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ABSTRACT

Initiated in 1959, Project PLATO has attempted to identify and promote technical innovations that improve computer based education and make it economically viable. Three successive systems (PLATO I, II, and III) displayed the potential of the computer to deliver high quality instruction, including programs emphasizing student autonomy and encouraging the development of inquiry and critical thinking skills. The aim of PLATO IV is to take advantage of technical advancements and economies of scale to produce computer-assisted instruction at $.35 per student contact hour, a much more economical figure than existing instructional costs. This report discusses the educational advantages of each of the PLATO systems, and it emphasizes the possible economic savings that will be demonstrated in PLATO IV. (EMH)

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A Progress Report on the PLATO Program

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I. Introduction.

Since its initiation in 1959, the PLATO program at the University of Illinois has been committed to exploration of the educational possibilities and the engineering-economic problems relating to the introduction of the modern high-speed computer into the educational process. During the course of the past decade, numerous other groups at universities, not-for-profit institutes, and profit-oriented corporations have also initiated exploratory efforts to utilize modern computer technology for instruction. A widely varying array of such efforts has been encompassed under the term "computer-assisted instruction" (CAI). Because the introduction of the high-speed digital computer into any field of human activity often has had very broad social implications and because the implications for education may be especially profound, it is not surprising that some of these activities have received widespread publicity.

The over-all setting is one in which the nation now invests over $50 billion annually in the formal educational process, a total commitment which is expected to increase to $150 billion annually by 1980. Yet despite this large national commitment, it is commonly agreed that there are vast unmet needs in education both in terms of quantity and quality. We are confronted with a conflict between the demands for more mass education over a larger fraction of the human life span and the demands for more individualized instruction tailored to the specific preparation and motivation of a given student. Many of the programs in CAI were originally motivated by the notion that the technology of the computer could provide a unique contribution to satisfying these demands. However, although great expectations have been aroused, the general reaction at this point in time might be described as a conflicting mixture of great enthusiasm, deep skepticism, and, in too many cases, general confusion. Such a variation in response can be explained if one realizes that the exploratory efforts in CAI do not constitute a well defined and coordinated national program; rather, these efforts encompass programs with a wide diversity of objectives and professional interests and an even greater diversity of available technological facilities. Hence, the perspectives, even of experts in the field, are often widely different.

As an example of the diversity of points of view, a number of proponents of CAI were postulating and publicly arguing that a significant operational application of CAI was feasible with the computer technology available in 1965. Significantly, the strongest proponents of instant CAI were often those with the least experience in the design or utilization of computer systems. In contrast to such viewpoints is a recent evaluation of the field presented in a report entitled "The Computer in Instruction: An Overview" and carried out in 1968 under the aegis of Associated Universities, Inc. The present status of the educational validity and economic viability of CAI systems is 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.*[1] (italics added)

The PLATO program has proceeded on the premise that the existing technology of the 1960s, while adequate for valuable exploratory research, was not yet capable of contributing in a significant and economically practical way to the nation's educational program. Among the approximately 75 projects currently enrolled in the field of CAI in this country, the PLATO effort is one of the very few which have included a significant program of research and development in all aspects of systems design--aimed at major innovations in systems hardware and computer software as well as in teaching strategies and lesson materials.

As early as 1964 our experience suggested the need for significant technological innovations if an economically viable system were to be achieved. We proceeded to identify and implement such innovations by enlarging the already powerful technological effort within our overall program. Although not promising immediate wide-scale utilization, this approach was in many ways far more ambitious 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 refer to the laboratory in which the current effort is centered as the Computer-based Education Research Laboratory. In this paper, however, we use the terms "computer-assisted instruction" (CAI) and "computer-based education" (CBE) interchangeably.

The PLATO program has developed in two distinct phases, each aimed at different though related objectives:

I. The 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?

II. The design of an economical and educationally viable system incorporating the most valuable approaches to teaching and learning developed in Phase I.

In Phase I of the program, which was initiated at the Coordinated Science Laboratory of the University of Illinois, 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. A significant result has been the realization of a broad set of educational objectives. 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 experiments are in progress in many disciplines and at all levels of formal education. At each level, CBE has met with unusual enthusiasm.

Several key features help to explain why computer-based education has captured 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.

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 detailed access to individual student progress, a powerful tool for lesson evaluation and modification, and a mechanism for measuring over-all educational effectiveness.

4. Teachers/authors can prepare, edit, or modify lesson materials after only a few hours of familiarization with the TUTOR[2] language, and with no previous experience with or need for computer programming.

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

Phase II of the PLATO program, initiated more than five years ago, has addressed itself to the problem of the high costs of existing technology for computer-based education. 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 economically justifiable. The over-all design of PLATO IV has been described elsewhere in a paper by Bitzer and Skaperdas.[3] Initial steps toward implementing the development of such a system at the University of Illinois have included the 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.

II. What Is Educationally Possible? The Potential Role of the Computer in Computer-Based Education.

Educational efforts with PLATO systems have now involved exploratory teaching in at least 20 fields of study and over 100,000 student-contact hours (most of it for academic credit) in course work at the elementary, secondary, college undergraduate and graduate levels. From the outset we have used the computer to supply appropriate responses to student questions or answers and to keep detailed records of such responses. Even the most primitive system, PLATO I, demonstrated a tutorial sequence for drill and practice, which provided an immediate feedback, allowing the student to proceed in the event of a correct response and to repeat or review in the event of incorrect responses. This role of the computer is perhaps the most widely known in the field of CAI and has led some to think that computer-based education is limited to an automated version of the Skinner teaching machine.[4] PLATO II provided a much more complex tutorial system with a greater variety of choices and alternate lesson materials for students with varying degrees of preparation or motivation. PLATO III, which is in continuing full-time use as an exploratory system, has demonstrated many powerful new approaches to teaching and learning with this flexible educational medium. Teaching strategies and lessons have been developed in fields as diverse as algebra and anatomy, foreign languages and pharmacology, life science and library science.

Without attempting to detract from the valid use of computer-based education in a tutorial mode for such rote learning situations as elementary arithmetic or vocabulary drill, we believe it should be emphasized that in the past few years teaching strategies have been devel-oped which are so far removed from the Skinnerian approach as to represent a totally different conception of the role of computer-based education.

To provide insight into the diversity of possible applications of the computer in education, it is important to correct certain misconceptions which are frequently promulgated both by proponents and by critics of CAI. We list some of these misconceptions together with a brief commentary on each.

Misconception I: 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 in which 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 (e.g., the human circulatory system) or an electronic circuit (e.g., a defective radio 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, making 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 II: 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 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 is not restricted to a given size or 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 III: Computer-based instruction may be useful for the transfer of information but it is not of value in the development of critical thinking skills.

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 develops intuition and insight. Although we view computer-based education as a way of enriching rather than replacing the human involvement in the teaching process, we do not relegate CBE solely to routine tasks.

Misconception IV: A computer system used for computer-based education can not be used in a time-sharing mode for conventional computer programming.

This 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 between individual requests over and above the statistical "average" time of individual student usage in order to avoid long waiting intervals at times of peak loading. In a large computer system this reserve time may be substantial. For PLATO IV the reserve is designed to be of the order of 40 percent of the total available time to assure that the typical waiting time for any student is less than 0.2 second. This reserve capacity may be accessed in various ways for conventional computer programming. As many as two or three hundred terminals could be used in a true time-sharing computational mode in concurrent operation with the instructional use of the remaining student terminals. Alternatively, this reserve computer time could be used for the processing of the educational response data from on-line students and could thus provide a mechanism for the 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 had significant value in the development of critical thinking skills and intellectual comprehension. In this teaching strategy, the student is presented with a problem statement which can not be dealt with by a simple or multiple-choice answer; it may call for a sequential analysis or constructed response which can not be uniquely anticipated. As an 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 its physical properties, to study its interaction with student-selected reagents, 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 makes the decisions as to the tests he wishes the computer to perform or the calcualtions 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 recommended 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 it 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, evaluation, 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 this general area are in progress at the University of Illinois, utilizing the PLATO III system as the basic research tool. Obviously, such a system may also be utilized for the evaluation of specific course materials and, eventually, in measuring and optimizing the effectiveness of this new medium.

Initial experiments aimed at evaluating educational effectiveness have been made at the University of Illinois and elsewhere.[5] Although the data sample is altogether too limited, the results have been most encouraging. As a typical instance, 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 student group taught with PLATO scored as well in grade performance even though they required only one-third to one-half as many 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.

The subjective evaluation of PLATO by students, teachers, and authors has been unusually positive in a wide variety of exploratory experiments. However, we hasten to add that the results which are attainable with any system of limited size can not 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:

1. That computer-based education is a plausible approach to improved individualized instruction in a very wide array of courses or subject-material areas.

2. 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 compiler has made it easy for educational innovators to use their intuitive notions to develop wholly new sets of teaching or testing strategies. Second, the large size of the computer makes possible a very wide variety of such teaching strategies, even in a single lesson. Third, the flexible software design, based on a powerful central computer, 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. Fourth, although the software system has become increasingly sophisticated, it is not necessary for an author to become or to be dependent on a systems programmer. 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 to monitor individual student progress or to respond to calls for human advice, interpretation, or help.

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 CBE at the various stages from pre-school to graduate education and beyond.

It seems reasonable to anticipate that computer-based instruction will provide a relatively small fraction (perhaps an hour per day) of the pupil's time at the elementary grades in view of the important role of teacher and pupil interactions during most of the school day. Special applications at the grade school level include individual drill and practice, the development of critical thinking skills, and periodic rest intervals for the human teacher. At the opposite end of the utilization scale we might envisage entire courses in continuing education for adults at remote locations.

We visualize a particularly valuable role for computer-based education at the undergraduate level at universities, colleges, and community colleges. As to the degree of its utilization, one may expect that CBE would assume a widely varying fraction of the instructional load. 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 in a prerequisite survey course. Such students might well take the entire course and proficiency examination within a week or two. Less qualified students might by this mechanism 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 would share the load more or less equally with human teachers. 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 teacher-student relationship.

CBE 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 orientation value for students who transfer to four-year colleges. They might, by this medium, share a common educational experience with other students prior to the junior year.

III. Engineering-Economic Considerations in the Design of a Viable Computer-Based Education System.

It is generally agreed that the present CAI systems (including PLATO III) entail total costs which range between $2.00 and $5.00 per student-contact hour (s.c.h.).[6] The PLATO IV system is intended to reduce this cost by approximately a factor of ten, 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. It is the purpose of this section to summarize the economic-engineering considerations and to identify the principal issues involved.

For this discussion, it is helpful to specify in broad outline the major subsystems which make up a computer-based instructional system and then to identify the associated costs. In making comparisons, we will set forth the cost elements for PLATO III, an existing system with which we have very considerable experience, and then proceed to compare the estimated costs for the proposed PLATO IV system. Although it is among the most versatile of present state-of-the-art systems, the PLATO III system has operational costs at the lower end of the range of costs for current CAI systems.

In the CAI systems presently in use or in the planning stage there are considerable variations in design. For example, significant differences occur in the nature of the communication channels between computer and student stations. Variations may also occur in the manner in which lesson materials are stored or 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 (CAI) systems is offered 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 specifying the language in which directions to the computer are formulated.

3. The individual student console which provides the interface between man and computer. It 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.

The design details of the PLATO III system and student terminal have been described elsewhere.[7] As indicated in the schematic diagram of Figure 1 and the photograph of Figure 2, lesson materials are presented to the student on a TV screen which can superimpose fixed images stored on photographic film and computer-generated or student-generated information. The student responds via an electric typewriter, or keyset.

Table 1 sets forth the estimated operational costs of the PLATO III system complete with an optimum number (50) of student terminals. The large cost range indicated for the central computer is based on the fact that the actual costs of the 1960 vintage computer used in PLATO III (at the high end of the range) are significantly greater than would be the case for a third-generation computer of comparable capacity.

The development of the basic computer software system for PLATO III has proceeded over a period of several years; since a major exploratory research effort was involved, it is obviously difficult to assess actual costs. However, it is feasible to make an estimate of the cost to develop the systems software for a new computer which would incorporate the basic elements of the CATO compiler and the TUTOR author language (essential features of the PLATO III software). We believe this could be carried out at a total cost of about $150,000. If applied to a single system, this would involve a cost of 30 cents per student-contact hour. However, after this initial development, such software could be provided for identical computer systems at little additional cost. Thus, if one assumed ten PLATO III systems, the incremental systems software cost per student-contact hour would be reduced to three cents, or a negligible fraction of the over-all systems expenses.

While of unique design, the student console for PLATO III is assembled from available commercial components. The cost estimate with current production techniques is $5,000 per student console. It is important to note that in the current design these student terminals must be connected to the computer via TV bandwidth cables; hence, they must typically be located within a few hundred feet of the central computer facility.

Assuming a third-generation computer, the operational costs for an updated version of PLATO III are estimated at about $1.60 per student-contact hour, excluding systems software. These costs are approximately equally divided among (a) the central processing unit, (b) the PLATO III student console, and (c) management of the computer center (including maintenance, scheduling, computer programming service, etc.).

From a budgetary standpoint, the operational cost of the computer-based education system corresponds to the direct instructional cost in the conventional setting. In addition, there is a need for CBE lesson materials which correspond to the textbooks and other instructional materials used in the classroom. The purchase of conventional instructional materials, largely supplied by private publishing firms selling to a national market, is also typically budgeted as a separate item. As will be shown, the cost for lesson materials for the PLATO system is reasonable compared with the total operational costs and commensurate with the cost of textbooks.

The cost of the preparation of lesson materials for a computer-based system varies significantly depending on the teaching strategy, content, number of branching choices, and complexity of simulated models. However, it is also critically dependent on the software system in which the teaching strategies are organized. The PLATO III software system was designed with a special view to reducing the over-all effort and associated cost of materials preparation. The development of the TUTOR user language has had a particular impact on the economics of this process. As indicated previously, 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 than in most CAI systems to arrange the material in a previously selected format or to change the format at any subsequent time. 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 can not be done without seriously degrading the entire system for student use.) Hence, for PLATO III, the incremental systems cost for editing or preparing materials is considerably lower than has been reported for other systems, in some cases by a factor of 50.[8]

On the basis of the preparation of hundreds of hours of lesson material, we estimate the commercial 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 or "production" services (photographic, computer access, secretarial, etc.) has actually averaged considerably less in our Laboratory. The above numbers are proposed for a high-quality version of a course involving many alternative teaching approaches. Without going into details, our experience shows that a drill and practice lesson can be prepared and edited by an experienced author in the course of 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 - $800 per hour of instruction.

To prorate the above costs obviously depends critically on the number of students expected to use a given set of material. An analogous situation occurs in textbook publication; the number of anticipated sales is a key factor in allocating unit costs as well as in establishing format.

We use a similar approach to arrive at an estimate of lesson material costs for computer-based education. If, for example, the number of student users expected to take a given lesson were 500 per year for five years, the prorated charge to cover the above costs ($600) would be approximately 25 cents per student hour. This would mean a total charge for a 50-hour semester course of about $12.50, or an expense comparable to that for a textbook. The number of anticipated student users would depend on the nature of the course, on the size of a given CAI system, and on the number of compatible systems in use. For a single PLATO III system, the range of operational costs (approximately $2/student-contact hour) and the total number of student stations are such that a nominal expectation of 250 students per year and a charge as high as 50 cents per hour for lesson materials would seem appropriate. If there were many compatible systems or larger individual systems, a far larger number of students could be served and hence permit 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 by a large factor 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:

1. The 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 4,000 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 could be economically linked within a 150-mile radius. At a given location each console would be connected by a regular telephone line.

The system modifications that account for sizeable 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 the successful commercial realization of the third-generation, general-purpose computer which has greatly increased the speed and reduced the unit operations cost of this central element by a factor of ten. The increased reliability of integrated circuitry in such computers has also made 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 4,000 student stations with the same quality of instructional sequencing as 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 if the system were in use only eight 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, the central management services. These services include supervision and operation of the central computer, maintenance of student terminals, supportive computer programming, scheduling, and routine assistance to new authors or teachers. The economic consequences for systems management are evident from the following comparison. For PLATO III, an annual incremental cost of $100,000 adds approximately one dollar to the cost per student-contact hour. For PLATO IV, a similar increment of $100,000 in annual costs adds approximately one 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 presently 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, or elementary schools. With computer-based systems of limited size, the initial venture into CAI by a school without previous experience or commitment involves not only the purchase or rental of a complete system at very substantial investment but, in addition, the requirement that a special administration be established 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 stations and the accompanying telephone lines. For such newly connected schools, it would also be feasible to provide for the use of course materials previously prepared at the University of Illinois or elsewhere. Thus, the initial venture into computer-based education would be possible for a participating institution without major investment in equipment, personnel, or lesson materials.

A second major change in PLATO IV lies in the proposed incorporation of student consoles of a novel, low-cost, high-performance design.

Two important considerations should be noted. First of all, the major emphasis of the PLATO effort on the design of a low-cost student terminal was initially motivated by the prior realization of a major breakthrough in the economics and capability of the central computer. Following the latter development, the need for a versatile, low-cost student station became the paramount issue in developing an economically viable system. Secondly, the possible design of such a large system enhances the desirability of connecting student stations at remote locations or in individual rooms and offices both on economic and educational grounds. Thus, there is an added impetus toward an over-all system design capable of communicating with student terminals via regular telephone lines.

A very promising technological innovation aimed at providing an improved low-cost student console is the plasma display panel,[9] 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, it may be addressed via telephone lines of conventional bandwidth. Under the trade name, "DIGIVUE,"[10] this electronic device is presently in the commercial prototype development stage and offers promise of excellent performance with significant further reductions in student terminal costs. Made up of a thin, flat, gas-filled glass container with transparent electrodes, the plasma panel is designed so that it is convenient to project and superimpose photographic images on the display surface. Thus, one can combine the presentation of textual material or slides with the computer-generated information, as is done on PLATO III.

Figure 3 presents 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 from the PLATO design effort. It permits the random selection by the computer of any image on a microform card on which the textual and photographic lesson material will be stored. Figure 4 shows a photograph of an actual pilot model DIGIVUE panel with a superimposed photographic image.

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.

Another technological innovation proposed for the PLATO IV system involves an economical method for communicating with student stations at a distance. By time-multiplexing a single educational-TV channel, it is possible to transmit to as many as 1,000 student stations. At a distance of 150 miles, such a communication channel would add a cost of only about two cents per student-contact hour. For telephone connections on a given campus, contingent property-line charges are nominal; a dedicated line rental would add only about one cent per student-contact hour.

Table II sets forth the projected operational costs for the PLATO IV system. The hourly costs assume a full utilization of the system, with all 4,000 student terminals in operation; they would be higher, of course, if the utilization factor were less than 100 percent. This is offset, however, by the fact that the hourly costs are based on an eight-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 in such current use 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 shifts. Thus, the educational use of this massive computer could help to pay for some of the computational needs of participating schools.

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 (excluding the audio) could be made available at a cost of approximately $1,500 when produced in quantity. A detailed analysis of such a projection lies beyond the scope of this presentation. At the present writing, the technological feasibility of the plasma display panel and the random-access image selector seems assured, though the specific confirmation of unit costs awaits further experience with pilot production models. While we have considerable confidence in meeting the above target cost (corresponding to 15 cents/s.c.h.) for a student terminal of radically novel design, we have also indicated a reasonable upper limit on the probable cost by listing the current cost (50 cents/s.c.h.) of existing state-of-the-art PLATO student stations. This accounts for the large range of console cost in Table II. In view of other cost elements, it becomes clear why we have placed such emphasis on reducing this expense item.

Our current estimates for software system development based on experience with PLATO III suggest a maximum incremental cost of the order of $500,000 for the PLATO software for a Control Data 6000 series computer. This is converted to a prorated hourly cost of about one cent per contact hour--amortized over a five-year period.

Lesson material preparation for PLATO IV would be comparable in cost to that for PLATO III. Following previous discussion, the costs of about $600 per hour could be prorated at approximately 25 cents per contact hour if 500 students per year were anticipated; a charge of only a few cents per student-contact hour would pay for such costs if as many as ten PLATO IV systems were installed in various parts of the country. For courses that are widely incorporated into many curricula, e.g., introductory courses in statistics or in chemistry, the amount of student use could easily reach 10,000 hours on a single PLATO IV system within three or four semesters. Hence, a substantial author royalty would be feasible even at a charge for lesson materials corresponding to $5.00 per 50-hour semester. For courses with small student use, e.g., an exotic foreign language, the charge would have to be increased, the materials used in a number of compatible systems, or the author's remuneration contributed in other ways.

In summary, the costs for the installation of the computer (including systems software) and the management of the computer center would total approximately $1.2 million per year, or about 15 cents per student-contact hour. If a comparable amount were associated with the rental of the student station and associated communications lines, the hourly cost for individual student instruction would be less than 35 cents per contact hour. As an upper estimate (involving the utilization of existing technology for the student console), the hourly cost would be approximately twice that figure. It is our firm conviction that the implementation of a system at the target figure is clearly attainable in the early '70s.

IV. 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 CAI at other institutions, for the most part with computer-based equipment far less flexible than PLATO III. The majority of such educators are increasingly persuaded that this medium represents a powerful means for addressing heretofore unmet needs in the entire range of the educational process. If there has been informed skepticism or concern about the potentiality of CAI, it has largely been addressed to the issue of economics.[11]

This paper has set forth 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 that of some systems in current use. This figure compares favorably with instructional costs at any grade level and would represent only a fraction (15 - 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 restricted to a small percentage of the population. Some of the possibilities that may well be realized through the application of computer-based education are:

* the alleviation of lock-step schedules and narrowly specified curricula in formal education; students could proceed at a pace determined by their own capacity and motivation;

* the provision of remedial instruction or tutorial assistance during regularly scheduled courses for students with insufficient preparation;

* the reduction of the number of large lecture classes at the college level in favor of small instructional groupings and seminars;

* special instruction at home for physically handicapped students;

* the development of arithmetical or other skills at the elementary level away from the exposed environment of the classroom;

* effective job training or retraining for any employee group especially affected by expanding technology;

* 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 ten hours a day could provide approximately 10 million student-contact hours annually at a cost of about $3 million (a total capital investment of approximately $12 million). This is equivalent to the entire annual instructional load of a four-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 a budget of less than $1 million each. Alternatively, this added capacity could relieve an equivalent portion of faculty time for developing new programs, teaching in smaller group settings, or providing extra help to individual students. The possibility of such an enrichment to our national educational capability has provided added incentive to our efforts to implement and test the PLATO IV design and to learn how such a system would function and contribute in a variety of educational settings.

The introduction of a major new technology into the educational process will undoubtedly raise questions among some educators concerning the possible negative impact of an inanimate tutor on the very human processes of learning and teaching. Similar concerns may well have been raised on the occasion of the introduction of the printing press and inexpensive paper into the educational process in the fifteenth century. It was not long, however, before the technology of the printed page became so identified with education that the (equally inanimate) library has become 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.

In conclusion, it is interesting to note that 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 inter-institutional relationships which would accompany the incorporation of computer-based systems in the educational process.

*The PLATO effort has been supported in part by the National Science Foundation, the Advanced Research Projects Agency, the Joint Services Electronics Program of the Department of Defense, and the Department of Health, Education, and Welfare.

TABLE I

OPERATIONAL COSTS OF THE PLATO III SYSTEM

Subsystem	Total Annual Cost Rental or Amortization Over Five-Year Period	Annual Cost per Student Station Rental or Amortization Over Five-Year Period	Cost per Student-Contact Hour*
1. Central Computer Facility	$50,000 - $150,000	$1,000 - $3,000	$ .50 - $1.50
2. Computer Systems Software**	$30,000	$600	$ .30
3. Student Terminals	$50,000	$1,000	$ .50
4. Central Management Services	$60,000	$1,200	$ .60
5. Communications Channels	(included in items 1 and 3)		

TOTAL OPERATIONAL COSTS PER STUDENT-CONTACT HOUR $1.90 - $2.90

*Annual use per student station = 2,000 hours (45 weeks @ 44 hours per week)
Maximum number of student stations = 50
Total annual use (50 student stations) = 100,000 student-contact hours (s.c.h.)

**These costs would be only 3 cents/s.c.h. if the software costs were shared among ten PLATO III systems.

TABLE II

OPERATIONAL COSTS OF THE PLATO IV SYSTEM

Subsystem	Total Annual Cost Rental or Amortization Over Five-Year Period	Annual Cost per Student Station Rental or Amortization Over Five-Year Period	Cost per Student-Contact Hour*
1. Central Computer Facility	$900,000	$220	$ .11
2. Computer Systems Software	$100,000	$25	$ .01
3. Student Terminals		$300 - $1,000	$ .15 - $ .50
4. Central Management Services	$240,000	$60	$ .03
5. Communications Channels**		$18 - $50	$ .01 - $ .03
TOTAL OPERATIONAL COSTS PER STUDENT-CONTACT HOUR			$ .31 - $ .68

*Annual use per student = 2,000 hours (45 weeks @ 44 hours per week)
Maximum number of student stations = 4,096
Total annual use (4,096 stations) = 8.2 million student-contact hours (s.c.h.)

**For telephone connections on a given campus, contingent property-line costs are about $1.50 per month per terminal (1 cent per s.c.h.). For student stations at a distance, communications would be transmitted using time-multiplexed TV channels for groups of 1,000 student stations per channel. At a distance of 150 miles, this would cost an additional 2 cents/s.c.h.

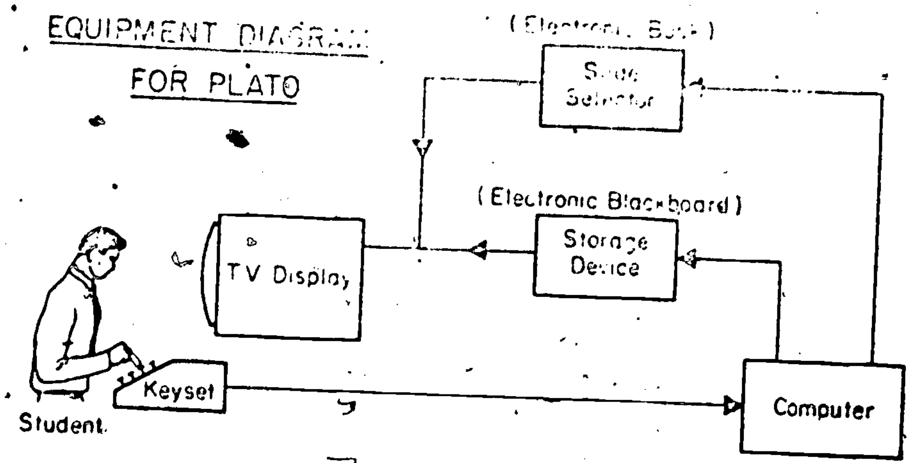


Figure 1.

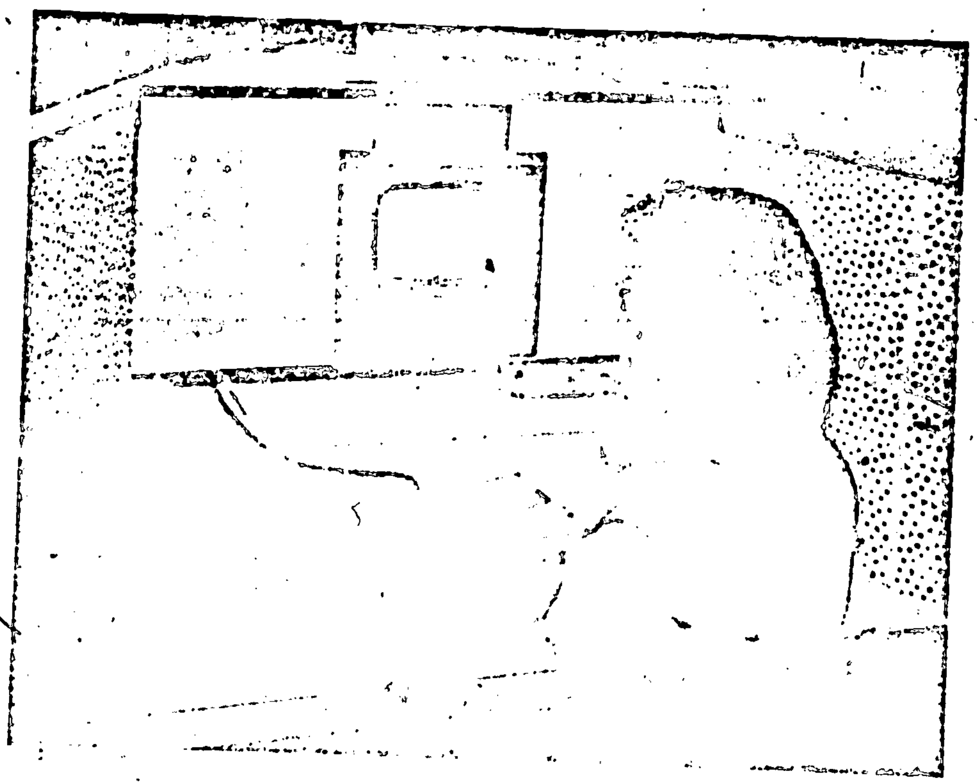
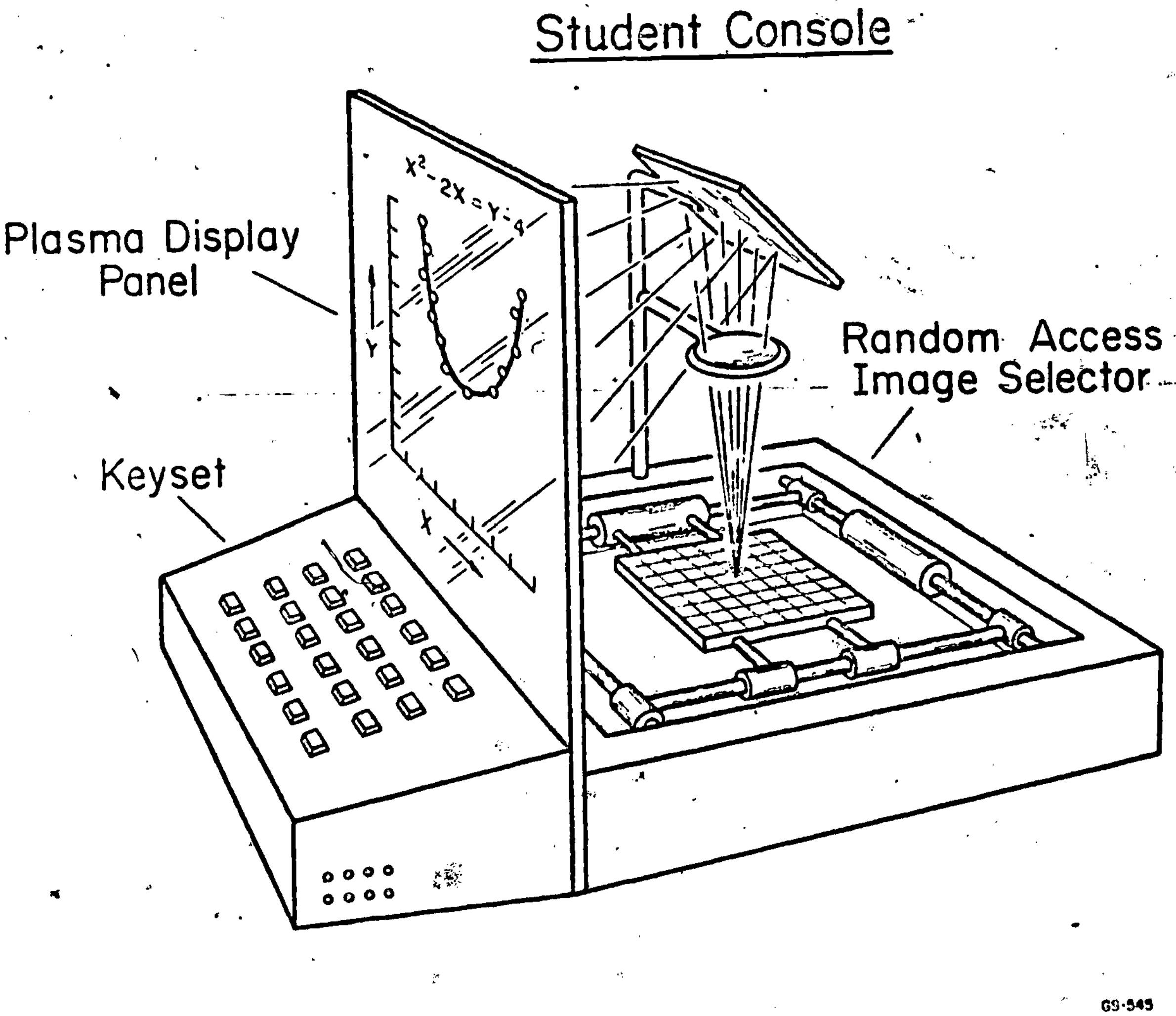


Figure 2.



Student Console
Plasma Display Panel
Random Access Image Selector
Keyset
$x^2-2x=y-4$
Y
X
G9-545

Figure 3.

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