupil needs special help; when this occurs, help can be provided on the basis of a precise indication of the nature of the difficulty as exhibited by the particular sequence in which the problem was encountered. Applications at the grade school level include individual drill and practice in arithmetic and the development of reading skills, and they provide periodic rest intervals for the human teacher.

At the opposite end of the utilization scale we might envisage entire courses given at professional schools, at remotely located graduate centers, and in continuing adult education programs. The individualized approach to education that the Plato systems provide would be uniquely suited to the updating of professional skills or the development of new skills for adults at the nonprofessional level.

We visualize a particularly valuable role for computer-based education at the undergraduate level at universities, 4-year colleges, and community colleges. As to the degree of utilization, one may expect that the fraction of the instructional load that can be taken over by computer-based education would vary widely. In certain instances—such as introductory courses in computer science, mathematics, basic anatomy, or genetics—a Plato-type system might well assume the entire load. This would be particularly attractive for well-qualified students who wished to register in an advanced seminar without devoting an entire semester or two to a prerequisite survey course. Such students might well take the entire course and a proficiency examination within a week or two. Students who are less well qualified might by this means take remedial work at all levels to aid in their preparation for more advanced courses. In addition, there would be many courses in which the computer-based system and human teachers would share the load more or less equally. Faculty instructors could spend more of their available time in advanced or interdisciplinary seminars in which the discussion of human values or the development of new ideas would occupy the entire time available for interchange between teacher and students.

Computer-based education would make a unique contribution at the community college level, not only because of the shortage of adequately prepared instructors in many fields but also because of the value of such a system in orienting students who transfer to other colleges or universities after 1 or 2 years. They might, by this means, share, prior to transfer, an educational experience with students at the other institution.

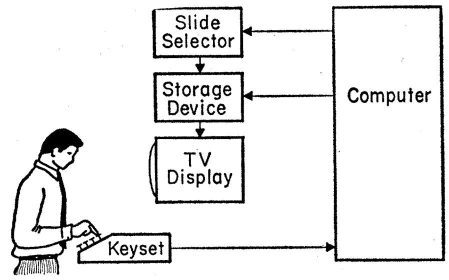

Fig. 2. Schematic representation of the Plato III system.

Considerations of Engineering and Economics

Presently available CAI systems (including Plato III) entail total costs which range between $2 and $5 per student-contact hour (*10*). The Plato IV system is intended to reduce this cost by a factor of about 10, to about 35 cents per student-contact hour—a figure comparable to the lowest instructional costs in elementary schools and considerably less than the comparable costs at colleges and universities. In this section we try to summarize the economics and engineering considerations and to identify the principal issues involved.

In the CAI systems now in use or in the planning stage there is considerable variation in design, in the type of communications channels between computer and student stations, in the manner in which lesson materials are stored, and in the format (teaching strategies) in which they are presented. However, although there exist important options in the systems design, a framework within which to discuss both the design and the economics of a large class of computer-based systems is given by the following listing of basic operational elements.

1) A central computer which provides the executive communications control and which encompasses the logic, the rapid-access memory, and the main data-processing facility for the system.

2) A computer software system for organizing various teaching, testing, or research strategies and for specifying the language in which directions to the computer are to be formulated.

3) The individual student console, which provides the "interface" between man and computer. This is also referred to as a student terminal or student station.

4) Management and other professional services in the computer-based education system.

5) Communication channels, such as telephone or microwave cables, which carry information between the computer and the individual student terminals.

To provide a basis for cost comparison, we will set forth the cost elements for Plato III and then proceed to compare the estimated costs for the proposed Plato IV system. The design details of the Plato III system and student terminal are described elsewhere (*11*). As indicated in Fig. 2, lesson materials are presented to the student on a television screen which can superimpose fixed images stored on photographic film and computer-generated or student-generated information. The student responds by means of an electric typewriter, or keyset. As indicated above, Plato III is one of the most versatile systems in current use.

An estimate, based on several years of experience, of the operational costs of the Plato III system, complete with an optimum number (50) of student terminals, ranges from $1.90 to $2.90 per student-contact hour. The actual costs (at the high end of the range) for the 1960-vintage computer used in Plato III are significantly greater than the costs for a third-generation computer of comparable capacity would be. The annual rental of a present-day computer is estimated to be about $50,000, or $1,000 per student.

Though of unique design, the student console for Plato III is assembled from available commercial components. The estimated cost, with current production techniques, is $5000 per student console. In the current design, these student terminals must be connected to the computer by means of television-bandwidth cables; hence, they must typically be located within a hundred meters or so of the central computer facility.

The operational costs for an updated version of Plato III, with a third-generation computer, are estimated at about $1.60 per student-contact hour, exclusive of systems software. These costs are approximately equally divided among

(i) the central processing unit, (ii) the Plato III student console, and (iii) management of the computer center (including maintenance, scheduling, computer programming service, and so on). The software for such a system could be developed at a cost which would add about 30 cents per student-contact hour; if ten or more Plato III systems were built, this cost would be reduced to a negligible fraction of the operational expense.

From a budgetary standpoint, the operational cost of the computer-based education system corresponds to the direct instructional cost in the conventional classroom setting. In addition, there is a need for CBE lesson materials, which correspond to the textbooks and other instructional materials used in the classroom and which are typically budgeted as a separate item. The Plato III software system was designed with a special view to reducing the overall effort, and associated cost, of preparing materials. The development of the Tutor author language has had a particular impact on the economics of this process. It is possible for a potential author to write such lessons without any previous acquaintance with, or need for, computer programming. Also, it is far easier with the Plato III system than with most CAI systems to arrange the material in a previously selected format, or to change the format. Furthermore, the author may either write or edit his material on-line at any student terminal while the other Plato terminals are in use. (In some systems, editing or "debugging" cannot be done without seriously degrading the entire system for student use.) Hence, for Plato III, the cost of preparing or editing materials is considerably lower than the cost reported for other systems—in some cases, by a factor of 50 (*10*).

Based on the experience of preparing thousands of hours of lessons, we estimate the commercial "production" cost of such preparation, exclusive of author royalties, to be in the range of \$300 to \$600 per hour of instruction; the cost for these supportive services (photographic, computer access, secretarial, and so on) has actually averaged considerably less in our laboratory. Our experience shows that a drill and practice lesson can be prepared and edited by an experienced author in a few hours; rather complex lessons covering an entire semester's work have been prepared on a part-time basis by a qualified instructor during the course of the previous semester. Thus, if the author's salary were included in the above figures, the total costs would range between \$400 and \$800 per hour of instruction.

Prorating of these costs obviously depends critically on the number of students expected to use a given set of material, as is the case for textbook publication. If, for example, the number of student users expected to take a given lesson were 500 per year for 5 years, the prorated charge to cover the costs would be approximately 25 cents per student hour. This would mean a total charge of about \$12.50 for a 50-hour semester course, an expense comparable to that for textbooks. If there were many compatible systems or larger individual systems, a far larger number of students could be served, hence there would be a substantial decrease in the charge for lesson materials.

The design of Plato IV envisages a computer-based system which could reduce the total cost per student-contact hour far below that of any system currently available while maintaining the unique student terminal and systems software capabilities demonstrated in Plato III. The principal design features proposed for Plato IV are as follows.

1) Incorporation of a large third-generation computer of the Control Data 6000 class. Such a computer configuration can be designed to serve as many as 4000 student stations and to teach several hundred lessons simultaneously.

2) The design and utilization of a novel and versatile student console providing a dynamic graphic display, superimposed pictorial images, and a keyset by which the student communicates with the system. As an additional accessory, individual random-access audio systems would be available for student terminals.

3) The capability of serving student consoles at remote locations. Groups of such stations located at a remote campus or school district could be linked to the computer at reasonable costs within a 150-mile (240-kilometer) radius. Each console would then be connected by a regular telephone line to a distribution center at the remote site.

The system modifications that account for sizable reductions in the projected cost of the Plato IV system are associated with significant technological developments in each of the major design features. The first of these has been commercial production of third-generation, general-purpose computers for which the speed has been greatly increased while the unit operations cost of this central element has been reduced by a factor of 10. The increased reliability of solid state circuitry in such computers has also made production of a much larger computer feasible; it is possible to increase the number of student stations by a factor ranging from 10 to 100. Thus, it is feasible with commercially available models to install a central computer system serving 4000 student stations with the same quality of instructional sequencing that is provided by Plato III. For such a system, the unit computer cost would be reduced to only 11 cents per student-contact hour, even on the assumption that the system was to be available for student use for only 8 hours per day.

The choice of a system capable of serving thousands of student stations has a major effect on the nature and costs of other elements of the system—in particular, of the central management services. The economic consequences are evident from the following comparison. On the assumption of an annual use of 2000 hours for each of the 50 student consoles, the total annual instructional load for the Plato III system is estimated at about 100,000 student-contact hours. Thus, for Plato III, an annual incremental cost of \$100,000 adds approximately \$1 to the cost per student-contact hour. For Plato IV, a similar increment of \$100,000 in annual costs adds approximately *1 cent* to the cost per student-contact hour. But the unit economic cost is not the only consideration of importance. A single Plato IV system, as now envisaged, will be capable of providing major educational services not only to thousands of students at a major university site but to students at dozens of other institutions, including, for example, colleges, high schools, and elementary schools. With computer-based systems of limited size, the initial venture into computer-assisted instruction by a school lacking previous experience or commitment involves not only the purchase or rental of a complete system at very substantial cost but, in addition, provision for special administrative personnel to operate and manage a relatively sophisticated computer-education center. With Plato IV, by contrast, a new institution may venture into this field by investing only in a modest number of student consoles and accompanying telephone lines. It would also be feasible for such newly participating schools to use previously prepared course materials. Thus, an institution could make its initial venture into computer-based education without major investment in equipment, personnel, or lesson materials.

In Plato IV, a second major change lies in the proposed incorporation of student consoles of a novel, low-cost, high-performance design. Following the development of large third-generation computers, the need for versatile, low-cost student stations became the paramount issue in developing an economically viable system. In addition, it was apparent that the design of a large-scale system would be greatly improved, on both economic and educational grounds, if student stations could be connected at remote locations or in individual rooms and offices.

A very promising technological innovation aimed at providing an improved low-cost student console is the plasma display panel (*12*), a recently invented graphics display device that is capable of storing on its viewing surface either computer-generated or student-generated information without the need for auxiliary storage devices. Furthermore, the panel may be addressed by way of telephone lines of conventional bandwidth. Under the trade name Digivue (*13*), this electronic device is at present in the commercial prototype development stage and offers promise of excellent performance, with significant further reductions in the cost of student terminals. Made of a thin, flat, gas-filled glass container with transparent electrodes, the plasma panel is so designed that photographic images can be conveniently projected and superimposed on the display surface. Thus, one can combine the presentation of textual material or slides with presentation of the computer-generated information, as is done in Plato III.

Figure 3 is an artist's conception of a Plato IV student console with keyset, plasma display panel, and a low-cost random-access image projector. The latter is another invention that resulted from the Plato design effort. It permits random selection by the computer of any image on a microform card on which textual and photographic lesson materials are stored. Figure 4 is a photograph of a small [4- by 4-inch (10- by 10-centimeter)] pilot-model Digivue panel with a superimposed photographic image. Plato IV plans call for a panel of considerably greater size (10 by 10 inches) and a resolution better than that of television displays.

A new low-cost, random-access audio system will make it possible for a student to call for, or to record, vocal messages on a locally situated magnetic recording device. This unit would typically be considered an optional feature, especially useful in certain language courses.

The design of the Plato IV student console makes possible a novel economical method for communicating with the central computer at a distance. By sending the information in digital form in carefully arranged time sequence, it is possible to transmit to as many as 1000 student stations by way of a single educational-TV channel. At a distance of 150 miles, such a communication channel would cost only a few additional cents per student-contact hour.

Table 1 sets forth the projected operational costs for the Plato IV system. The hourly costs are based on the assumption of full utilization of the system, with all 4000 student terminals in operation; these costs would be higher, of course, if utilization were less than 100 percent. This assumption is offset, however, by the fact that the hourly costs are based on an 8-hour day. The costs can obviously be lowered either by using the system for education during a larger part of the day (Plato III is currently in use for education at least 60 hours per week) or by using some student stations and the large, general-purpose computer for other computational or research applications during the remaining hours. Thus, the educational use of this massive computer could help pay for some of the other computational needs, and vice versa.

The greatest variance in the estimates of operational expenses lies in the projected cost of the Plato IV student station. It is our considered judgment that this entire unit (exclusive of the audio system) could be made available at a cost of approximately $1800 when produced in quantity. A detailed analysis of such a projection lies beyond the scope of this article. At the present writing, the technological feasibility of the plasma display panel and the random-access image selector seems as-

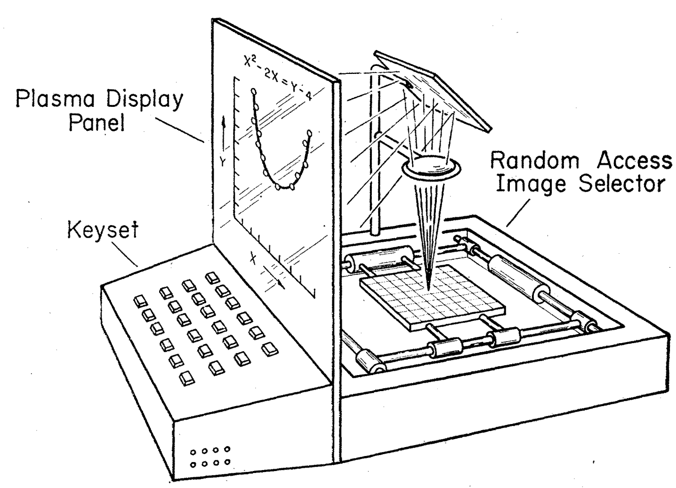

Fig. 3 (above). Schematic diagram of the Plato IV student console.

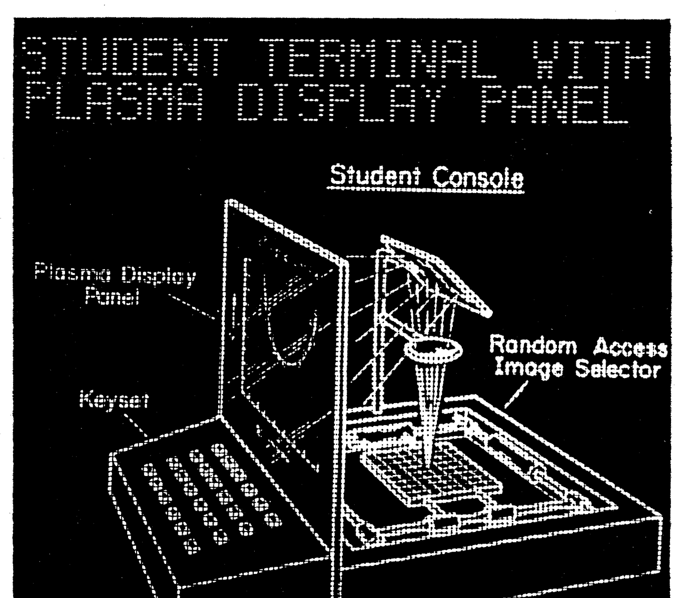

Fig. 4 (right). Superimposed photographic and computer-generated images on a Digivue plasma display panel. (In normal viewing the lines which appear in the projected photograph of the student console would not be visible.)

sured, though specific confirmation of estimated unit costs must await further experience with pilot production models. While we have considerable confidence that the target cost of 18 cents per student-contact hour for a student terminal of radically novel design can be met, we have also indicated a reasonable upper limit on the probable cost by listing the current cost (50 cents per student-contact hour) of existing Plato student stations. This accounts for the wide range of console costs listed in Table 1.

Preparation of lesson material for Plato IV would be comparable in cost to preparation of material for Plato III. A charge of only a few cents per student-contact hour would cover such costs if as many as ten Plato IV systems were installed in various parts of the country. For courses that are widely incorporated in many curricula—for example, introductory courses in statistics or in chemistry—student use could easily reach 10,000 hours on a single Plato IV system within three or four semesters. Hence, authors could receive a substantial royalty even if the charge for lesson materials was as low as $5 per 50-hour semester. For courses for which there is little student demand—for example, a course in an unusual foreign language—either the charge would have to be increased, or the materials would have to be usable in a number of compatible systems, or some of the author's remuneration would have to come from other sources.

In summary, the costs for installation of the computer (including the systems software) and management of the computer center would total approximately $1.2 million per year, or about 15 cents per student-contact hour. If rental of the student station and associated communications lines totaled a comparable amount, the hourly cost for individual student instruction would be less than 35 cents per contact hour. An upper estimate (based on utilization of existing technology for the student console) for hourly cost would be approximately twice that figure. It is our firm conviction that the implementation of a system at the lower target figure is clearly attainable in the early 1970's.

Table 1. Operational costs of the Plato IV system.

Subsystem	Total annual cost (rental or amortization over 5-year period) (dollars)	Annual cost per student station (rental or amortization over 5-year period) (dollars)	Cost per student-contact hour* (dollars)
Central computer facility	900,000	220	0.11
Computer systems software	100,000	25	0.01
Student console		360–1,000	0.18–0.50
Central management services	240,000	60	0.03
Communications channels†		18–50	0.01–0.03
	Total operational costs per student-contact hour		0.34–0.68

* Annual use per student, 2000 hours (45 weeks at 44 hours per week); maximum number of student stations, 4096; total annual use (4096 stations), 8.2 million student-contact hours. † For telephone connections on a given campus, contingent property-line costs are about $1.50 per month per terminal (1 cent per student-contact hour). For student stations at a distance, communications would be transmitted by means of time-multiplexed television channels for groups of 1000 student stations per channel. At a distance of 150 miles this would cost an additional 2 cents per student-contact hour.

Some Implications

The cumulative and overwhelming trend of our exploratory research results with the Plato III system suggests that this new medium will be educationally effective and enthusiastically received by students at all levels of age and experience. There is every evidence thus far that this enthusiasm is shared by teachers and authors as well. Supporting this appraisal is the corresponding experience of educators working in the field of computer-assisted instruction at other institutions, for the most part with computer-based equipment far less flexible than Plato III. Most such educators are increasingly persuaded that this medium provides a powerful means of meeting heretofore unmet needs in the entire range of the educational process. If there has been informed skepticism or concern about the potentiality of computer-assisted instruction, it has largely been addressed to the issue of economics (*14*).

In this article we have discussed a number of advances in the economical implementation as well as the educational capability of computer-based education systems. We have described a system for which the projected target cost of 35 cents per student-contact hour is about one-fifth that of an updated Plato III system and about one-twentieth the cost of some systems in current use. This figure compares favorably with instructional costs at any grade level and would represent only a fraction (15 to 25 percent) of similar costs at the college level.

The availability of a large-scale, economically viable CBE system could provide a wide variety of educational opportunities which are currently either totally unavailable or available to only a small percentage of the population. Some of the possibilities that may well be realized through the application of computer-based education are the following.

1) Gradual abolishment of lock-step schedules and narrowly specified curricula in formal education. Students could proceed at a pace determined by their own capacity and motivation.

2) Provision of remedial instruction or tutorial assistance during regularly scheduled courses for students with insufficient preparation.

3) Reduction in the number of large lecture classes at the college level, in favor of small instructional groupings and seminars.

4) Special instruction at home for physically handicapped students.

5) Development of arithmetical or other skills, at the elementary level, away from the exposed and often competitive environment of the classroom.

6) Effective job training or retraining for any employee group especially affected by expanding technology.

7) Continuing education for professional personnel, permitting the updating of knowledge and skills in their own offices and on their own schedules.

Some of the available options would be economically justifiable even at the higher unit costs associated with Plato III. A much larger number of opportunities would be accessible with a fully implemented network of Plato IV systems.

A single Plato IV system operating 10 hours a day could provide approximately 10 million student-contact hours annually at a cost of about $3 to $4 million (a total capital investment of approximately $12 million). This is equivalent to the total annual number of hours of instruction at a 4-year undergraduate institution with 24,000 students! Such an institution would typically have direct instructional expenses of well over $20 million annually and, in a university setting, a total budget several times greater. This comparison is obviously not meant to suggest that Plato could be substituted for such an institution. Rather, it is intended to indicate that a single Plato IV system could augment by 20 percent the instructional capacity of five such institutions on an annual budget of less than $1 million each.

Alternatively, this added capacity could release an equivalent portion of faculty time for developing new programs, for teaching in smaller group settings, or for providing extra help to individual students. The possibility of such enrichment of our national educational capability has provided added incentive for implementing and testing the Plato IV design and for learning how such a system would function in various educational settings.

The introduction of a major new technology into the educational process will undoubtedly raise questions on the part of some educators concerning the possible negative impact of an inanimate tutor on the very human processes of learning and teaching. Similar questions may well have been raised when the printing press and inexpensive paper were introduced into the educational process in the 15th century. It was not long, however, before the technology of the printed page became so identified with education that the library became the universal symbol of educational excellence. We believe that the resulting explosion of knowledge and of information has made the introduction of computer-based education all the more needed in a rapidly changing world.

The Plato program has called for a unique combination of educational and engineering talents. The program has benefited from cooperation among experts in many disciplines and among educators in universities, community colleges, high schools, and elementary schools. Finally, it has depended in a critical way on cooperation among educational institutions, industrial corporations, and government agencies. These features may be indicative of a new level of interinstitutional relationships which would accompany the incorporation of computer-based systems in the educational process.

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Purpose and Function of the University

University scholars have a major responsibility for survival and quality of life in the future.

V. R. Potter, D. A. Baerreis, R. A. Bryson, J. W. Curvin, G. Johansen, J. McLeod, J. Rankin, and K. R. Symon

Early in 1967 the Interdisciplinary Studies Committee on the Future of Man, together with other groups on the University of Wisconsin Madison campus, was asked to comment on four questions raised by the Board of Regents about the purpose and goals of higher education: (i) What are the purposes of higher education? (ii) What should be the goals for the University as an entity? (iii) What should be the goals for each segment of the University? (iv) To what extent should students and student organizations be involved in University government?

The University's response to these questions included a recommendation for a more thorough study of some issues. Because our committee was not fully satisfied with either its own recommendations (*1*), or the University's response we expanded and extended our earlier comments.

The Interdisciplinary Studies Committee on the Future of Man has been in existence since 1962 and has considered many aspects of university purpose and function in connection with our concern about the future of man. Together with many other faculty members and students we share the malaise that affects other members of society who are concerned about the future. We affirm the views that the survival of civilized man is not something to be taken for granted, that governments throughout the world are experiencing great difficulty in planning for the future while trying to cope with the present, and finally, that the university is

Dr. Potter is chairman of the Interdisciplinary Studies Committee on the Future of Man at the University of Wisconsin at Madison. The other authors were members of the committee. Drs. Baerreis and Bryson were previous chairmen.