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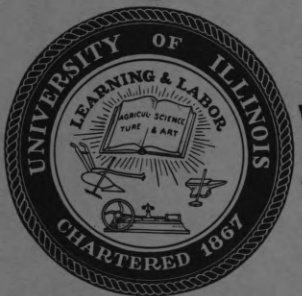
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— REPLAB —
A STUDY IN SCIENTIFIC INQUIRY
USING THE PLATO SYSTEM

D.L. Bitzer, E.R. Lyman and J.R. Suchman

REPORT R-260

DECEMBER, 1965

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REPLAB -- A Lesson in Scientific Inquiry
using the PLATO System[†]

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Coordinated Science Laboratory
University of Illinois

Report R-260

November, 1965

ABSTRACT

One of the teaching techniques employed in the Illinois Studies in Inquiry Training project was a lesson, REPLAB, written for use with the PLATO computer-controlled teaching system. The lesson was designed to develop inquiry skills and to study inquiry styles of individual students. A film, showing an event involving a bimetallic strip was presented to the students by means of a computer-activated projector. The students answered questions about the event posed them via the PLATO "electronic book." Answers to some of the questions could be found by careful observation of the film, others by obtaining further information from results displayed on their "electronic blackboards" by the computer in response to their inquiries in the PLATO experiment laboratory, property laboratory or condition laboratory. One set of questions in the question sequence tested the students' ability to go beyond the data they had obtained from the computer and formulate theories. The detailed record of the REPLAB student responses provided by the PLATO system gave data for a correlation of variables in the REPLAB lesson with those from pre-tests and post-tests given the students.

[†] 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).

I. Introduction

Recent research in the learning process has indicated the importance of pupil autonomy and self-direction. From 1959 to 1965 the U.S. Office of Education has supported research projects in inquiry training at Illinois under the direction of Dr. J. Richard Suchman, College of Education. These projects have investigated means of promoting inquiry development in the classroom.¹ Materials and teaching techniques were developed and tested and the effects of inquiry training on elementary school children were systematically investigated. Among the techniques resulting from these investigations was an inquiry session conducted with the aid of the PLATO system, the computer-controlled automatic teaching system developed in the Coordinated Science Laboratory of the University of Illinois. The PLATO system was especially suited to the purpose for the following reasons: (1) Its flexibility and vast storage capacity enable the system to provide a highly responsive environment for the learner. Inquiry requires random access to data that permits the learner to retrieve from the system the information he requires at any given instant. The PLATO system, through the electronic blackboard combined with the electronic slide selection system, combines the qualities of large storage capacity, random access and virtually instantaneous response (measured in milliseconds). (2) The PLATO system has the capacity of recording, storing, retrieving, and processing almost unlimited data pertaining to learner behavior. This permits a continuous and cumulative analysis of the inquiry process. (3) The PLATO system can couple an inquiry logic with the more traditional programmed instruction logic and permit the learner to choose at any instant between being taught and finding out for himself.

II. The Lesson

A. Conditions for Inquiry

Three conditions that are necessary to sustain inquiry are freedom, focus, and a responsive environment. Freedom permits the learner to gather data and test theories in his own terms, at his own pace, and in a sequence most meaningful to him. Focus establishes goals and gives him a direction to move in. The responsive environment feeds back the data he requests and provides a sounding board for his theories.

Although it may seem otherwise, the teacher's role is more crucial in promoting inquiry than in traditional didactic instruction. Being responsive requires more knowledge and skill than being directive. The responsive teacher can help the child gain more meaning through inquiry than the directive teacher can impart through didactic methods. A teacher can help an inquirer learn how to learn, and help him to become aware of the operations and strategies available to him in his pursuit of meaning.

B. The PLATO System

The PLATO system employs a high speed digital computer as the central control element. Each student has a keyset sending information to the computer and a television screen for viewing information selected by the computer. The computer generates information in two ways. First, the computer can select previously prepared slides from an electronic slide selector ("electronic book") with a random access time of less than one millionth of a second. Second, the computer can draw letters and figures on the student's electronic blackboard. The images from the blackboard and the slide selector are superimposed on the student's television screen. Figure 1 shows students working in a PLATO classroom. A more detailed description of the system can be found

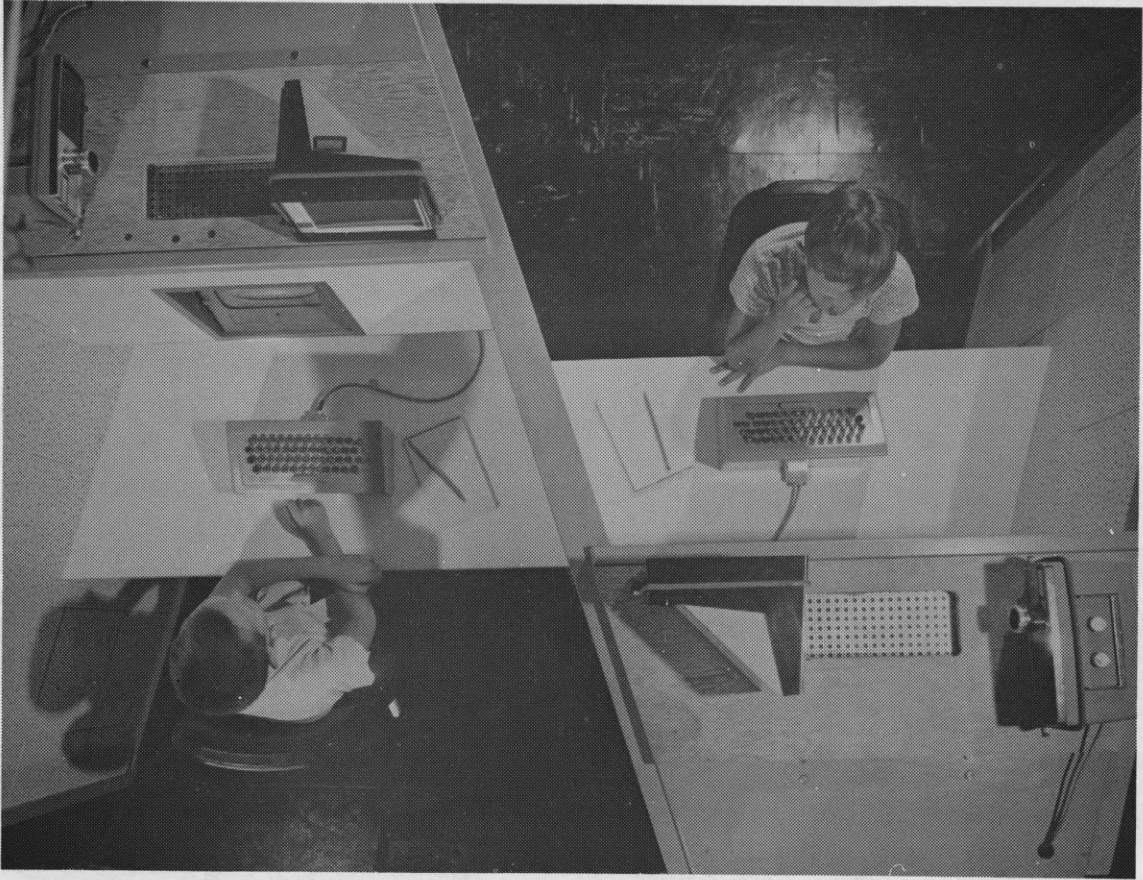


Figure 1. Students working at PLATO Stations

in previously published reports.²

The teaching carried on by the PLATO system is usually characterized as teaching by one of two methods - either "tutorial" or "inquiry." The tutorial method is defined as the method in which a student acquires information supplied on his television screen by the "electronic book" or "electronic blackboard" and then constructs answers to questions posed him on his screen, the answers appearing on his blackboard. The inquiry method allows the student to ask questions and obtain information from computer responses to his requests. The responses appear as writing or drawings on the student's blackboard.

The flexibility of the PLATO automatic teaching system seemed to offer great possibilities for inquiry training since it allows the students to participate actively in the learning process. The procedural technique for the PLATO lesson was adapted from the classroom inquiry technique and contains the three conditions for inquiry - focus, freedom, and a responsive environment. In fact, the PLATO inquiry lesson is named REPLAB which stands for Responsive Environment Programmed Laboratory.

C. REPLAB

The REPLAB lesson begins by showing the student an inquiry film of a discrepant event, the puzzling behavior of a bimetallic strip subjected to alternate heating and cooling. Thus the film provides the first condition for inquiry, the focus. In inquiry training, a discrepancy creates the focus by prompting the child to sense a gap between what he knows and understands and what he perceives. The learner is motivated by curiosity, or the desire for closure, to take action toward closing the gap.

The student's objective for the lesson is to answer thirty-two

questions about the experiment he had viewed. As the student works on the questions in the lesson, he becomes more familiar with the elements of inquiry. The questions to be answered are accessible to the student on his PLATO television screen (Figure 1). The questions were chosen by the lesson author from those (available from tape recordings) which had been most frequently asked in classroom inquiry sessions using the bimetal strip experiment. An element of reinforcement and challenge for the student is introduced by right or wrong feedback to the learner as he "punches up" answers. The goal for the student is to answer the questions with the lowest possible number of wrong answers. The questions are presented in sets of eight. Each set has to be completed before the pupil can proceed to the next sets. The student has freedom, however, within a question set, to answer the questions in any order or to stop answering questions and perform various inquiry operations. He has the freedom, therefore, to inquire and obtain information necessary to prepare to reply to the questions posed by REPLAB.

The third condition for inquiry, namely responsiveness, is provided in the PLATO lesson by the computer-controlled system which presents information to each student as he asks for it. The system responds to requests either by judging the student's answers, showing the film again, presenting the results of selected experiments, or by giving the pupil data that he requests in the form of properties, conditions, or identity of the objects involved in the demonstration film (Figure 2).

1. Lesson Structure

The Buttons

The REPLAB lesson procedure on the PLATO system is very simple since it uses only nine keys or "buttons" on a PLATO keyset. The reason for the extreme

What do you want to do?	0
1. Answer questions	
2. See film again	
3. Experiment	
4. Check properties	
5. Check conditions	

Figure 2. The "LAB" Page

simplicity of operation is because REPLAB was written originally in 1963 using the ten auxiliary "buttons" which the keysets in use with the PLATO II version of the equipment had available in addition to the standard PLATO keyset with its alphanumeric character and "tutorial" control buttons. Although REPLAB was subsequently reprogrammed for use with new keysets and the PLATO III equipment, its original lesson format was not changed.

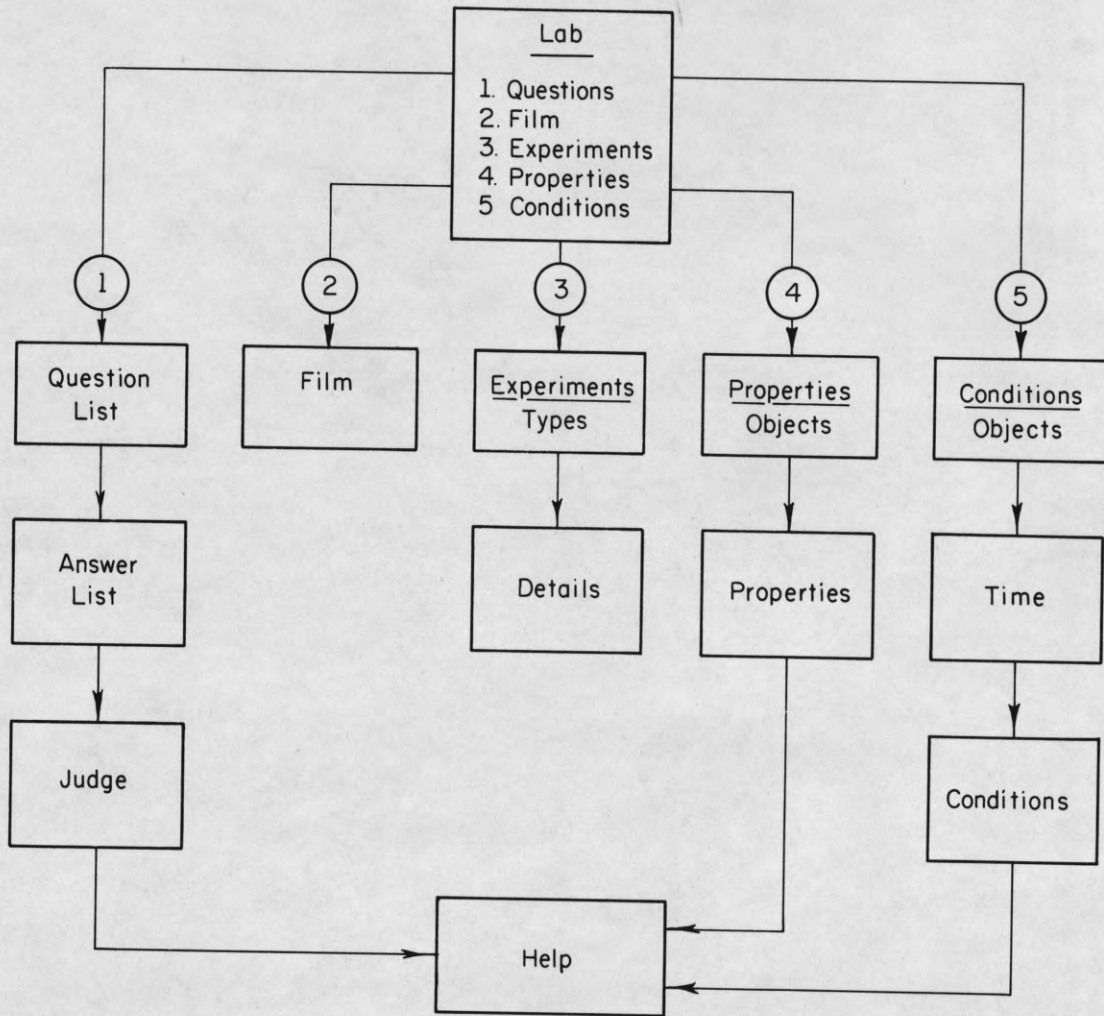
One of the nine keyset buttons is labelled "LAB" and the other eight merely by numbers "1" through "8". The flow diagrams of the lesson is illustrated in Figure 3.

The "LAB" button serves as a "security" feature for the student because the student always can return to the point of original "choice" (Figure 2) by pushing the "LAB" button. A student, therefore, is given the secure feeling of being able to get back to a known starting point at will. Figure 3 does not show the return arrows to "LAB" (mode 0) (they were omitted in order to avoid a confused diagram); however, one can imagine that the "LAB" button is legal for each item in the flow diagram and returns the student at any time to the initial choice mode "What do you want to do?"

Throughout the inquiry lesson the student directs his moves toward answering questions or obtaining information by pushing the buttons corresponding to the numbers of his choice. Thus when the student looks at the page shown in Figure 2, pushing the "1" button leads to the questions, the "2" button operates the film projector allowing the film to be seen again, the "3" button leads to experiments, the "4" button to properties, and the "5" button to conditions.

The Film

An auxiliary piece of equipment at each student station is used



Replab flow chart

Figure 3. REPLAB Flow Chart

with the REPLAB lesson. Above each student TV display is set a small "TECHNICOLOR 800" projector and screen (see Figure 1). The projector is fitted with a continuous cartridge 8 mm film and is adapted so that the projector is turned on by computer control and automatically turned off at the end of the film (one whole cycle of operation) when a restriction in the width of the film activates an "end of film" switch. The student merely presses the "2" button, "See film again," and the film starts and runs until finished. The student can proceed with the REPLAB lesson on his television screen while the film is running if he has obtained the desired information from the film.

The Question Sets

In the question mode, certain rules are written into the computer program to govern the student's actions. The student selects the question he wishes to answer by pushing the appropriate button (Figure 4). The next slide to appear shows him the question for which he has asked and gives him a choice of five answers. When the student has chosen his answer, the computer judges it "right" or "wrong" showing him one or the other of the slides illustrated in Figure 5. He then makes a choice as to his next move. If he has not completed the question set, and has chosen to return to the question page, his success or failure on questions attempted to date appears on the question page as a "plus" sign next to correctly answered questions, or a "minus" number next to unsuccessfully answered questions indicating the number of incorrect responses. (Figure 5A). After answering correctly the eight questions in a set, the score for that set is written on the student's screen as a number indicating the total number of attempts at answering the questions in that set. Thus a score of eight represents a perfect score, the correct answer on the first attempt for each question. The next time the student chooses to answer questions, the

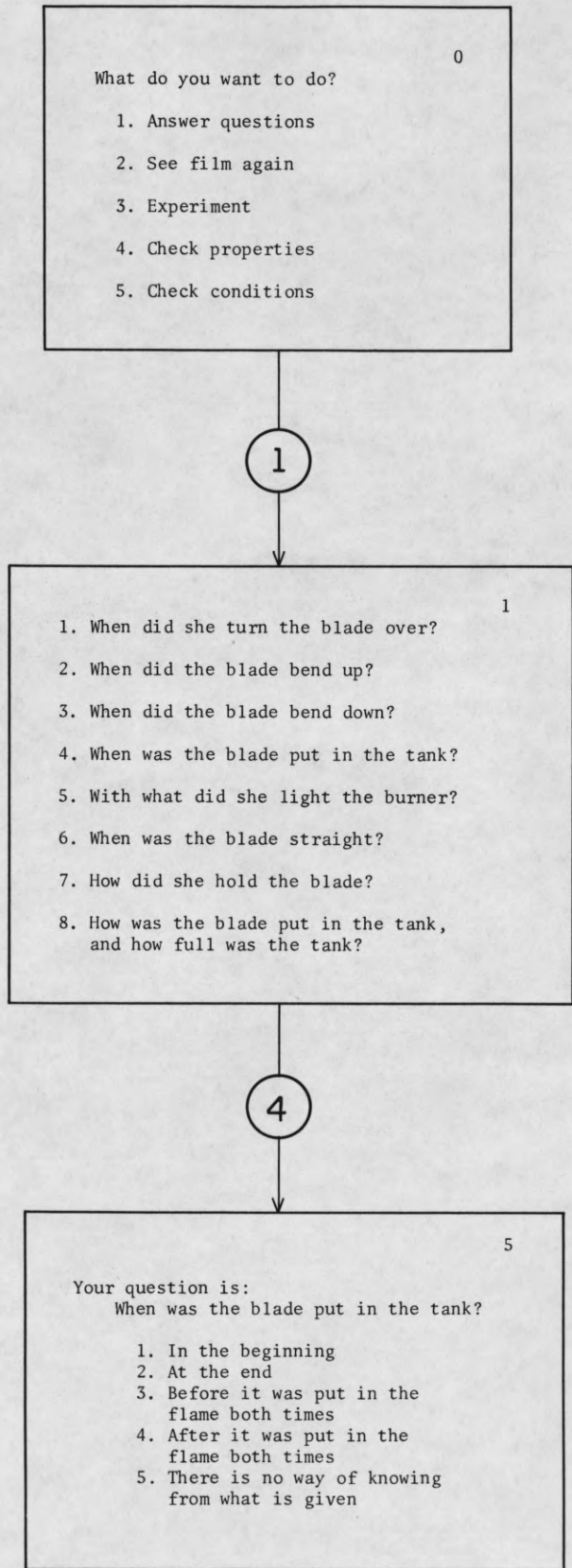


Figure 4. Example of Question Set and Answer Choice Sequence

11

Your answer is correct. What do you want to do next?

1. You may go back to the beginning.
2. You may go back to the questions.

10

Your answer is incorrect. What do you want to do next?

1. You may go back to the beginning.
2. You may go back to the questions.
3. You may get help.

Figure 5. "Correct" or "Incorrect" Slides

- 1
- + 1. When did she turn the blade over?
 - + 2. When did the blade bend up?
 - 1 3. When did the blade bend down?
 - 4. When was the blade put in the tank?
 - 3 5. With what did she light the burner?
 - 6. When was the blade straight?
 - + 7. How did she hold the blade?
 - 8. How was the blade put in the tank,
and how full was the tank?

computer presents the next question set. When all four question sets are completed, the total score for the lesson appears (Figure 6), a final score of thirty-two representing perfection. The computer program then blocks out further attempts to answer questions, although further inquiry into experiments, properties, and conditions are still possible.

The character of the questions in each set varies (Figure 7). The first two sets are analytical, asking about objects, events and conditions as determined primarily from the film, and some inquiry about properties, conditions, and experiments. The third set asks the student for predictions, requiring him to apply some of the data he had observed and determined. The fourth set tests the student's power of synthesis of the facts available to him as he is asked to choose for each question the best explanation for various events occurring in the film. By the fourth question set the student is able to show his ability to organize the informative data which he had obtained from the computer.

The Experiment Laboratory

If a student wishes to see what would have happened in the event that the experiment shown in the film has been performed differently, he chooses the "3" button on the "LAB" page, and the computer takes him to the "experiment" simulated laboratory. Here he is able to perform simulated bimetallic blade experiments under a choice of alternate circumstances (Figure 8).

He chooses the type of experiment he wishes to do, pushes the button indicating his choice, and then chooses which change he wishes to make in the original experiment. The experiment laboratory offers him the capability of changing the temperature or the depth of the liquid or even the liquid itself into which the bent bimetal blade was dipped, the material of either side of

Your answer is correct. What do you want to do next?

1. You may go back to the beginning.
2. You may go back to the questions.

SCORE THIS QUESTION SET	14
FINAL SCORE	57

Figure 6. Illustration of "Scoring"

- 1
1. When did she turn the blade over?
 2. When did the blade bend up?
 3. When did the blade bend down?
 4. When was the blade put in the tank?
 5. With what did she light the burner?
 6. When was the blade straight?
 7. How did she hold the blade?
 8. How was the blade put in the tank, and how full was the tank?

- 12
1. Of what was the blade made?
 2. What was in the tank?
 3. What kind of flame was it?
 4. How does the blade bend when heated?
 5. How does the blade expand when heated?
 6. How does the blade melt when heated?
 7. What happens to the heat in the blade?
 8. What happens to the liquid when the blade is put in it?

- 30
1. What if she had held the blade in air instead of in liquid?
 2. What if she had used a deeper tank?
 3. What if the liquid had been hotter?
 4. What if she hadn't turned over the blade?
 5. What if she had put it in ice instead of liquid?
 6. What if the two sides had been the same?
 7. What if the two sides had been separated?
 8. What if she had used a different liquid?

- 39
1. Why did she use liquid instead of air to cool the blade?
 2. Why did the two sides of the blade have to be different?
 3. Why did the blade bend?
 4. Why would a deeper tank have made no difference?
 5. Why did the temperature of the liquid change?
 6. Why would the blade have bent the other way in crushed ice?
 7. Why could the liquid have been different?
 8. Why did the two sides have to be joined?

Figure 7. The Question Sets

EXPERIMENTS YOU CAN TRY

Do you want to

1. Change temperature of liquid in jar.
2. Change depth of liquid in jar.
3. Change material in jar.
4. Change material of blade (one material).
5. Change material of blade (combinations).
6. Change temperature of flame.
7. Change way heat is applied to blade.
8. Change time of heating and also method of bending.

Figure 8. Experiments

the blade or the whole blade, the temperature of the flame heating the blade, the way heat is applied to the blade, the amount of heating time and the method of bending the blade. The computer then shows, in a drawing on the student's electronic blackboard, the resultant shape of the blade under the circumstances designated by him. Figure 9 illustrates an experiment substituting blades of varying materials for the original blade. If the student had not been cognizant of the fact the blade was made of two metals, he should have been able to glean from this experiment some conclusive information relevant to the construction of the blade.

The Property Laboratory

Seven properties can be obtained for each of six objects appearing in the experiment in the film. The student can interrogate the computer for the taste, color, melting point, hardness, weight, state or conductivity of heat of each side of the blade or of the whole blade, the liquid, the flame or the tank holding the liquid. The computer writes the information on the student's blackboard. An example of property inquiry is shown in Figure 10 where the student asks successively for the melting point of the top, the bottom, and the whole blade. It is obvious from the facts obtained that the blade is made of two different materials.

The Condition Laboratory

There are also seven conditions which can be obtained for each of the objects in the experiment (except the tank). The conditions can be checked at five different times during the experiment, i.e., the hardness, volume, temperature, structure, weight, pressure, length or depth can be found for the beginning of the experiment, after the blade is held in the flame the first or second times, or after the blade is placed in the liquid

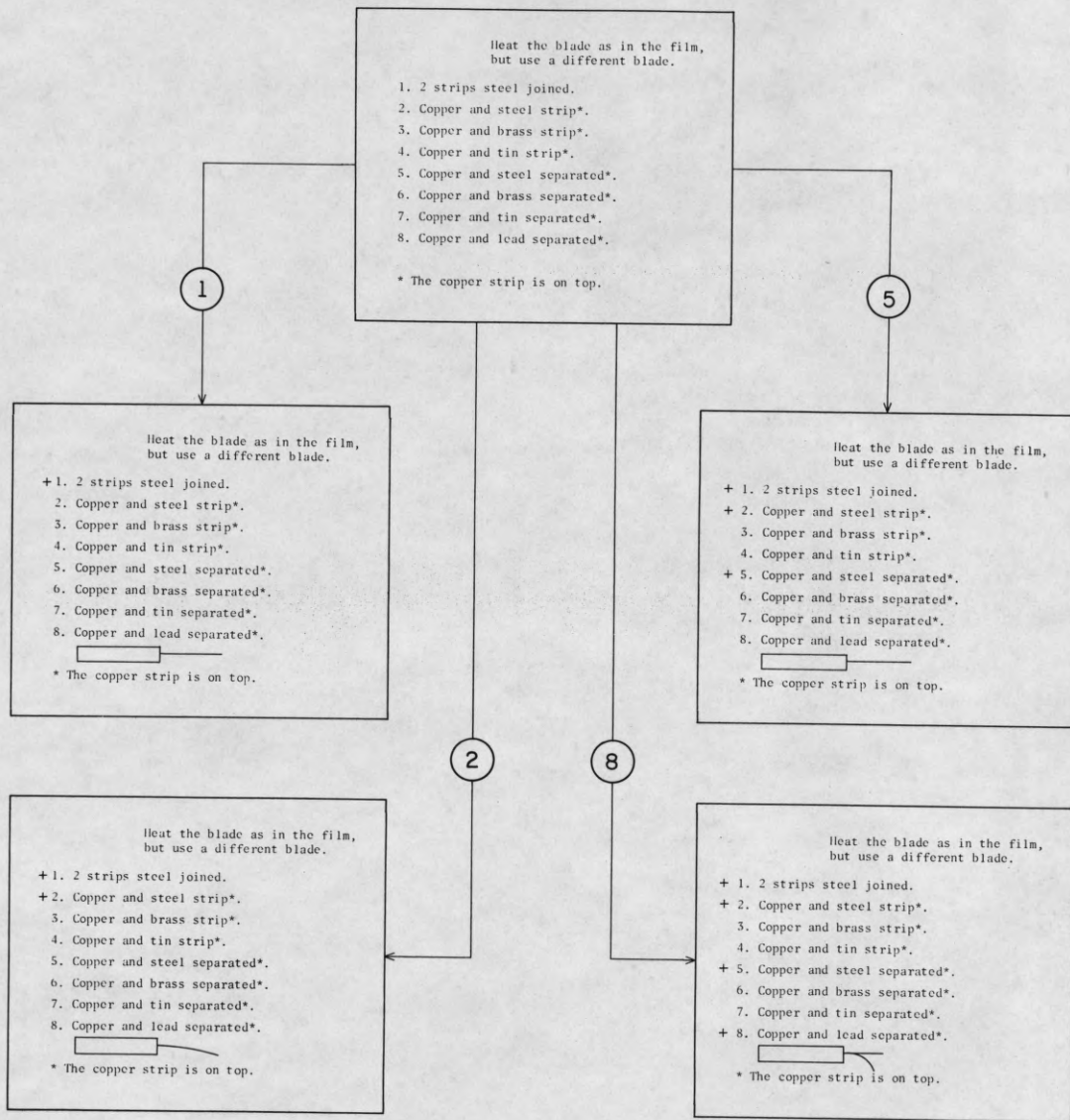


Figure 9. Example of an Experiment Varying the Material of the Blade

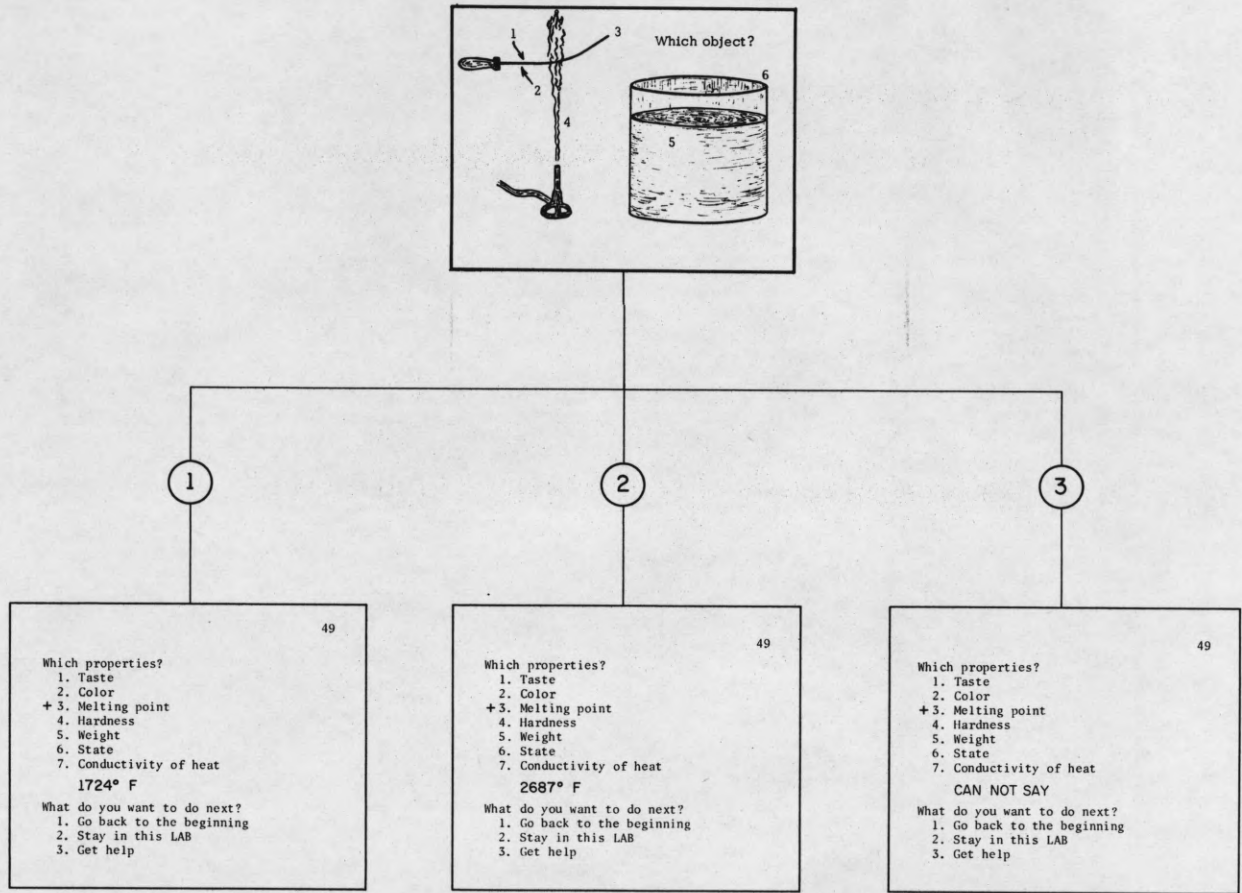


Figure 10. Property Determination

the first or second times. A student examining the temperature of the liquid in the tank would learn that its temperature remained virtually unchanged during the whole experiment (Figure 11).

"Help"

There are "help" slides available to the student in each of three places in the lesson: when the student answers a question incorrectly, or when he cannot interpret the condition or property information he has obtained. The "help" consists of suggestions likely to lead to more fruitful inquiry showing the functions of various operations and their relationships to the questions asked (Figures 12, 13, 14).

2. Data Analysis

One of the outstanding features of the PLATO system is the "perfect workbook" of student operation which is available. In PLATO vernacular, the procedure of record storing is called "doping." The computer writes on magnetic tape a record of each button each student pushes, the time at which he pushes it, and the mode (or place) in the lesson in which he is when he pushes the button. The teacher can, therefore, examine each student's record of operation to analyze pupil strategies and overall performance. Since the record is stored on magnetic tape, it can be processed at any time in whatever statistical way is desired.

For REPLAB analysis, it was deemed advisable to obtain a printed record for each student which showed at a glance each of his moves throughout the lesson. Figure 15 shows a typical print-out of a portion of a student record. The time in minutes and seconds for each move is recorded in the left-hand column. One can see from the record how often he viewed the film, his progress in answering each question set, the times at which

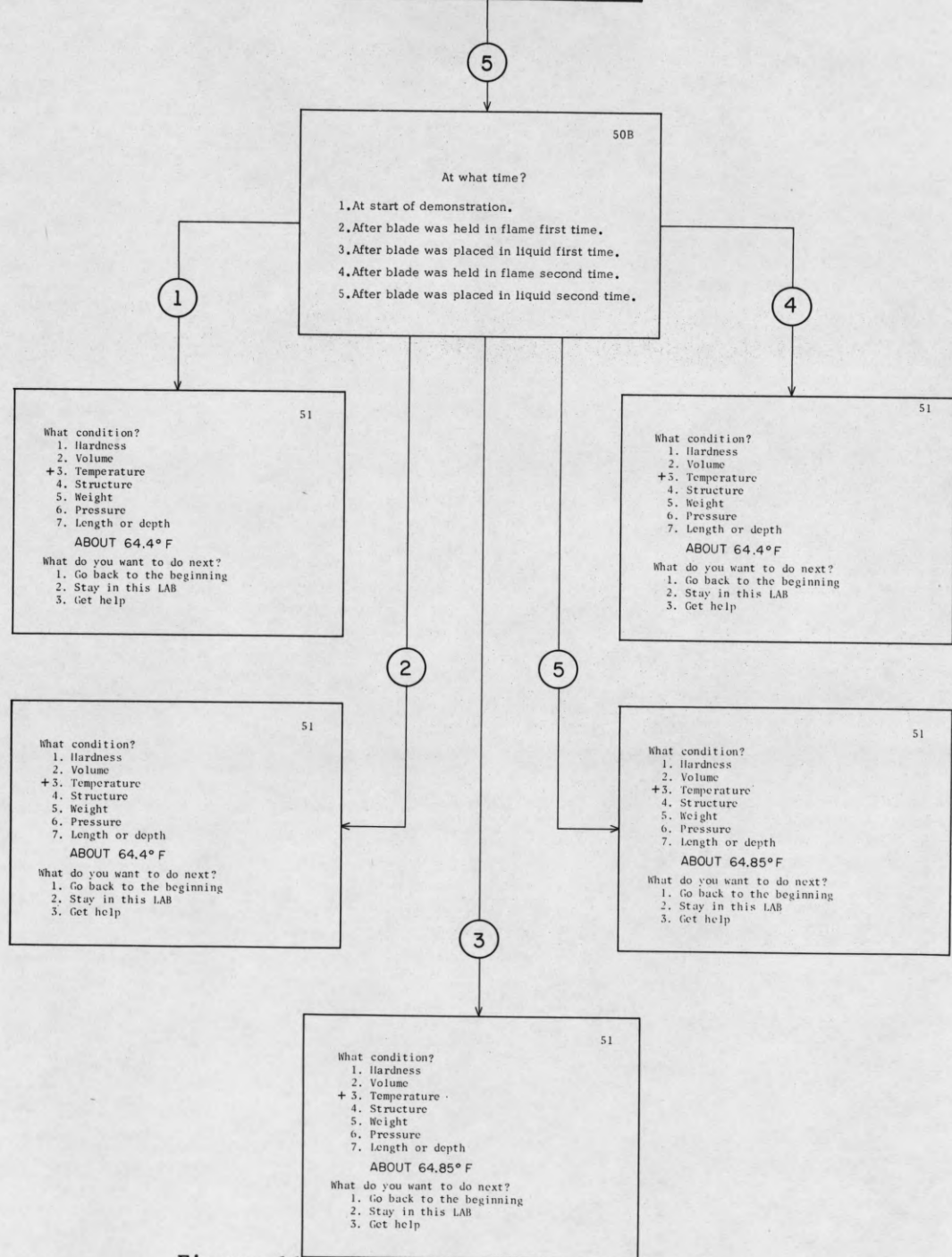
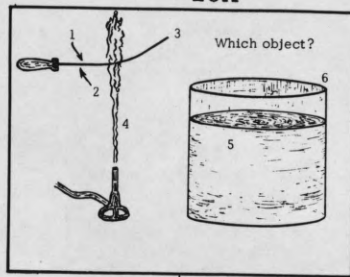


Figure 11. Condition Determination

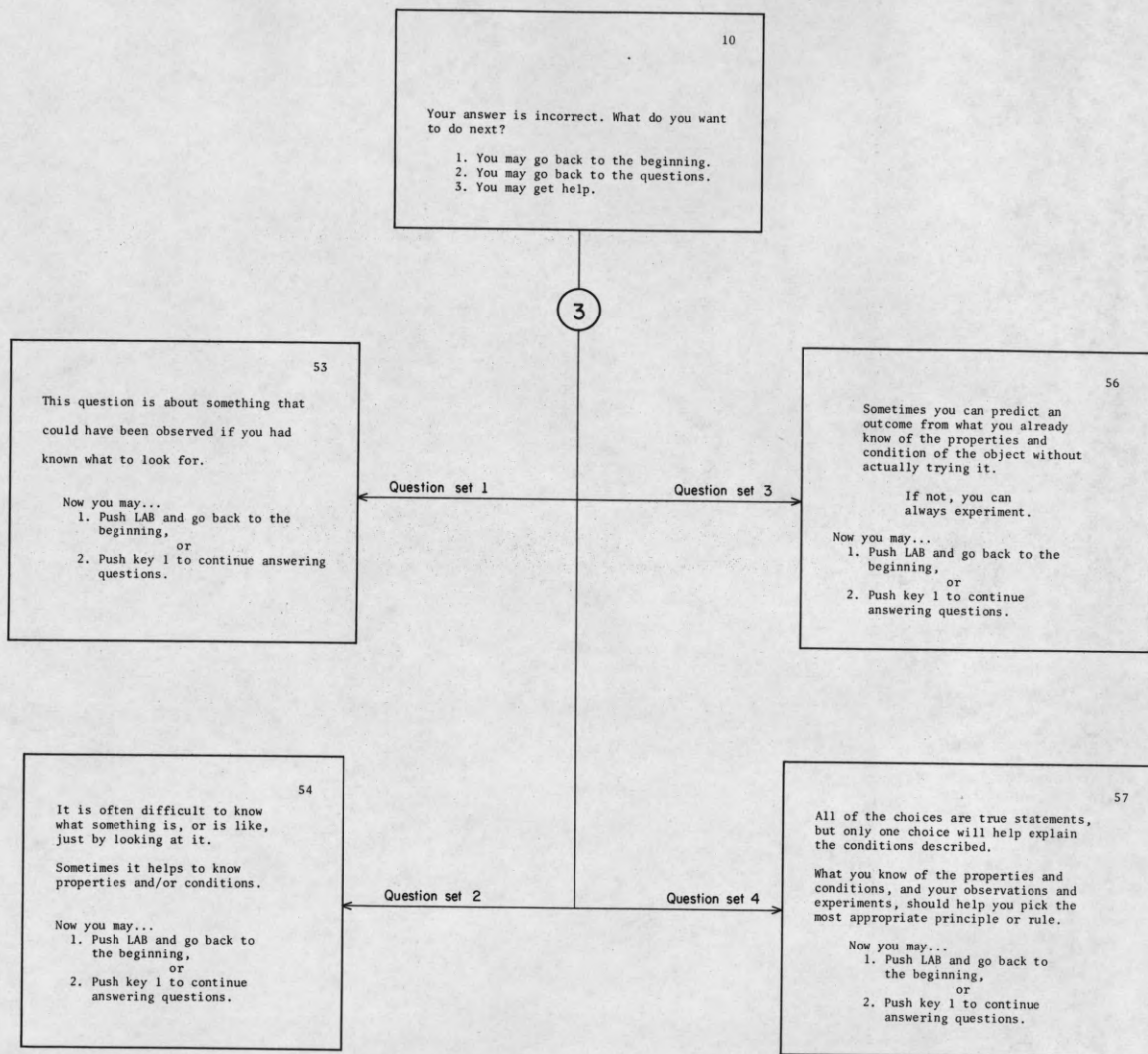


Figure 12. Question Help Pages

This LAB will be most useful if you compare different objects on the same property.

You may also need to know several properties of the same object.

Push key 1 when you are ready to continue.

Figure 13. Property Help Page

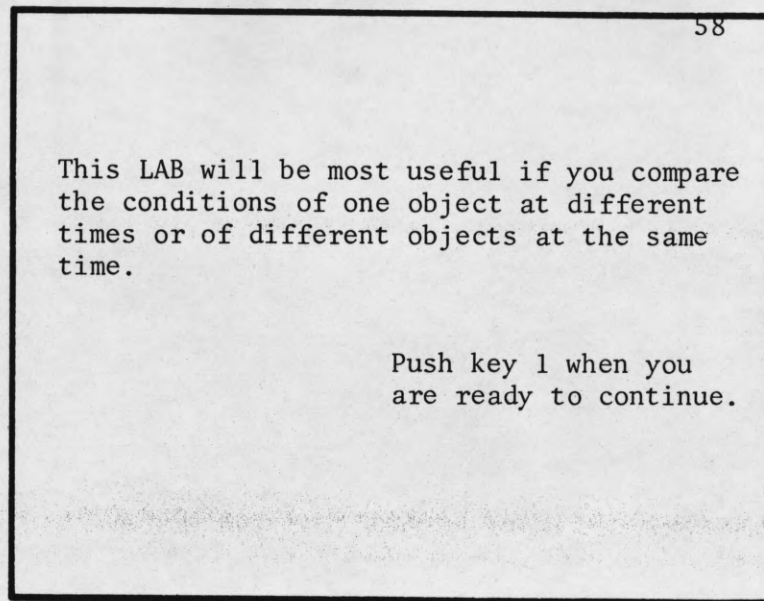


Figure 14. Condition Help Page

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STUDENT NUMBER 1

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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 15. Example of Printout of a Portion of a Student's Performance Record

he went to the various laboratories and what information he obtained there (i.e., the buttons he pushed in each lab which the teacher could then interpret knowing the experiments, properties, or conditions entries). An "answer-guesser" was easily spotted because his "dope" showed few, or even no, "information" inquiries.

In addition to the record of moves through the lesson, the record provided the variables needed for a correlation study with results from pre-tests and post-tests given the student. The REPLAB variables used included the total score (number of attempts to answer questions), number of wrong answers, shifts from one to another of the five permissible operations, times the film was seen, experiments tried, property verifications, condition verifications, help requests, number of guesses divided by the number of incorrect answers (the guess quotient), number of completed laboratory operations divided by the number of attempts to answer questions (laboratory/question quotient) and the total number of completed laboratory operations, including help (Figure 16).

3. Programming

The REPLAB computer program was originally written in 1963 by Dr. Donald L. Bitzer for PLATO II (2 student stations) and the Illiac computer. The first type of PLATO system logic had been tutorial in design, but when the idea of inquiry was suggested, the computer program was extended to include subroutines which would allow the computer to perform tasks at the student's demand other than merely writing his answer on his blackboard and judging it. With the designing of the REPLAB program two types of PLATO teaching logic were, therefore, available: tutorial and inquiry. The next step in programming development for PLATO was to adapt to the Laboratory's

MAY8
STUDENT NUMBER 1

TOTALS

NUMBER OF ATTEMPTS TO ANSWER QUESTIONS = 46
NUMBER OF WRONG ANSWERS GIVEN = 27

NUMBER OF SHIFTS FROM ONE OPERATION TO ANOTHER = 25
NUMBER OF TIMES FILM WAS VIEWED = 1
NUMBER OF EXPERIMENTS TRIED = 22

NUMBER OF PROPERTY VERIFICATIONS = 13
NUMBER OF DIFFERENT OBJECTS SELECTED FOR PROPERTY INVESTIGATIONS = 6
NUMBER OF DIFFERENT PROPERTIES SELECTED = 4

NUMBER OF CONDITION VERIFICATIONS = 6
NUMBER OF DIFFERENT OBJECTS SELECTED FOR CONDITION INVESTIGATIONS = 3
NUMBER OF DIFFERENT TIME STATES TRIED = 3
NUMBER OF DIFFERENT CONDITIONS TRIED = 1

NUMBER OF REQUESTS FOR HELP = 4

LAB/QUESTION QUOTIENT = .913
GUESS QUOTIENT = .593
ACTIVITY SCORE = 92

LAPSED TIME = 49 MINUTES AND 35 SECONDS

Figure 16. Sample Variable Tabulation from an Analysis of a Student's REPLAB Performance.

Control Data Corporation 1604 computer in place of Illiac. While the 1604 reprogramming of the master, or resident, PLATO program was going on, use was made of an ILLIAC simulation routine, SIMILE, available with the 1604 so as to continue using the existent PLATO programs with PLATO II equipment. In the spring of 1964, REPLAB was reprogrammed by E. R. Lyman in 1604 machine language, CODAP, so as to be compatible with the resident PLATO program, CATORES, developed for use with the PLATO III equipment by D. L. Bitzer, Andrew Hanson, and Michael Walker. Two stations of PLATO III were operable throughout 1964. The CODAP version of the PLATO resident program, CATORES, was written to be used by a maximum of 32 students and allowed the use of 64 modes rather than 16, 128 keys instead of 58, 64 characters descriptions and 256 special subroutines of unlimited length rather than 64 subroutines of twenty words a piece. The special subroutines are subroutines written just for the specific lesson and are not included as "systems subroutines" available for any lesson. The special subroutines are the ones executed when designated keys are pushed or mode changes are made (i.e., questions, properties, etc., in contrast to the systems subroutines: slide, erase, plot, etc.). CATORES also wrote the students' records automatically on magnetic tape as the students worked rather than storing them solely in the computer memory.

During the summer of 1964, the CATORES program was refined, made more flexible and became compatible with the PLATO compiler written by Steve Singer and completed in October of that year. The maximum number of characters and modes provided by the compiler version of CATORES has no practical limitations. The new PLATO III keysets provide 128 different key inputs. At this time REPLAB was programmed for the third time, using the original logic, but being written in PLATO compiler language.

The final version of REPLAB provides a character description list for the electronic blackboard of numbers, 0-9, and letters, A-Z, punctuation symbols (period, space, plus, minus, and degree), and 24 characters, combinations of which draw pictures of the bent bimetal blade on the students' screens.

The logic of the lesson contains seventeen modes. There are thirty-eight subroutines necessary in addition to the usual systems subroutines contained in the resident CATORES. The subroutines are written in PLATO FORTRAN language. Each student bank (special storage for each student) utilizes eighty-five words of memory space. The property, condition, experiment, and correct answer numbers indicating the computer responses to student requests are dependent on which keys are pushed by the students when choosing objects, times, specific experiments, etc.; therefore these numbers are arranged as arrays and are read into the computer memory by a data tape and stored in "common" storage at the beginning of a lesson run. The key on the PLATO key-set to be pushed in order to read the data tape is one never used by a student. The sentence responses which the computer might give in answer to property or condition inquiries are packed and stored by the PLATO FORMAT routine; sixty-six sentence possibilities are available in the program. The sentences require one hundred ninety-eight words of computer memory space for storage.

During the course of running REPLAB with students two major changes were made in the program. The first was the rewriting of the "experiment laboratory." Originally it involved a student referring to a notebook describing experiments in order to choose the number of experiments he desired. The use of the notebook proved awkward, so the "experiment laboratory" was redesigned so that it is presented entirely on the student's screen.

The second change was the addition of an introductory sequence to explain the operational procedure of the lesson. The introduction involves the same pages as in the lesson, but limits the button choices the student makes in order to show him examples of everything that can happen.

III. REPLAB as a Research Tool

REPLAB was used by the Inquiry Training Project as an instrument to sample and analyze the inquiry characteristics of about fifty pupils undergoing inquiry training. It afforded the researchers the opportunity to sample many performance variables in a simple inquiry session. This technique of assessment is still beset by a number of methodological problems, but the basic approach holds much promise. Inquiry is a complex pattern of behavior that involves many interrelated functions.* Chief among these are perception, storage, retrieval, action, motivation and the coordination of all of these in the search for new levels of meaning. The clearest picture of the inquiry process is not obtained simply through the measurement of the amount of new material that is stored. The ultimate criterion is the amount of increase in measuring level. But the patterns of learner behavior that lead to that level are important for the teacher as well as the researcher. REPLAB offers a new technique for sampling this behavior and analyzing its components.

*

A final report of the Illinois Inquiry Training Project will appear in the near future as a publication of the U.S. Department of Health, Education and Welfare entitled "Science Concept Development in the Elementary School through Inquiry Training" by J. Richard Suchman and Sybil B. Carlson.

Dr. J. Richard Suchman, formerly a Professor of Education at the University of Illinois, is now in the Bureau of Research, U.S. Office of Education.

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