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A COMPUTER-CONTROLLED TEACHING SYSTEM

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REPORT R-268 OCTOBER, 1965

This work was supported in part by the Joint Services Electronics Programs (U. S. Army, U. S. Navy, and U. S. Air Force) under Contract No. DA 28 043 AMC 00073(E) and by the Advanced Research Projects Agency through the Office of Naval Research under Contract No. Nonr-3985(08).

The Uses of PLATO: A Computer-Controlled Teaching System[†]

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ABSTRACT

The use of a high-speed digital computer as a central control element provides great flexibility in an automatic teaching system.[*] Using a computer-based system permits versatility in teaching logics since changing the type of teacher merely requires changing the computer program not the hardware. In addition, having access to the decision-making capacity of a large computer located as one unit, permits complicated decisions to be made for each student. Such capacity would be prohibitively expensive to provide by means of decision-making equipment located at each student station. The results of exploratory queuing studies show that the system could teach as many as a thousand students simultaneously without incurring a noticeable delay for any student's request.

The educational results thus far have been extremely encouraging. However, reliable conclusions on educational achievement must await the results of more thorough experiments now in progress which include larger numbers of students learning under a variety of conditions. The adaptability and useability of the system for a variety of purposes in education and the behavioral and physical sciences have been clearly demonstrated.

[†] This work was supported in part by the Joint Services Electronics Programs (U.S. Army, U.S. Navy, and U.S. Air Force) under Contract No. DA 28 043 AMC 00073(E) and by the Advanced Research Projects Agency through the Office of Naval Research under Contract Number Nonr-3985(08).

[*] Portions of the material in this report have appeared in Computer Augmentation of Human Reasoning, Chap. 6, pp. 89-103, Spartan Books (1965).

Introduction

During the past five years, the Coordinated Science Laboratory at the University of Illinois has developed and experimented with an automatic teaching system called PLATO in order to explore the possibilities of automation in individual instruction. The PLATO system utilizes a high speed digital computer as the central control element for teaching a number of students simultaneously, while still allowing each student to proceed through the lesson material independently.

Three models of PLATO have evolved, each embodying improvements indicated by the previous model. The first consisted of a single student station connected to ILLIAC, a medium-speed computer built at the University of Illinois.[1] The second model had two student stations, which are shown in Figure 1, was connected first to ILLIAC and then to a CDC 1604 computer and was used to study the problems created by multiple student use of the system.[2] The third and current model has 20 student stations, shown in Figure 2, connected to the CDC 1604 computer.

The rules governing the teaching process are included in the program read into the central computer. A complete set of rules is referred to as a "teaching logic". The Coordinated Science Laboratory has experimented with two basically different types of teaching logics, a "tutorial logic" and an "inquiry logic". A tutorial logic is designed to lead the student through a fixed sequence of topics, but it also provides branching between problems which is under the student's control, voluntary or involuntary. In a lesson that uses the tutorial teaching logic, the system first presents facts and examples, and then asks questions covering the material presented. The student composes answers and, when he is

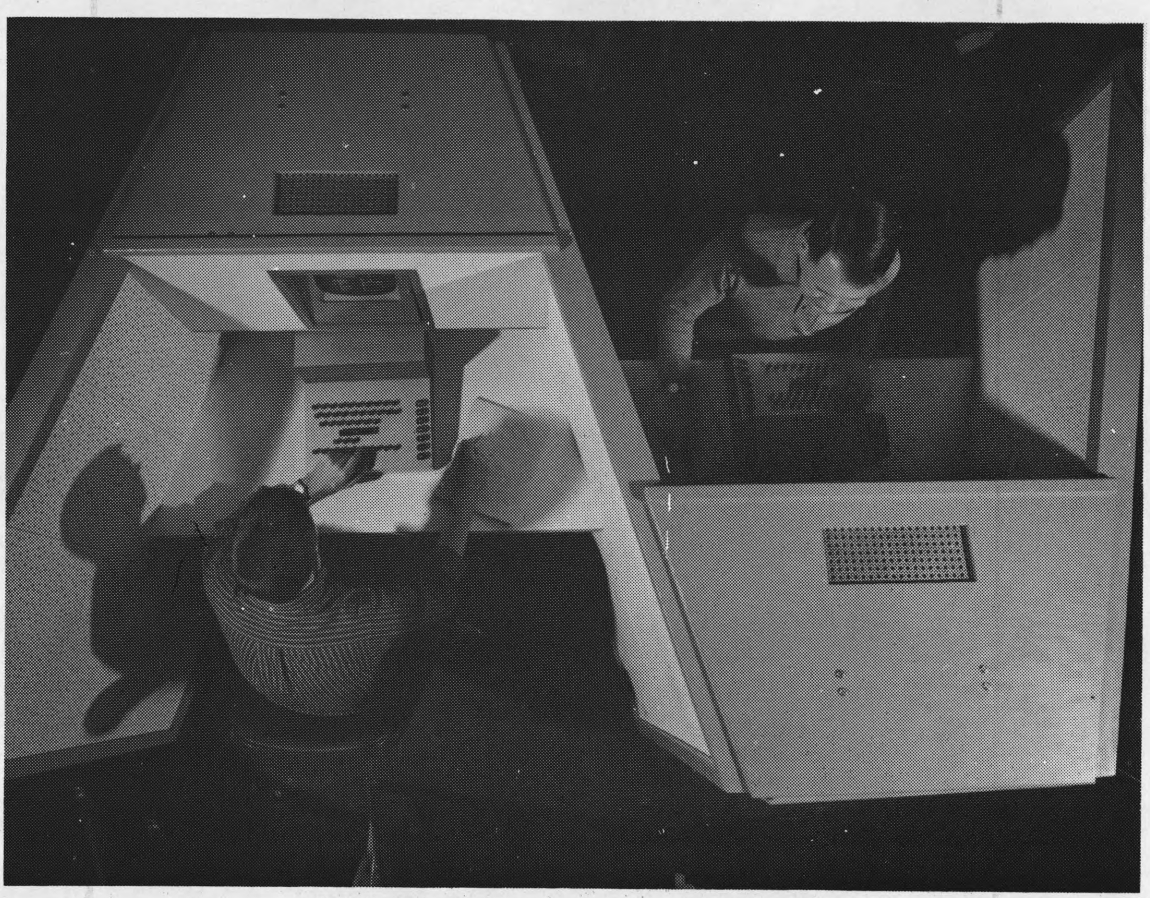

Figure 1 Top View of the Two Student Stations with PLATO II Equipment

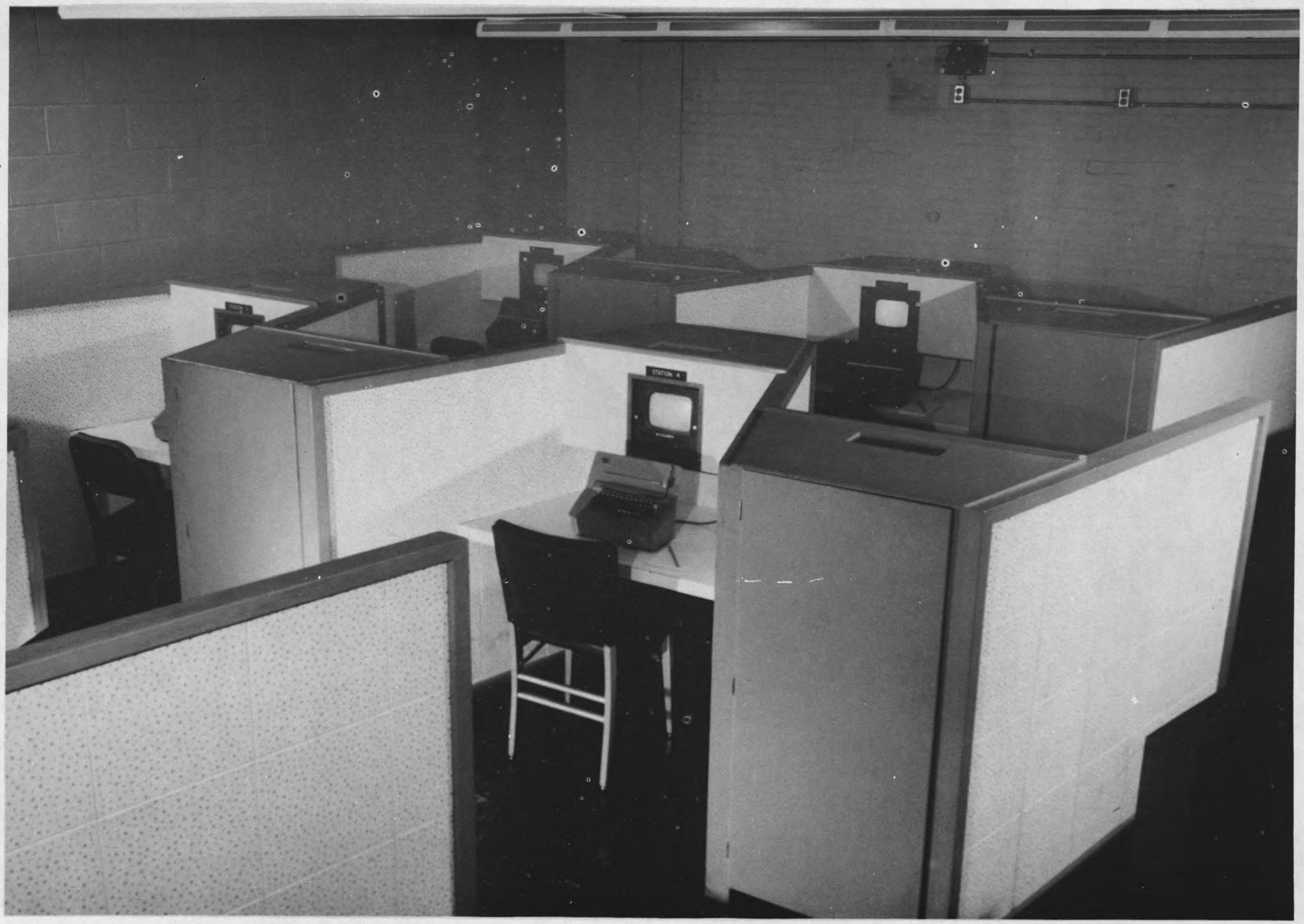

Figure 2 Twenty Student Station Classroom

ready, asks the system for a judgment. When he finds the questions too difficult, he may branch to easier material. Involuntary branching occurs when evaluations of the student performance are included in the lesson program which prescribes branching, if predetermined criteria are met by the student. An inquiry teaching logic, on the other hand, can be characterized as a system permitting dialogues between the student and the computer. Typically, in a lesson that uses an inquiry teaching logic, general problems are presented to the student. To solve them he must request and organize appropriate information from the computer. In such a teaching logic, the student may be asked to demonstrate his achievement by answering questions, but he may also ask questions within a given range of possibilities in order to obtain information.

Both types of teaching logics and a variety of lesson materials have been employed in exploratory studies in order to test the capabilities of the system. Some of these exploratory studies investigated system variables such as data rates between the students and the system.[3] Other studies had to do with the psychological aspects of the lessons and variations in the teaching logics.[4,5,6]

The PLATO Teaching System

Student Stations

A block diagram of a single student station in the PLATO teaching system is shown in Figure 3. The system provides for communication in two directions. Each student is provided with an electronic keyset as a means of communicating with the central computer and a

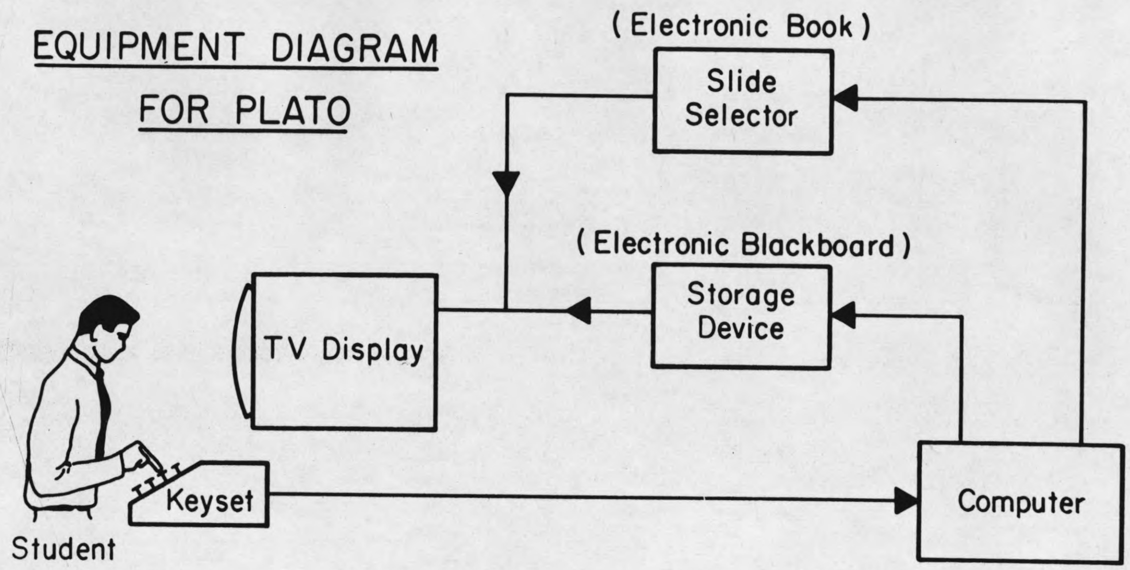

Figure 3 Block Diagram of the PLATO Teaching System

television screen for viewing information selected by the computer. Figure 4 shows the student's main keyset, which resembles a typewriter keyboard. The keys can be assigned any functions the teacher desires. Usually the alphanumeric characters are assigned positions similar to those on a standard typewriter keyboard, and punctuation, special characters or special control functions are assigned to the extra keys.

Electronic Book

There are two sources of information which are usually displayed on the student's television screen. These sources (called an electronic book and an electronic blackboard) are shown in Figure 3. The electronic book consists of a bank of slides pre-stored in an electronic slide selector which is controlled by the computer. In the latest model of PLATO, the random-access slide selector stores 122 slides and has a slide access time of less than a microsecond. Information stored in the slide selector is the type that would usually be found in a textbook or in class notes. Although the slide selector is shared by all the students, the students can view the same or different slides simultaneously. This is accomplished by having the video information available from all slides concurrently, and electronically connecting the students' television display to the proper video output.

Electronic Blackboard

The electronic blackboard consists of a computer-controlled storage tube at each student station. Diagrams, symbols, and words are plotted in a point-by-point fashion on the student's storage tube. Approximately forty alphanumeric characters can be written on the student's

Figure 4 Student's Keyset for Communicating to the Control Computer

blackboard per second, and the entire blackboard can be erased in two-tenths of a second. This arrangement permits information to be presented to the student that cannot be predetermined, such as information generated while teaching the student. For example, the system can display a sketch of an experiment the student has requested or an answer the student has composed which cannot possibly be anticipated. The image from the blackboard and the electronic slide selector may be superimposed on the student's television display, enabling the student, at request, to fill in blanks on the slide and compare his answer with the question. Figure 5 shows a block diagram of two student stations, indicating the shared and the individual parts of the system. Information for a student can appear on his television screen from either the blackboard or the book or from both simultaneously.

Teaching Logics for the PLATO System

Original Tutorial Logic

The tutorial logic was the first of the two main types of teaching logics explored on the PLATO system. A flow diagram of the original tutorial logic is shown in Figure 6. In the tutorial teaching logic, the keys were divided into two types, those used for inserting constructed responses to questions and those used by the student to control his progress through the lesson material. The lesson material was organized in two sequences: the main sequence consisting of the minimum material that must be used by all the students, and the help sequence that was provided for students who had difficulty with questions in the main sequence.

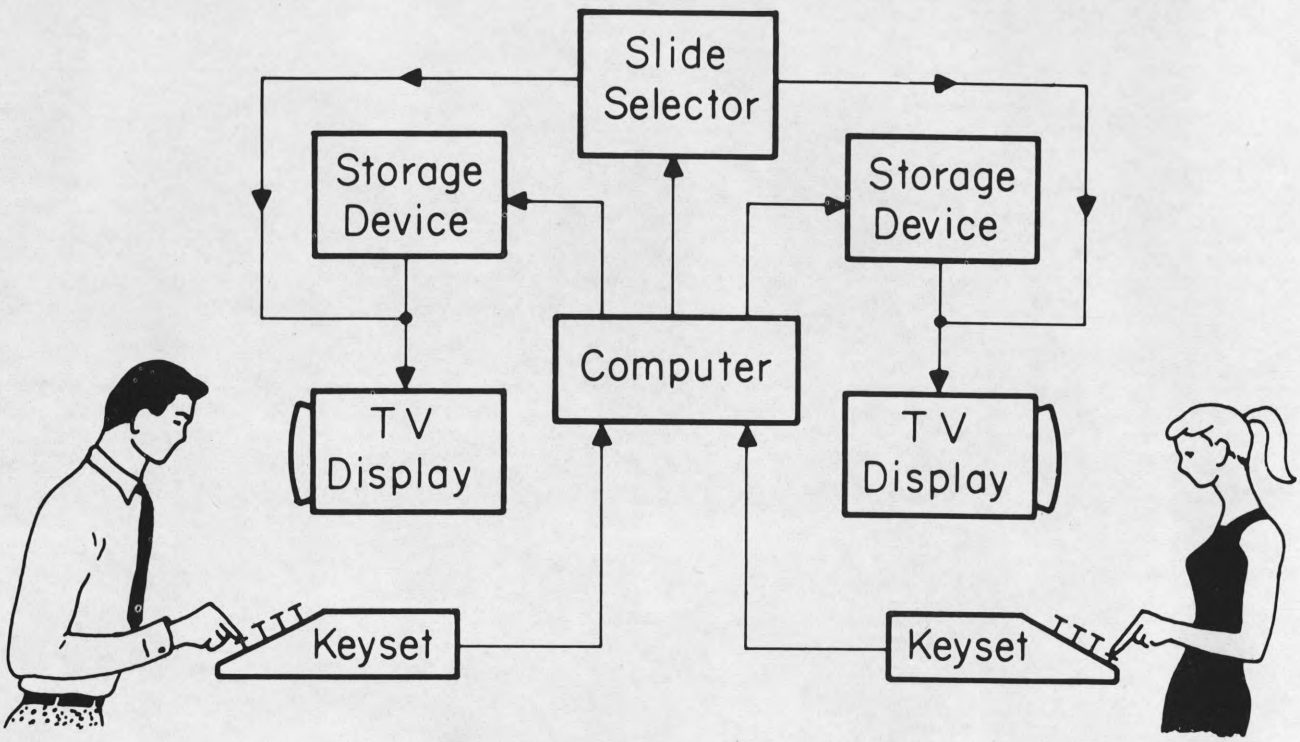

Figure 5 Block Diagram of the PLATO Teaching System Showing Shared and Individual Parts of the System

The student began by viewing text material in the main sequence. When he completed reading a page of text, he proceeded to the next page by pushing the button labelled "continue," or returned to a preceding page by pushing the button labelled "reverse". (See Figure 6.) As the student proceeded through the lesson, he was presented with questions. When the student was working on a page which contained questions, the teaching logic required that all the questions be answered correctly before he could continue.

The student answered a question by using the buttons labelled with numerals and letters, or with any other symbols chosen by the lesson planner. As the student typed his answer, it appeared on his television screen. The student then pushed the "judge" button and the computer determined the acceptability of the answer and immediately wrote an "OK" or "NO" next to the answer. The student used the "erase" button to remove incorrect answers. Thus, he was allowed as many attempts as necessary to answer the question correctly. If he had difficulty with a question, he could push the button labelled "help". The "help" button took the student into a help sequence which pertained to the question. The logic in a help sequence was similar to the logic in the main sequence. The student was presented with additional explanatory material and "help material". Each question in a help sequence had to be answered correctly before proceeding further through the help sequence.

After completing a help sequence the student automatically returned to the question he was trying to answer in the main sequence.

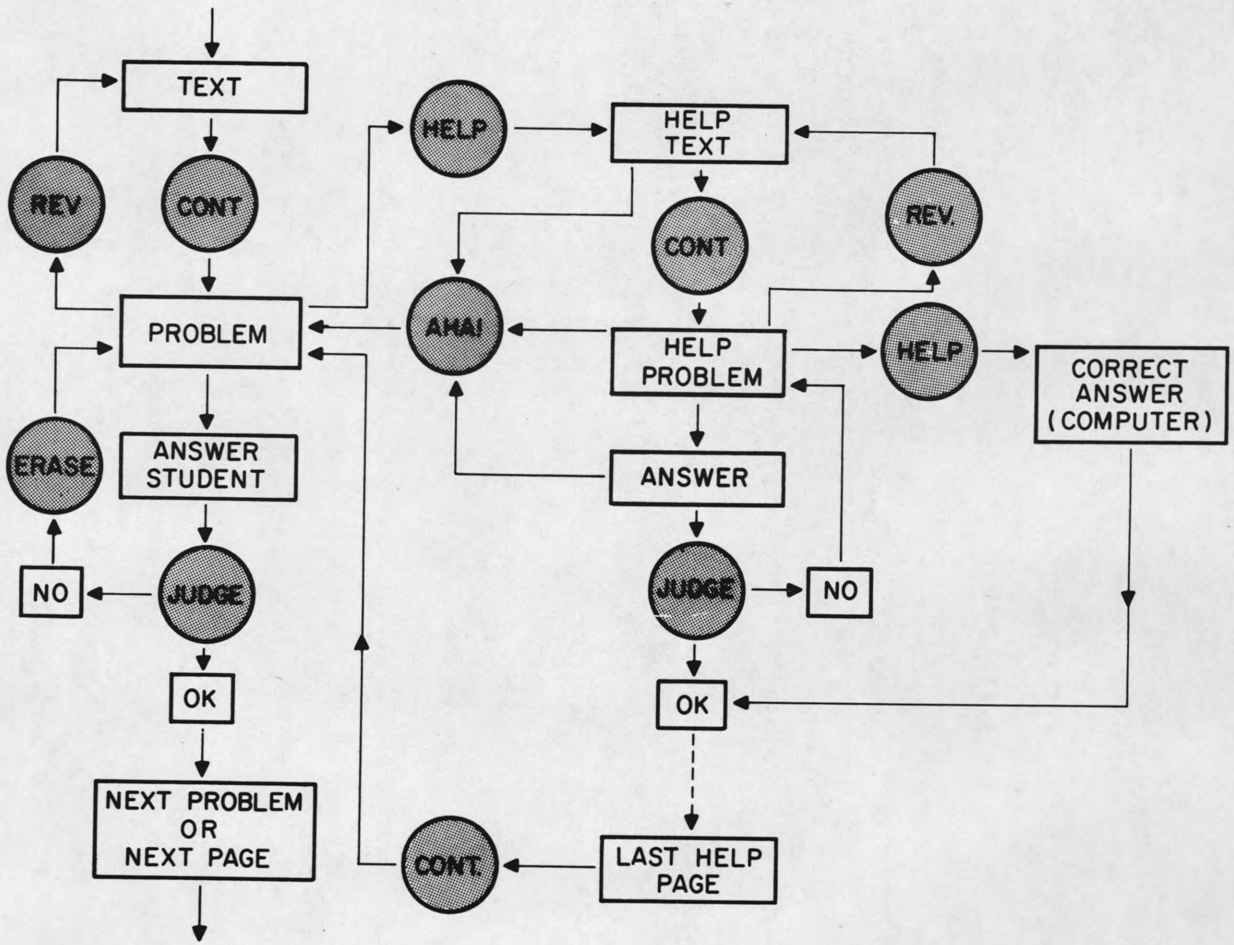

Figure 6 Flow Diagram of Original Tutorial Teaching Logic

However, if the student wished to return to the main sequence from any point in the help sequence, he could push the button labelled "aha". An additional request for help on the same question would return the student to his previous position in the help sequence.

In a later version of the original tutorial logic, as developed by Braunfeld, different types of wrong answers called for different help sequences. The use of an error detector for automatically controlling branching is shown in Figure 7. If the student gave a second wrong answer that was classified differently by the error detector, and if he asked for help again, he was given a help sequence to that wrong answer. If he exhausted the available help appropriate to the error he had made, he was informed that no more help was available and given the choice of trying to answer the question again or having the computer supply the correct answer.

In addition, the later version of the original logic permitted some questions to be designated for monitoring by an evaluator in the computer program. In Figure 8, two sets of such problems are indicated on a typical flow diagram. The student's responses to monitored problems were used to determine whether he was branched forward to the next section of the main sequence or routed through material specially designed for students who failed the criterion test in the evaluator.

In order to prepare lesson material for the original "tutorial logic", one had to organize the material into a set of slides with at least one help slide for each question in the main sequence as well as to prepare a parameter tape. The parameter tape contained the

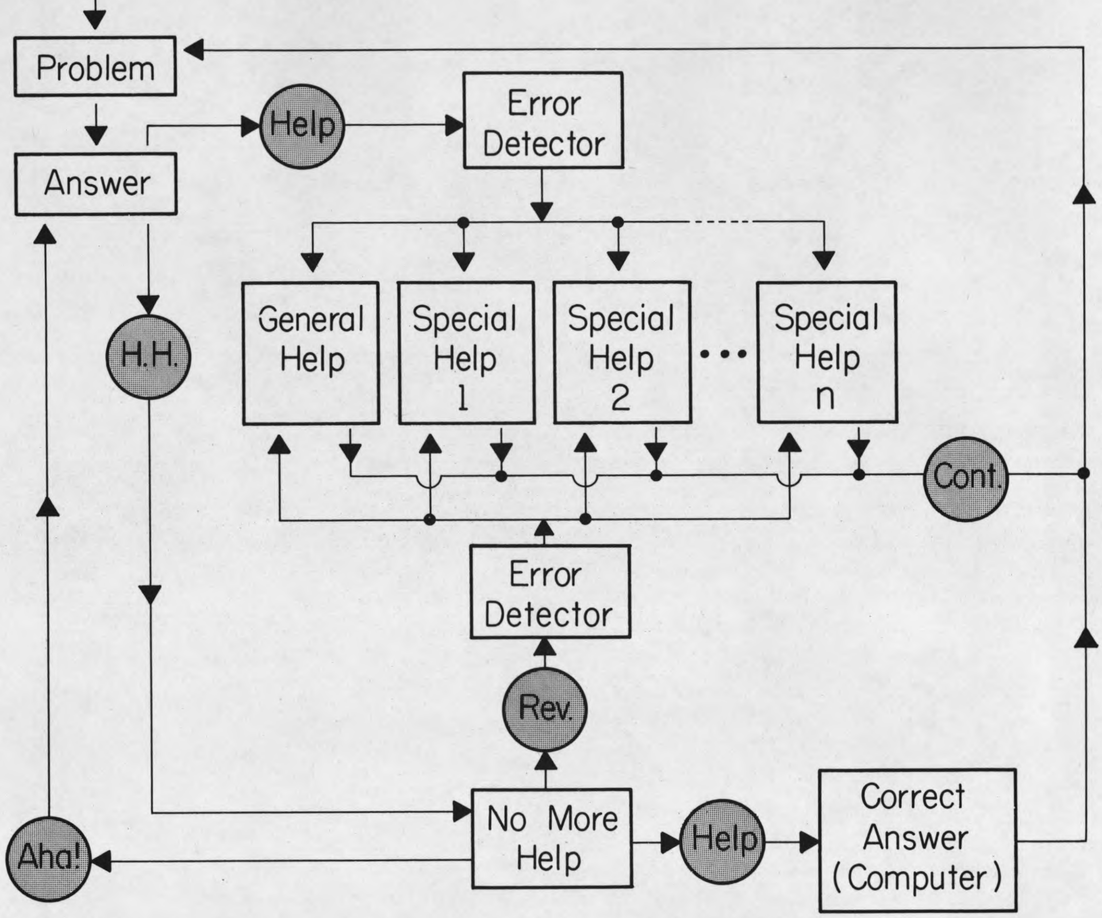

Figure 7 Flow Diagram Showing Provision for Special Help Sequences in PLATO III Tutorial Logic

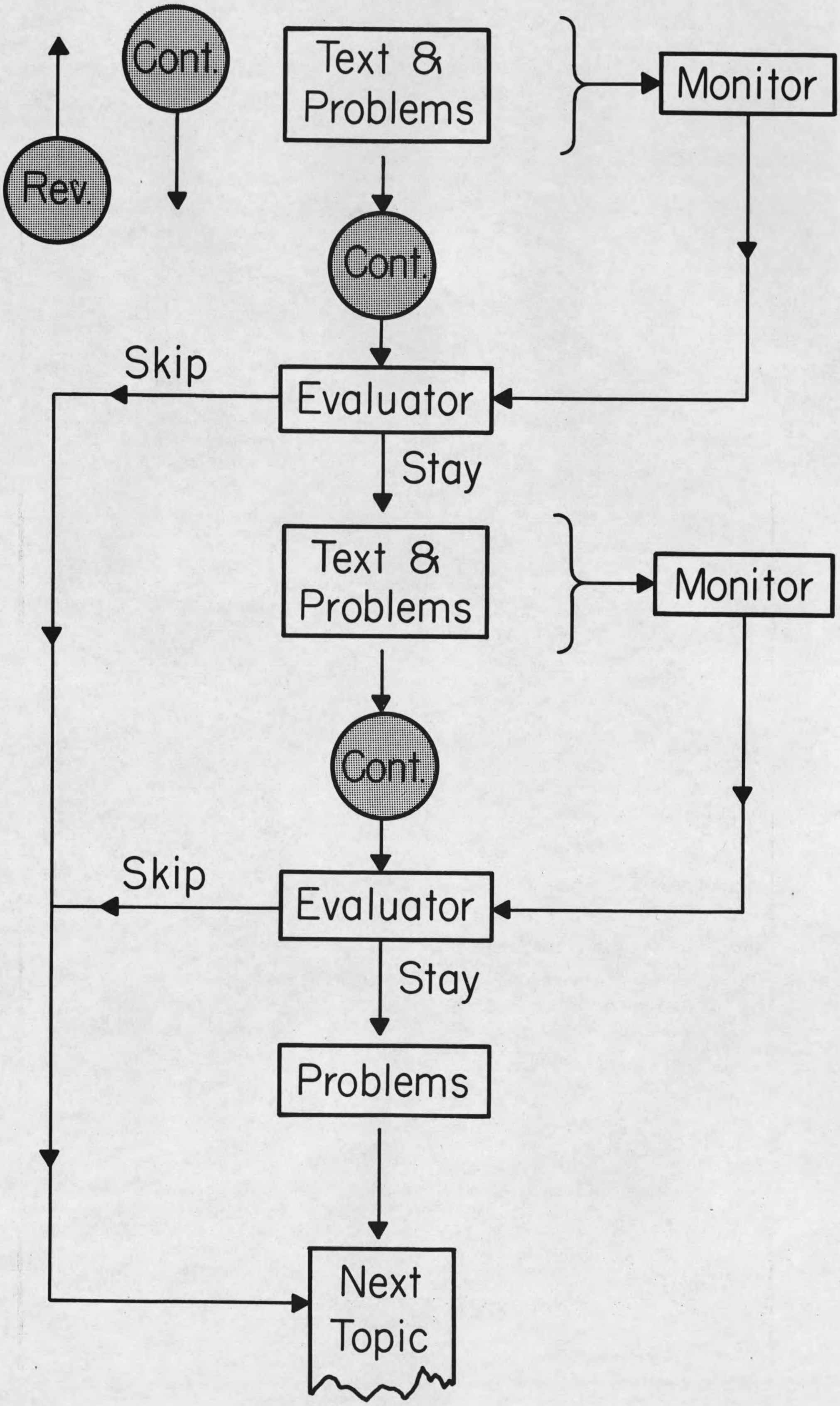

Figure 8 Flow Diagram Showing Provision for Monitoring Main Sequence Problems and Automatic Forward Branching in PLATO III Tutorial Logic

answers to the questions, their location on the slide page, and the order in which the slides were logically connected. If the special help sequences and the evaluator were used, error categories had to be specified for the error detector and a list made of monitorized problems and their criteria for evaluation.

The most recent version of the PLATO tutorial logic is much more generalized than its predecessors. It will be described in a later section of this paper.

Inquiry Logic

While the tutorial logic serves well for many purposes, there are types of problems in which even more control given to the student is important as well as an opportunity for the student to ask questions of the computer. To accomplish this the inquiry teaching logics were written.

An inquiry teaching logic permits a student to request information. The computer correctly interprets the request and replies from stored information or calculated results. This logic provides, in effect, a syntax for the student to use in communicating with the computer. The student is taught by composing his own requests.

In the tutorial logic, the student communicates with the computer either with one of the control requests--turn the page, judge my answer, give me help--or he composes short answers which usually must match one of the several alternative stored responses. If he should type a question such as "What does 'exponent' mean?", the computer would only respond with a "NO", since it treats his response as an answer. However, the inquiry logics provide a syntax by which a student can ask questions about the lesson he is studying. The syntax he uses can be viewed as a tree of choice points in which selections are made at each choice point.

Figure 9 presents a simplified flow diagram of a simulated laboratory, illustrating the general form of classification syntax. The student, by pushing the button labelled "lab", is shown the general categories of available information. Having chosen one of these categories, he is shown more detailed selections within that category. In general, sucessive sub-categories can be chosen until the detailed classification is specified. However, it is often desirable to have the major categories specified independently, e.g., object, conditions it is exposed to, and particular properties about which information is desired. In such a case, the student will pass through several successive levels of selection, once for each general category. Specifications made within one general category can be stored and used in conjunction with those made within another category. (That is, specifications within one general category can interact with specifications within another.) When the requested information has been completely specified, it is displayed on the student's television screen.

Many variations on this classification scheme are possible. Figure 10 shows how a student might have set up two experiments in a simulated laboratory in which the property to be measured is chosen first and the object and the condition specified later. The properties about which information can be obtained are the weight and overflow volume of objects listed. The conditions available are the liquids in which an object is immersed. Figure 10 also illustrates the use of both graphical

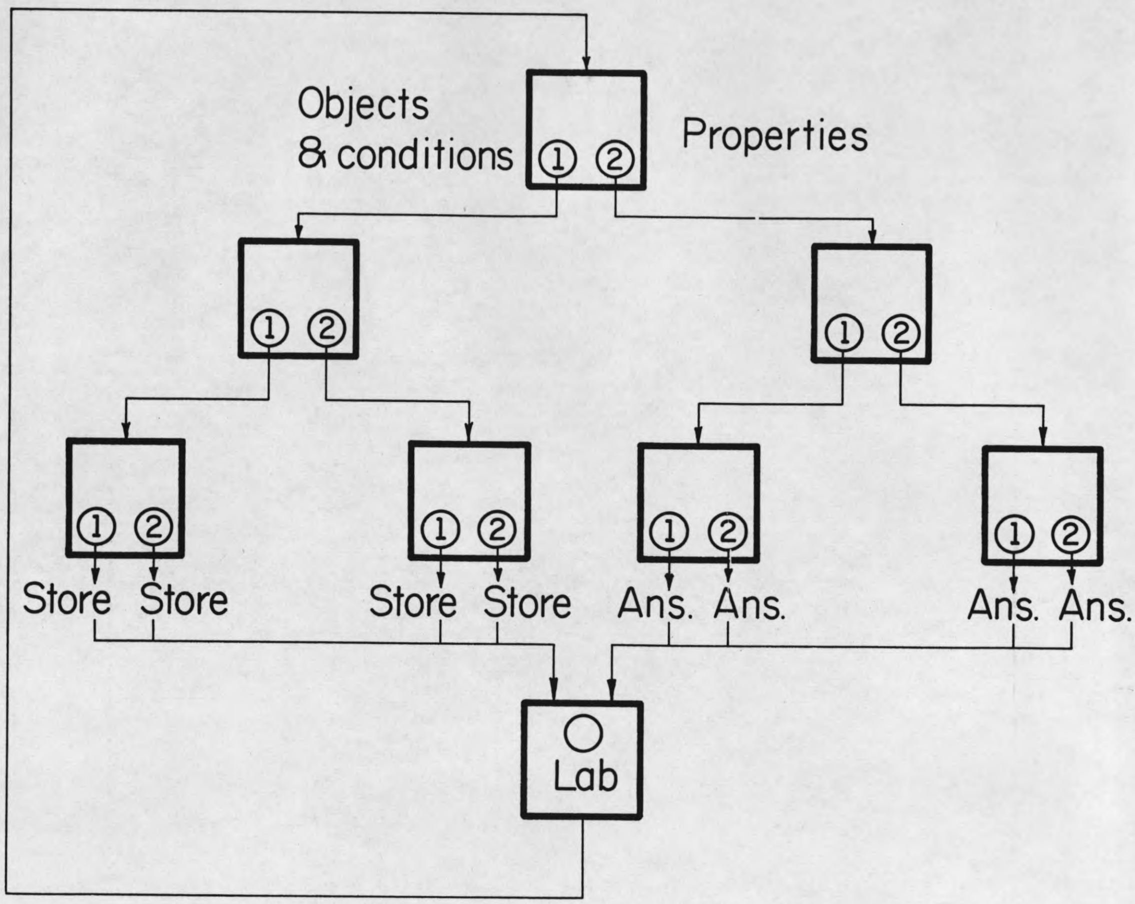

Figure 9 Simplified Flow Diagram for Simulated Laboratory Experiments using PLATO III Inquiry Logic

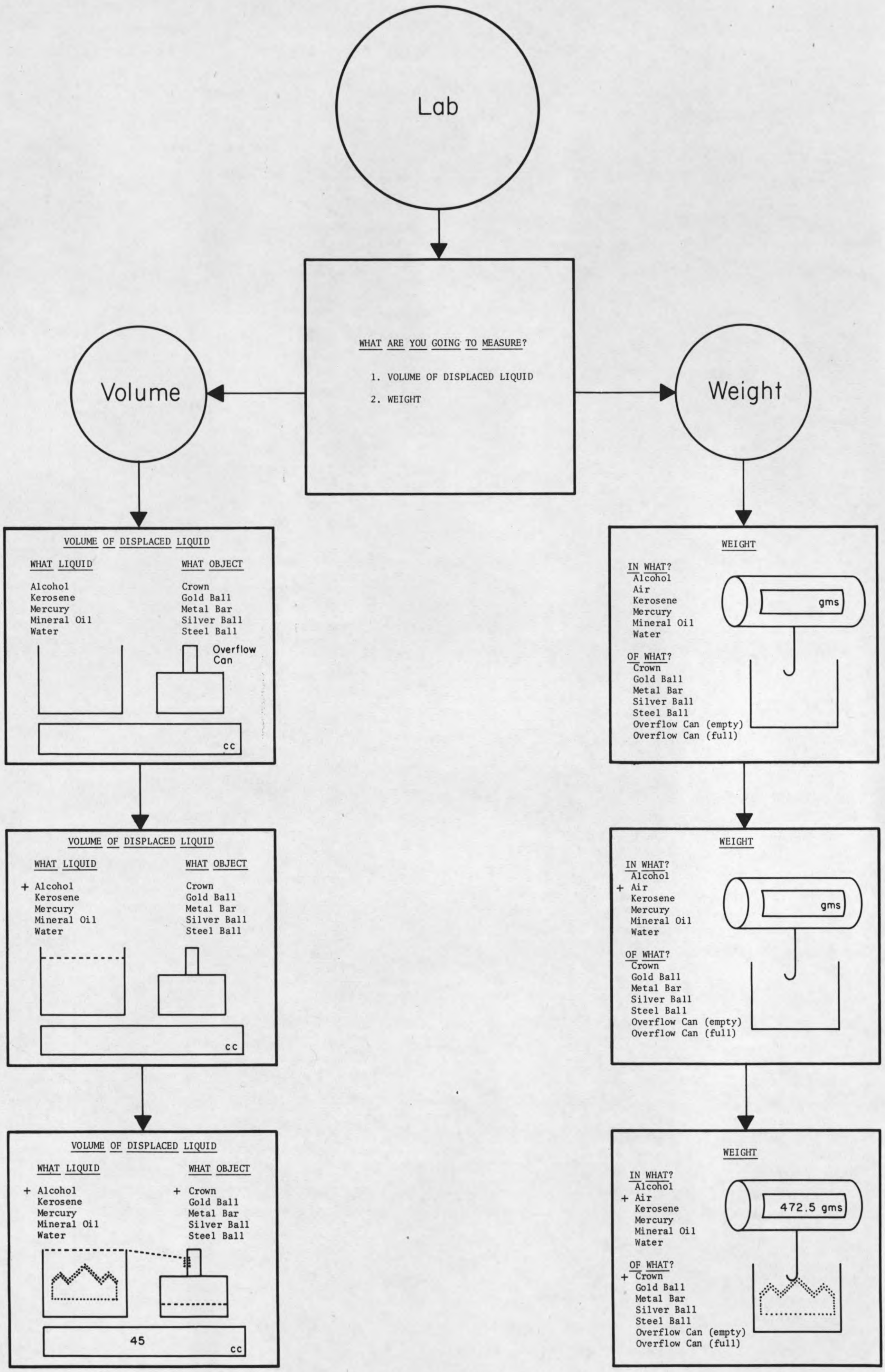

Figure 10 Example of Students Use of an Inquiry Teaching Logic

and numerical display of results. Figure 9 shows only two choices at each choice point, and Figure 10 shows two for the first choice and five for each of the next two in the volume experiment (six and seven respectively for each of the next two in the weight experiment). Figure 9 illustrates only four specifications on each pass through the tree, but two passes provide 16 combinations of objects and properties. Figure 10 provides 50 possible specifications on one pass through the volume experiment, and 84 through the weight experiment. Some combinations have been used involving two passes. Ten choices at each choice point on three levels would permit a thousand specifications on each pass through the tree. PLATO III permits 96 selections at each of 64 choice points which should be more than adequate for any forseeable educational purposes.

Specification at choice points may seem a somewhat artificial way of asking a question, but it resembles the way one locates merchandise in a department store, and even elementary school children adapt to it easily. It requires only a slight rearrangement of ordinary language. For example, instead of typing "What's the effect of administering nitroglycerine on the heart rate of the patient?", the student in a PLATO teaching program for nurses who wished to ask this question, typed coded numbers for the following sequence of phrases: return patient to original state, give drugs, select nitroglycerine, check condition of patient, vital signs, pulse rate (at this point the computer answers with the pulse rate).[7] Students quickly learned the syntax required and usually formed such coded questions more rapidly than they could type them in English. The computer responded immediately, displaying information obtained by computation or from memory. The student proceeded to try other experiments until she was confident of what the treatment of the patient should be. If the student were required to answer a question such as "What would you do to lower the patient's blood pressure?", the same syntax outlined above could be used to construct an answer. The computer could easily process a description of the procedure and respond with an appropriate evaluation. Furthermore, the choices in such a program need not have been designated by coded numbers, but could have been designated by specially labelled keys (e.g., a key designated "drug", "condition", "vital signs",...).

One inquiry logic written for the PLATO system which deserves special comment is one which permits the student to solve mathematical problems that require many lines of work and in which all possible solutions cannot be anticipated.[8] In this teaching logic, the student is informed whenever he violates any of the rules of mathematical logic. The computer does not store a set of correct solutions, but it does store the mathematical principles available to the student. The rules of mathematical logic are built into this teaching logic by means of decision programs. This logic thus simulates a teacher who watches students at work and tells them whenever they make an error, but doesn't tell them what they should have written. The student is, in effect, asking whether each move he proposes is a valid one, a question to which he gets an immediate reply. A prototype model of this teaching logic was written in machine language and tried out successfully on the PLATO II system by a few high school students and mathematics teachers-in-training.[8]

Inquiry teaching logics have been tested with students from the sixth grade through college level. In addition to those already mentioned, a logic designed by Richard Suchman to teach sixth graders elements of scientific inquiry deserves special mention. It begins by showing the students a film (with a computer-controlled projector) in which an unusual physical phenomenon is displayed. The student is then asked (by a set of questions) to explain this phenomenon. To get information, he can check the properties or conditions of the objects pictured or perform experiments similar to those described in the previous section of this paper. The logic has provided a method of teaching inquiry as well as a means of studying the inquiry style of individual students.[9]

The PLATO Compiler

A PLATO compiler was developed in 1964 which permits simple preparation of all types of new teaching logics. Using this compiler educational researchers have prepared several new teaching logics suited to their own purposes in fields varying from mathematics to behavioral sciences.

Preparing an inquiry type teaching logic requires specifying the tree structure of the syntax the student uses to communicate with the computer. Preparing a tutorial logic also requires specifying the structure which the student or teacher uses in communication decisions with the computer. The PLATO compiler permits the logic designer to specify for each choice the next choice point to which each response leads. Each choice point can present a slide, some message printed on the blackboard, operate a piece of auxiliary equipment, etc. All of these details are specified in

Pseudo-English. Special decision rules are written as necessary using an augmented FORTRAN language.

All the PLATO programs or lessons written since the fall of 1964 have been written for the compiler. Many of the old lessons have been revised and reprogrammed using the compiler.

New PLATO Tutorial Logic

The new PLATO tutorial logic, written for the compiler, allows very flexible rules for the teacher.[10] The teacher may allow the student to respond with long answers. Several help sequences are permitted. Many judgers are available including a spelling judger (which prints "SP" instead of "NO" on the blackboard when a spelling mistake is made). Sixteen special effects are allowed (such as disallowing certain keys at specific times in the lesson or introducing an inquiry procedure such as curve-plotting available upon student request). Special remedial or challenge sequences are possible. A comment page allows a student to make comments on the lesson at any time. An instructor page allows the student communication with the instructor via the PLATO display. Finally as the most important feature, the new logic contains an author mode so that the teacher may insert or change page answers and page descriptions on-line with the computer.

Interconnection of Student Stations

Although independence of student stations was initially thought desirable, many uses of station interconnection were later suggested. The interconnection was accomplished with a short addition to the resident computer program. This development has allowed teacher-student interactions, negotiation studies and concept development exercises.

New Logic for Problem-Solving

The more generalized version of the mathematical problem-solving logic has been written using the compiler. This logic, incorporating improvements indicated by experience with the prototype, now allows the student to formulate his own problems and conjectures and work them out with the same supervision as if they had been problems stored by the author of the lesson. The judgment of student errors can also be postponed until the student requests that his work be marked. It is expected that this logic will be able to cope with problems in elementary algebra, logic and set theory, and some portions of geometry.

Student Records

One of the important features of the PLATO system is the "perfect workbook" of student performance which is kept by the computer. The student records include a record of each button the student pushed and the time at which he pushed it. This information is available in two forms. One form is a printed history of events that can be immediately scanned by the teacher, such as shown in Figures 11 and 12. Another form is one stored on magnetic tape that can be processed by the computer for a detailed statistical analysis.

Exploratory Studies Using the PLATO System

Student Performance and Queuing Studies

Several studies, some of which have already been mentioned, have been completed using both the tutorial and the inquiry teaching logics. Lesson material drawn from mathematics, computer programming, and electrical engineering initially were programmed with the original tutorial logic. Most of these studies employed approximately ten to twelve students as subjects, each of whom attended three of four one-hour sessions. Results of

PLATO II: HISTORY OF EVENTS

STUDENT 1, RUN 1, LESSON 1, CHAPTER 6.

TIME IN MINUTES	PAGE NUMBERS (MAIN)	PAGE NUMBERS (HELP)	ANSWER	OK/NO
.0	1			
.1	2			
.1		100		
.2			EMORY	OK
.3			87	OK
.4			71	NO
.5			710	OK
.5			A	OK
.5	2			
.6			103	OK
.6	3			
.8		101		
.8			L	OK
.9			200	NO
1.6			100	NO
1.7	NO MORE HELP			
1.7	HELP-HELP GIVEN		100F	
1.9	3			
2.1			L5 200F	OK
2.1		102		
2.2			L	OK
2.3			A	OK
2.4			OLD	OK
2.4	3			
2.5			L4 202	NO
2.9			L4 202F	OK
2.9		103		
3.0	3			
3.2		103		
3.4			EMORY	OK
3.4			87	OK
3.5			710	OK
3.6			A	OK
3.6	3			
3.8		112		
3.8		4		
3.8		104		
3.8	3			
4.1		112		
4.1	4			
4.2		105		
4.2		0		

NET FINGER TROUBLE = 9 ERRORS.

Figure 11 Printout of Student's History of Events for Lesson with Tutorial Logic

JUNE 22

STUDENT NUMBER 1

TIME Min. Sec.	LAB.	FILM	QUES. SET	QUES. NO.	ANS. NO.	OK/NO	EXP. LAB.	PROP. LAB.	COND. LAB.	HELP PAGE
15 00	X									
15 02		X								
17 50	Illegal Key 11									
17 51			1							
18 34				4						
18 55					4	OK				
19 03			1							
19 06				1						
19 26					4	OK				
19 29			1							
19 34				2						
19 44					4	NO				
19 48								X		
19 51								1		
19 56								2		
19 57	X									
20 01			1							
20 05				5						
20 19					3	NO				
20 24			1							
20 30				6						
20 49					4	OK				
20 53			1							
20 59				7						
21 12					2	NO				
21 17			1							
21 26				8						
21 34					1	OK				
21 39	X									
21 44							X			
22 08							6			
22 24							1			
22 31							2			
22 35							3			
22 39							4			
22 43							5			
22 50							1			
22 54	Illegal Key 11									
22 55	X									
23 03									X	
23 15									4	
23 21									3	
23 30									6	
24 00										Ques.

Figure 12 Printout of Student's History of Events for Lesson with Inquiry Logic

some of these studies are available in another report.[3] Briefly, the results from the early investigations showed the following:

1. There was no significant difference between the post-test scores of students who received instruction via PLATO system and those who attended regular class. However, the amount of time spent on the lesson material was significantly less for the students working on PLATO.

2. Using over 50,000 student requests obtained with the lesson material, queuing studies were performed. It was determined that a general purpose computer, having a high speed capacity of one million, five hundred thousand bits, would allow 1,000 students to be tutored concurrently on 8 different lessons without incurring a noticeable delay for any student's request.

University Courses

Recently the new PLATO tutorial logic was used to program half of the material for a semester's work in a course in circuit analysis offered to electrical engineering junior and senior students. Although no detailed analysis or evaluation of the students' responses were made, some of the more obvious results showed the students appreciated the flexibility of the system, enjoyed the features such as curve plotting, and thought the course material markedly clarified by the PLATO lessons. At present the logic is being used for credit courses in "How to Use the Library" and "Fortran Programming for Business and Commerce Students" as well as for the electrical engineering course. Evaluation of student performance will be made from the detailed records provided from the system.

Text-Testing

Worthy of mention is a study now in progress which uses a logic basically tutorial in nature to record performance of students as they test new text books. The student works freely through a text book, which is reproduced on the PLATO system, answering problems or questions at will. The on-line author input allows on-the-spot changes and revisions by the author. Detailed evaluation programs will give the author a variety of information useful in his next revisions.

Auxiliary Equipment

It should be noted that the PLATO system can include auxiliary devices operated under computer control. The inquiry training lesson used a computer-controlled motion picture projector.[9] Physiological recording devices have also been used with the system.[4] One of the more unusual studies is one substituting a piece of experimental apparatus for a student at a station with input from the experimental set-up replacing the operator response at that station. A student at a second station can manipulate a real experiment through his station without ever touching the apparatus and can obtain the experimental results on his display.

Teaching with the PLATO system can be very varied since laboratory as well as classroom work is possible. Experiments may be performed which are either real-time like those just described or wholly simulated like those referred to in the discussion of inquiry logics.

Other Research

Other teaching research projects have included drill sequences for remedial arithmetic studies, physiological studies relating to mathematical discovery,[4] and work in the area of verbal learning and retention. The range of exploratory studies with the PLATO system is wide and serves to demonstrate the versatility and flexibility of the system.[11]

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

Bitzer, Donald L.; Lyman, Elisabeth R.; Easley, Jr., J. A.

6. REPORT DATE	7a TOTAL NO. OF PAGES	7b. NO. OF REFS.
October, 1965	29	11

8a. CONTRACT OR GRANT NO. DA 28 043 AMC 00073(E) b. PROJECT NO. 20014501B31F Also Advanced Research Projects c. Agency through the Office of d. Naval Research Nonr-3985(08)	9a. ORIGINATOR'S REPORT NUMBER(S) R-268 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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The use of a high-speed digital computer as a central control element provides great flexibility in an automatic teaching system. Using a computer-based system permits versatility in teaching logics since changing the type of teacher merely requires changing the computer program, not the hardware. In addition, having access to the decision-making capacity of a large computer located as one unit permits complicated decisions to be made for each student. Such capacity would be prohibitively expensive to provide by means of decision-making equipment located at each student station. The results of exploratory queuing studies show that the system could teach as many as a thousand students simultaneously without incurring a noticeable delay for any student's request.

The educational results thus far have been extremely encouraging. However, reliable conclusions on educational achievement must await the results of more thorough experiments now in progress which include larger numbers of students learning under a variety of conditions. The adaptability and useability of the system for a variety of purposes in education and the behavioral and physical sciences have been clearly demonstrated.

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