evolution, nature has been able to find more than one efficient molecular mechanism for maintaining a vital organismic function.

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Educational Uses of the PLATO Computer System

The PLATO system is used for instruction, scientific research, and communications.

Stanley G. Smith and Bruce Arne Sherwood

The PLATO (*1*) computer-based educational system has been specifically designed to provide interactive, self-paced instruction to large numbers of students (*2*). Lesson material is displayed on a screen 22 centimeters square and may consist of text, drawings, graphs, and color photographs. Students interact with the material through a special keyset that closely resembles a typewriter keyboard, and they receive essentially instantaneous reinforcement of correct work and assistance where they are having difficulty. Students can work at their convenience in classrooms such as the one shown in Fig. 1.

The users of PLATO range from grade school students learning reading and math to graduate students in the medical sciences. The system now has 950 terminals located in universities, colleges, community colleges, public schools, military training schools, and commercial organizations (*3*). The users have access to more than 3500 hours of instructional material in more than 100 subject areas (*4*). We will mainly describe one area of PLATO use—that of university science education and research.

Examples of PLATO Lessons

The character of PLATO lesson material varies greatly since the computer system does not impose a pedagogical structure on the authors of the materials. Some appreciation of the breadth of approaches used may be gained by reviewing brief segments of a few programs in chemistry (*5*) and physics (*6*). The examples below are illustrated with photographs of the student's plasma-panel screen (*7*). Unfortunately, however, these static photographs do not fully convey the dynamic nature of the interactively changing displays seen by the student.

A physics lesson on oscillations contains features common to many expository science lessons. The student is given a table of contents for the lesson so

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that he may choose to study any section or even go directly to a final quiz that will test his understanding of the material. The intent of the lesson is to take students from no knowledge of oscillating systems up to a point where their understanding allows them to solve typical homework problems.

The first part of the lesson deals with an oscillator consisting of a block sliding up and down two smooth inclines, a system that the student analyzes by simple kinematics formulas. In order to help the student understand the system, the computer shows an animation of the motion and allows him to experiment with values of the initial displacement (Fig. 2).

After the student has experimented with the system until he thinks he understands it, the program tests his knowledge by asking a number of questions about the system. Help is provided where necessary, but where help is required the student must answer the same question later with different numerical factors. Such checkup sections follow each expository section of the lesson.

The final quiz is constructed from questions asked in the earlier sections with randomly chosen numerical factors. No help is provided. The lesson distinguishes between incorrect numerical results and typing errors, such as unbalanced parentheses. In this lesson, if the student misses more than two out of six questions, he must take the whole quiz again. He can, of course, review sections of the lesson if he wishes.

Students also have the opportunity to study systems of their own design and to program the computer with a special language so that they may obtain immediate graphical results. Figure 3 illustrates an example of large-amplitude pendulum motion in which the student has used s for angle, g for gravitational acceleration, l for length, v for angular velocity, t for time, and d for a short time interval. The graphs that have been produced for the student correspond to running the program with a starting angle of 45 degrees and with a starting angle of 179 degrees.

Since much of science is based on the results of experiments, it seems important to have students learn to design experiments and interpret the experimental data. However, many of the key experiments in the development of important concepts cannot be carried out by large numbers of students because of the lack of adequate equipment, time, and experimental technique. The use of computer simulation can serve to provide some experience with the concepts. For example, a comparison of the sensitivity of the rates of ethanolysis of *n*-butyl bromide and *t*-butyl bromide as a function of ethoxide concentration serves to clarify some aspects of the concepts of unimolecular and bimolecular reactions. Students can quickly discover what happens through simulated experiments in which the computer plots the percent reaction as a function of time as would be observed under the experimental conditions they suggest. Since the student is free to explore the relation between experimental conditions and reaction rate, it is important to have the program ask questions and, if necessary, suggest additional experiments to assure that a suitable set of experiments has been done. In this case, after the experimental facts have been established and a suitable interpretation has been developed, the system provides a visual picture of the transformations involved by means of an animation that shows the sequence of bond making and breaking which occurs.

Fig. 1. One of the PLATO classrooms at the University of Illinois. This classroom in the Foreign Language Building contains 80 terminals.

In more advanced lessons, students are given a problem that can be solved by conducting some simulated experiments on the computer. The student is expected to design the experiment, select the compounds and reaction conditions, and then collect the experimental data, do the mathematical analysis, and outline the conclusions that can be derived from his experiments. This approach to teaching is possible because the computer can rapidly calculate the outcome of experiments of a given type from algorithms which describe the results of actual experiments that may be beyond the experimental skills of the students and the available laboratory facilities.

It is also necessary for students to gain experience in dealing with problems for which there are many possible solutions. The synthesis of organic compounds is an example of this type of situation, in which there are many viable routes from the starting materials to the designated product. This is illustrated in Fig. 4 where the student is given the task of converting a given starting material into a designated product molecule. He proceeds by suggesting a reagent for each step in the transformation. Since there are many possible paths between the starting material and the product, the computer is programmed (*8*) to carry out the reaction suggested by the student and compare the structure of the product with that of the desired material. If they are the same, the synthesis is judged completed. If not, the reagent for the next step is requested. This approach does not impose a specific solution to the problem on the student but recognizes a wide range of acceptable routes.

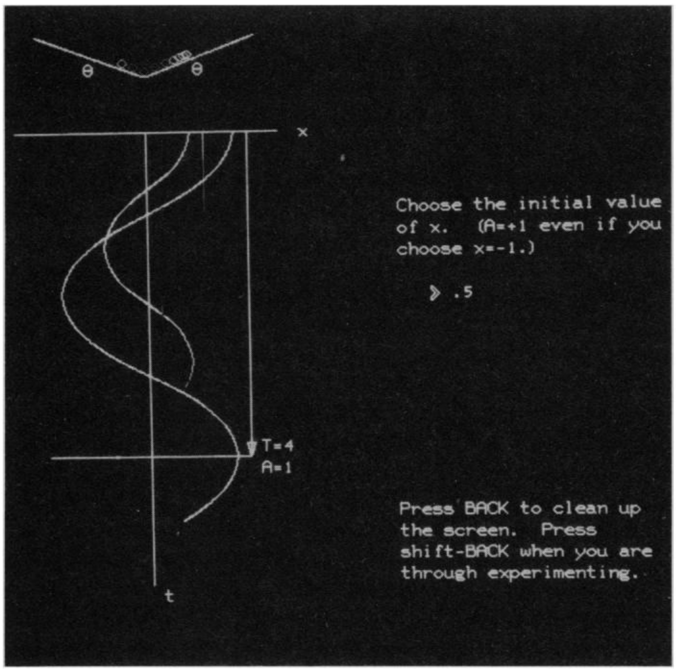
One way to provide practice problems for organic reactions is illustrated in Fig. 5 where the student has been given 16 compounds and ten reagents and is asked to find at least 20 different ways of interconverting pairs of the compounds with the use of the reagents shown.

To cause the interaction, the student simply points to a compound and then to the reactant or product side of the reaction arrow to indicate his choice. The computer senses which compound the student is pointing at by means of a matrix of infrared light-emitting diodes and sensors that lie in a 16 by 16 array around the edge of the display screen. The use of such a "touch" sensitive display makes it easy and quick for the student to specify the reactants and products. Errors are corrected by having the computer show either the correct product for a given reactant and reagent or the required reagent for a reactant product pair.

Additional flexibility in the use of the computer as an aid to teaching comes from the ability to have the computer control the projection of color photographs on the plasma panel. This is illustrated in Fig. 6, which has been abstracted from a lesson on the use of an analytical balance. In this example the student must identify the function of the knob on the side of the instrument.

Structure of Lessons

The successful application of program segments such as those described above to a real teaching situation involves the integration of practice problems and associated help sequences with the development of the necessary theoretical framework to assist the students in understanding the material. The ability of the PLATO system to support a one-to-one dialogue with the student offers the possibility of presenting the material in unique new ways that make the student an active participant in an effective learning situation. Well-designed lesson material tends to be highly interactive and requires frequent inputs from each student in the form of answers to questions, predictions of the outcome of some experiment, parameters to be used in simulated experiments, and interpretation of a set of data or facts. In addition, since the understanding of the subject matter



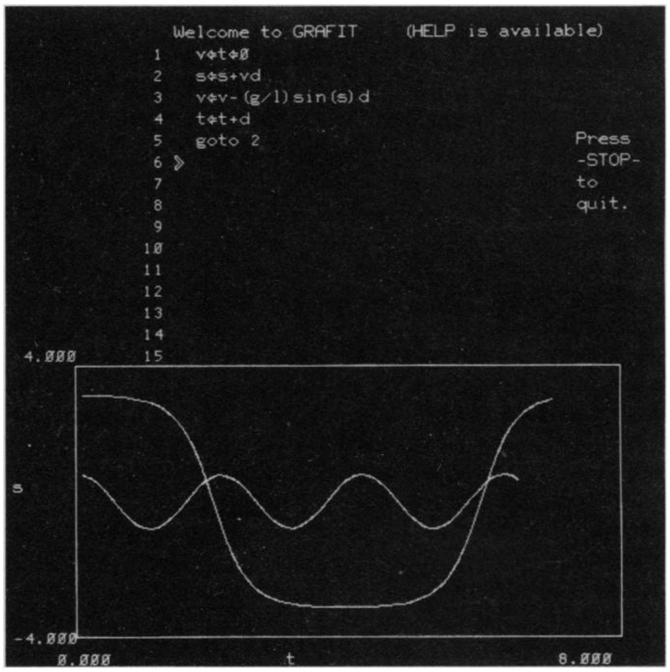
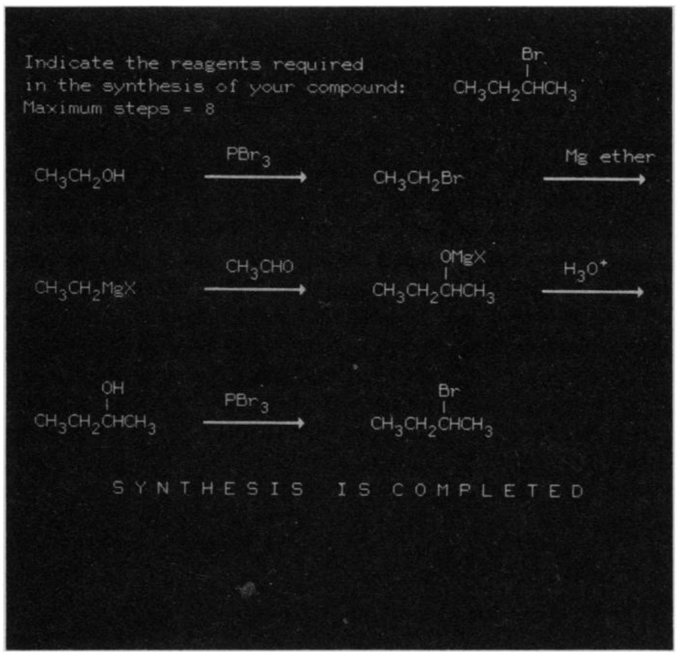


Fig. 2 (left). The student can choose the amplitude of this nonlinear oscillator and study the effect of amplitude on frequency. Fig. 3 (right). The student has written a numerical integration program to study the motion of a pendulum with large-amplitude swings. The two graphs correspond to amplitudes of 45 degrees and 179 degrees.



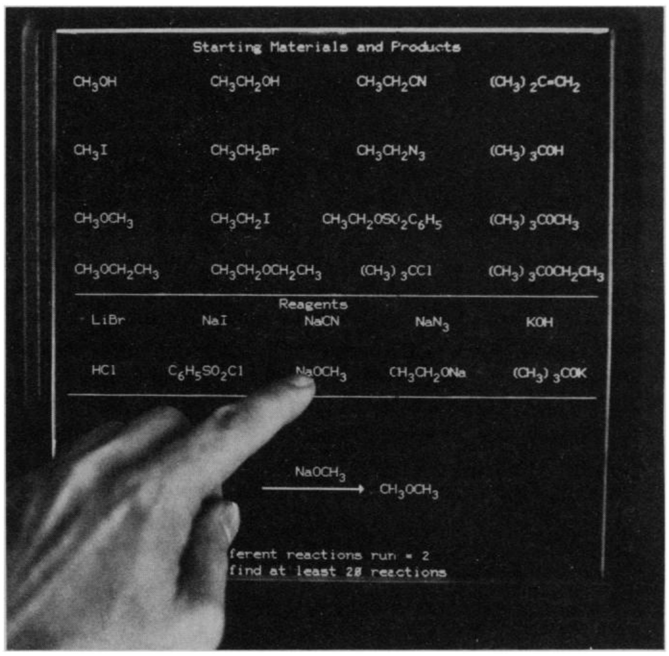


Fig. 4 (left). Typical multistep synthesis in which the student has typed in the reagent for each step as the computer draws the structure of the reaction product. Fig. 5 (right). The student can specify the starting material, reagent, and product by simply touching the compound on the screen. A 16 by 16 array of infrared light-emitting diodes and sensors determines where the student is pointing.

that a student has before starting a given program varies enormously, it is desirable to structure the program to accommodate students who just need a brief review as well as those who are learning the material for the first time. One simple way to provide students with flexibility in the way they study and use a given program is to provide an index to the lesson which allows easy access to any section.

Since students can proceed at their own rate, time spent in the lesson, unlike a lecture, automatically adjusts to the needs of the student. In fact, students proceed at greatly different rates when given the opportunity. For many lessons the time required for students to complete the lesson often varies (*9*) by a factor of 3 to 7.

Although lesson material can make some adjustments to meet the needs of individual students, it is important to develop criteria and data that indicate how the difficulty of the programs matches the abilities of the students. One criterion that has been used is the percentage of the questions posed within the program which students answer correctly on their first try. The assumption in this approach is that if nearly all student responses in instructional material are correct, then the programs are not adequately challenging them, while a very small percentage correct suggests that the lesson is unduly discouraging. The plot of percentage OK on the first try as a function of the number of students, shown in Fig. 7, suggests that for most of the students the level of the material was adequately adjusted for the class (*10*).

In addition to allowing multiple entry points and the ability to review as frequently as desired, lessons should tend to adjust to each student within each section. For example, help should be provided either when requested by the student (there is a key on the keyset labeled HELP) or when it is clear that he is having difficulty. The number of problems presented can be easily adjusted to the student by such simple means as requiring that he get two right in a row of a certain type or, perhaps, simply by returning a given problem to the list of those that need to be worked if the student needed assistance in working it. Data from lessons are used to check that the lesson is adjusting properly to the students' needs.

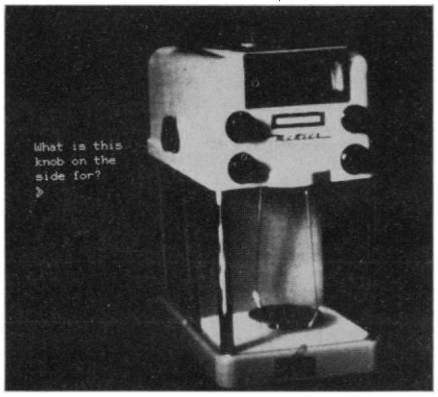


Fig. 6. The student must give the function of the knob on the side of the analytical balance. The computer controls the projection of color photographs from a microfiche onto the back of the plasma panel.

Computer-Managed Instruction

A complete lesson on PLATO has many of the characteristics of a chapter in a textbook. Like chapters in a book, such lessons need to be assembled in a form that is easy for students to use. All of the lessons associated with a particular course can be made available from an index. Then, when a student signs on to the PLATO system with his name and the name of the course, he may choose topics or lessons to study. He makes his selection from a list of descriptive titles, much as chapters in a book are selected from the table of contents. (As mentioned above, many lessons have, in addition, a table of contents for the subsections of the lesson.)

If there are a large number of lessons associated with a particular course, it may be desirable to provide the student with some guidance in the selection of lessons that are appropriate to the course at that time. The PLATO system makes this possible by a course management scheme that allows an instructor to set up an index of lessons by simply selecting the lessons from a catalog of lessons displayed on the screen. Many such indexes may be set up for a course. For example, all of the lessons associated with a given topic or concept may be placed on one index. The instructor then specifies the criteria for allowing students to move from one index of lessons to another. For example, the student might be required to complete three of four lessons before moving ahead to the next topic. Or, this criterion may be modified so that at a given date the next set of lessons is made available even if the specified number of earlier lessons has not been completed, so that a student who has gotten behind at one point in the course can keep up with the new material. If on-line quizzes or exams are included in a given module or set of lessons, a satisfactory score can be included in the criteria specified for completion before new topics are presented.

The relations among the student, instructor, and the lesson author are diagramed in Fig. 8. This scheme, which is available to all instructors, provides guidance to the student on current work, makes it easy to review earlier lessons, and allows students to work ahead of the rest of the class. The result is an efficient and effective integration of the techniques of computer-based teaching and computer-managed instruction. While this generally available management scheme is used by many instructors, it is also possible to create other management structures to meet special requirements.

Integration of PLATO Activities

PLATO has been integrated into the structure of courses in several ways. For example, in a classical mechanics course (*11*), computer-based tutoring made it possible to drop one of the two weekly lectures. The remaining lecture is used chiefly for demonstrations rather than for basic instruction. The discussion period is spent in the physics PLATO classroom (which has 30 terminals), where students work individually but can get help from the instructor. Students spend additional study time at a terminal on a nonscheduled basis. Thirty terminals used 60 hours per week, providing 4 hours of contact to each student, can serve 450 students. Large numbers of terminals are required to make an impact on instruction.

There are three main components of the PLATO aspects of the course: instructional lessons, homework, and an on-line gradebook. Students are assigned instructional lessons to study, and part of their grade is based on how many of these lessons they complete. Homework is graded by PLATO rather than by the instructors. The student is given printed homework problems that he is encouraged to work at home. When the student is ready, he goes to a terminal to enter his results. If the problem involves numerical quantities, each student has different numbers. A convenient calculator is always available. The student obtains a numerical score on the homework; homework scores form another basis for the course grade.

Both lesson completion data and homework scores flow automatically into an on-line gradebook. Instructors also enter other grades into this gradebook, such as exam scores and lab report scores. Each student can look at his own scores and can see his position in a graphical display of distributions throughout the course to compare how he is doing with respect to the rest of the students. Each instructor can look at and change the scores of his own students and can see scores for his section marked on the course distribution graph. The overall director of the course can look at the status of any section. One important benefit of this machinery is that an instructor can plan class activities on the basis of up-to-date information on how far students have gotten in their studies. Instructors also get rapid and accurate indications of students who are falling behind.

Just as the same textbook is used in association with many different kinds of courses, PLATO materials are integrated in various ways with other activities. The same PLATO physics materials used at the University of Illinois in the rather structured scheme described above are used at Carnegie-Mellon University in a self-paced course where PLATO instructional lessons are simply another resource for student study. In addition, the modularity of PLATO lessons makes them easy to use with diverse textbooks.

PLATO has been integrated into instruction in many other ways. For example, in language courses (including French, Spanish, German, Russian, Hebrew, Latin, and Esperanto), PLATO is used heavily to drill the student on vocabulary and grammar and to give practice in translating sentences from one language to the other. A two-semester course designed to teach students how to read Russian consists of a standard textbook plus PLATO lessons for each chapter of the textbook (*12*). This reading course is an alternative track to the general language course for undergraduates and graduate students who wish only to read Russian. Optional laboratory drills for the standard beginning Russian course are also on PLATO.

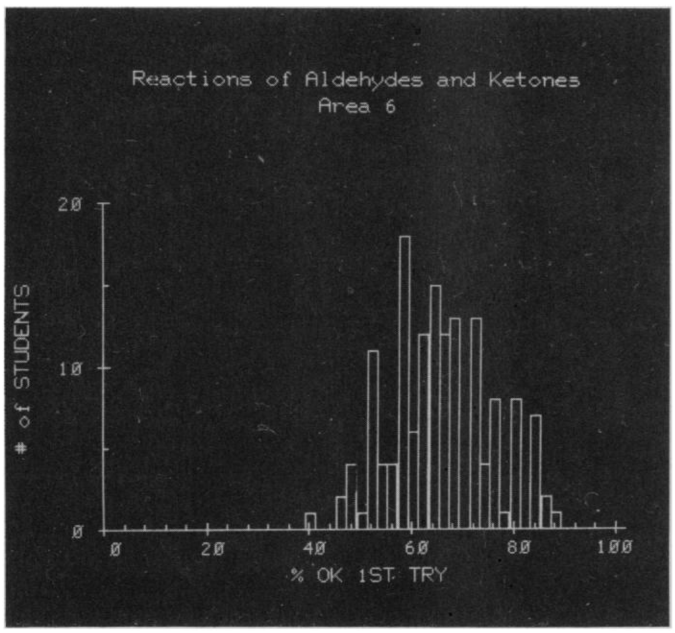
The function of the PLATO lessons is not only to give practice but also to test, with instant feedback, whether the student understands the concepts presented in the textbook. The materials are also used for review, either within the course, or by persons who want to refresh their knowledge of Russian. There is normally a class discussion before and after each textbook lesson, occurring every one-and-a-half to two weeks. The student spends the bulk of his study time at the PLATO terminal. In all areas, PLATO lessons are usually integrated with additional classroom activities. However, in such environments as continuing or adult education where, because of constraints of time or distance, the student may not be able to participate in scheduled classroom activities, a course consisting only of PLATO materials is a viable alternative.

Another important integration of PLATO into courses is illustrated by the use in chemistry of simulated laboratory experiments as a means of better preparing the student for a real laboratory experiment. Merely simulating an experiment would be inappropriate if the manual techniques themselves and not just the intellectual content are important. A PLATO lesson on the theory of titration is followed by a PLATO simulation of an actual titration, in which the student must specify all the steps, including controlling the flow from the buret, and then analyze the data. Errors made in doing the simulated experiment lead to the same problems that would be observed in the laboratory. These preparatory activities are then completed by going into the laboratory and actually performing the experiment, at a time when the student has a thorough understanding of the content of the experiment and can concentrate on the practical complications that arise. PLATO lessons may also be used to extend laboratory experience by simulated experiments which, because of limitations of time, facilities, and experimental skills, students are not able to do in the laboratory. One such example is shown in Fig. 9, which is taken from a lesson on fractional distillation.

There are ambitious curriculum development projects for reading (*13*) and mathematics (*14*) in the elementary school. Both of these projects constitute highly integrated packages of instructional materials, with automatic routing from one activity to another (based on performance) and extensive reporting to the teachers.

Writing Lesson Material in TUTOR

Lesson material for use on the PLATO system is written in the TUTOR programming language (*15*) which has been designed to facilitate the development of interactive instructional programs on a



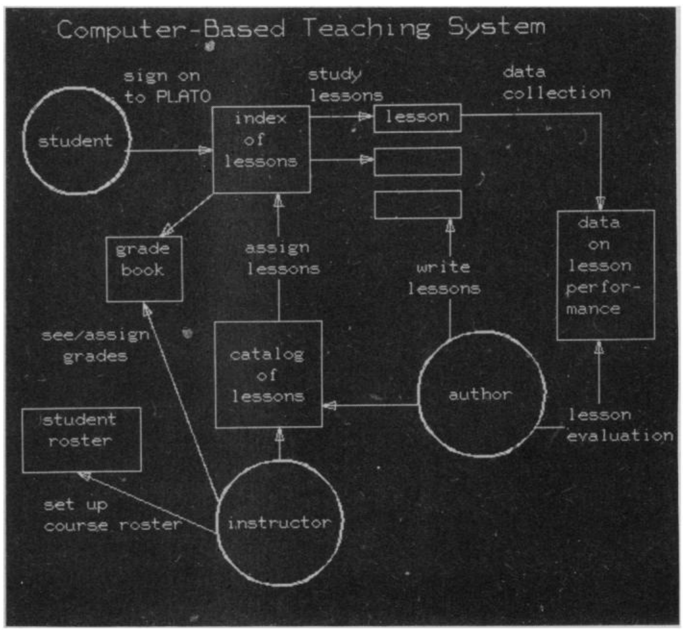


Fig. 7 (left). Histogram showing the percentage of the questions which students got correct on their first try. Fig. 8 (right). Outline of the PLATO computer-based education system. Students who have been put on the roster have access to lesson material selected by the instructor from the catalog of lessons. Students have access only to their own grades in the gradebook, which can automatically collect scores from lessons. Data related to the lesson performance are stored for review by the author of the programs.

graphic computer system. As a further aid to authors, who should be primarily concerned with the problems of teaching and not with learning about computers, professional consultants can be reached easily through a PLATO terminal. The consultant, who can be at another terminal anywhere on the system, can see the program on the author's screen and type and receive comments at the bottom of the screen. In addition, a very complete random access, cross-indexed description of TUTOR and its use is available by simply typing one of more than 2000 key words that describe the type of thing on which information is desired (*16*). The key words do not have to be spelled correctly, yet information is delivered to the requester almost instantaneously. More than 1600 such requests per day are answered by the system. A single key press returns the lesson author to the point in his work where he requested information. Another crucial feature is that an author can construct a display consisting of text and line drawings on the screen, and PLATO will generate automatically the TUTOR program corresponding to that display. The extensive on-line help for authors of lesson material makes the PLATO system a programming aid to authors as well as a learning aid to students. One result is that it takes less time to create quality lesson materials than has been typical with earlier systems.

To demonstrate some of the features of the TUTOR programming language, below is an example of the complete computer program to provide a chemistry student with a simple problem.

```
unit     reagent
at       710
write    Indicate the reagent required for
         this reaction.
at       1318
write    C6H6 → C6H5Br
arrow    1225
answer   (Fe,     FeBr3,     ferric*bromide)
         <and> (Br2, bromine)
wrong    (Br2, bromine)
write    You also need some Fe.
no
writec   ntries-2,
         This is an electrophilic bromina-
         tion.,
         Try Br2 and Fe.
```

The program says that "at" line 7 of the 32 lines on the screen, spaced over 10 of the 64 horizontal spaces, the computer should "write" "Indicate the reagent required for this reaction." Then at line 13, space 18, the chemical reaction is drawn on the screen. The command "arrow" indicates the location on the screen where the student's answer is to appear. With the "answer" command are listed the common reagents that the students would be expected to know. Words enclosed in parentheses are regarded as synonyms while words enclosed in printed brackets < > may be present in the answer but are not required to be there. The phrase "ferric*bromide" is treated as a single word. The "wrong" is an example of a typical anticipated wrong answer for which the response given in the next "write" statement will be given. The "no" followed by "writec" instructs the computer to judge the answer NO if the indicated reagents are not given and to write a message contingent ("writec") on the number of times the student has tried ("ntries") to answer the question. Here, the author has decided to first provide a clue, then a suggested correct response.

This example involved judging a student's sentence. Other TUTOR judging techniques used heavily in science lessons include judging algebraic and numeric responses, with optional dimensional analysis of answers involving scientific units.

Programs dealing with chemistry and physics often involve displaying graphs for students to interpret or plotting functions or data supplied by the student. The short program given below will plot the amplitude response of a driven oscillator as a function of the driving frequency. The student can choose the time constant associated with the damping of the system. Figure 10 shows the result of this program where the student has superimposed several graphs. The basic display components of the program, such as the positioning on the screen of the axes and the graph titles, were created automatically by PLATO; the author merely positioned these elements on the screen and PLATO created the corresponding program statements.

```
define   z = v1, c = v2
unit     resonant
origin   75,200
axes     360,250
scalex   2
scaley   8
labelx   1,.2
labely   1,.5
delta    .02
at       2252
write    ω/ω0
size     1
rotate   90
at       1505
write    Amplitude
size     0
at       2316
write    Choose a value for the time con-
         stant (in units of 1/ω0):
arrow    2720
store    c
ok
funct    1/[(z² − 1)² + (c × z)²], z
```

For accuracy in plotting, the alternative fine grid coordinate system is used in which ($x = 0, y = 0$) is the lower left corner of the screen, and (511,511) is the upper right corner of the screen. The command "origin" specifies that the origin of the plot will be at $x = 75$ and $y = 200$. The "axes" command defines the length of the x and y axes. The axes are scaled to the units of the problem by means of the "scalex" and "scaley" commands. The "labelx" and "labely" indicate how the axes should be labeled, and the "delta" command establishes an increment to be used in plotting the function. The "size" and "rotate" commands permit writing a rotated label ("size 0" restores normal writing options). The "store" command evaluates mathematical expressions typed by the student and stores the result in the variable "c." The "funct" command instructs the computer to plot the stated function of z ($= \omega/\omega_0$) for values of z within the range of the x-axis.

PLATO as a Communication Medium

The highly interactive character of the PLATO system has promoted the development of efficient communication systems between the users. These communication systems take several forms. There is a general note file where authors may ask questions or make suggestions for changes to the system. Similar forums for exchanging notes of general interest among smaller groups of users, such as all authors in a given subject area, are also widely used. Perhaps the most important communication system between users comes from the ability to send a personal note, which can be several pages long, to another individual on the PLATO system. The "letter" is delivered instantaneously to the addressee at whatever terminal he is using or uses next. Although the message is delivered immediately, it need not be answered until it is convenient. It is not at all uncommon for several exchanges of "letters" to occur across the country within a single day. On a typical day, more than 1000 such personal notes are written on the PLATO system.

If immediate discussion is desired, Smith can page Sherwood by name. If Sherwood is at a terminal (and has specified that he will accept calls), he receives a message at the bottom of the screen informing him that Smith (of the chemistry group) wants to talk to him. Sherwood has the option of accepting or rejecting the call. Smith does not have to know where Sherwood is located because the computer system can find him. If the call is accepted, the two authors can converse by typing at the bottom of each other's screens. To ensure privacy, neither author can see the rest of the other's screen unless it is explicitly offered, in which case Smith can watch Sherwood's screen (or vice versa). Being able to see what is on the other person's screen is extremely useful for discussing programming and lesson design problems. Both authors can continue to type comments at the bottom of the screen.

Computational Uses and On-Line Data Collection

The characteristics of the PLATO system which make it particularly useful for the development of instructional material also make the system a versatile computing tool in research laboratories (*17*). The TUTOR language makes it easy to write programs to do calculations to analyze the data, and special graphing commands coupled with the full graphic display facilitate accurate construction of graphs. These may be reduced to hard copy with a special terminal (made by Varian) which contains an electrostatic copier.

The introduction of experimental data from laboratory equipment is accomplished through a connector on the terminal which allows two-way communication between the computer system and peripheral equipment. Currently the PLATO system can accept an average of about three keys per second per terminal (students enter about 0.5 key per second), so the rate of transfer of data from peripheral equipment is limited to about 25 bits per second. This means that, for experiments which gather large amounts of data rapidly, a buffer is necessary between the experiment and the terminal to avoid exceeding the bandwidth of the computer system. The data can, of course, be stored permanently on the system, recalled, processed, and displayed in graphical form on the terminal.

The speed and ease of use gives the impression of dealing with an on-line computer which, however, has the extraordinary calculating and graphical capability of a very large system. It may be possible that a PLATO-like system will meet the needs of many laboratories for an on-line computer system.

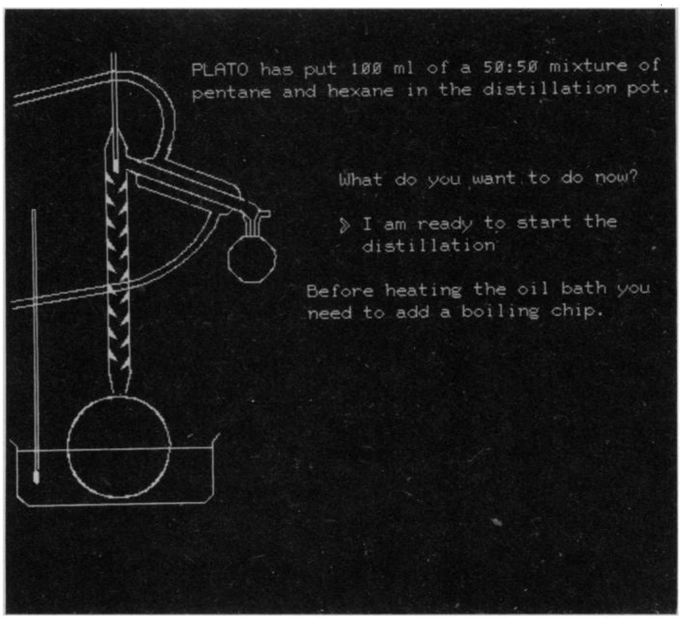
It is also possible to run standard computational jobs on the computer at the same time that interactive PLATO services are being provided. On the Urbana system this additional computational capability has been used only for internal purposes, but it is planned in the long run to make such services more generally available.

Development and Distribution of Lessons

The cost of the development of curriculum material for the PLATO system is mainly the time required by the teacher to create the programs. A college teacher experienced in the PLATO system will spend 10 to 50 hours at a terminal while creating an hour of instruction, with some additional planning time spent away from the terminal. That is, the time or money costs of producing a PLATO lesson, which is one "chapter" of a PLATO course, are probably similar to the costs of producing one chapter of a textbook (*18*). Generally speaking, curriculum costs have been much higher on other computer-based systems, but PLATO offers significantly improved aids to authors.

There has been much study of the severe problems associated with distributing educational computer programs from one institution to another. Problems include lack of compatibility from one computer system to another and lack of adequate communications among institutions. The PLATO system has finessed the problem by tying large numbers of terminals to one center, thus providing compatibility automatically and making possible extensive electronic communications. The intention is to tie all PLATO systems together to form a national grid of regional networks, thus ensuring the same level of compatibility and communications.

Accounting procedures are now in effect which log usage of lessons, both to provide authors with information on which institutions are using a lesson and to provide a basis for paying royalties to authors. If PLATO services are sufficiently widespread, a few cents per hour of use of a lesson could provide significant income to authors. This would stimulate production and make it self-sustaining without artificial subsidies. There would also be competition among similar



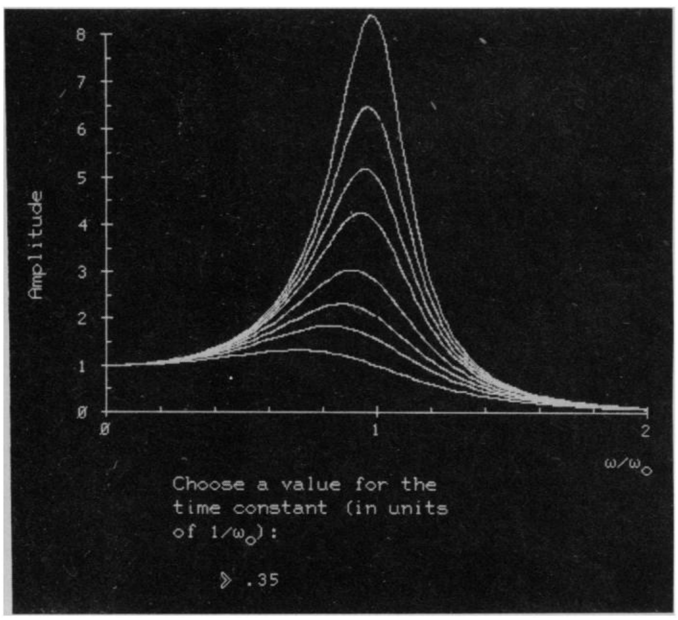


Fig. 9 (left). In a lesson on fractional distillation, the computer has reminded the student that he needs to add a boiling chip before proceeding with the distillation. Fig. 10 (right). The student can specify a damping factor and see a plot of the frequency response of a driven oscillator. The program required to produce this display is described in the text.

materials, which is extremely important. Only a small fraction of published college textbooks are considered adequate. It is likely that good computer-based materials will also be rare since similar creative processes are involved.

Electronic publishing does differ in some interesting ways from paper publishing. Often an instructor would like to pick chapters out of various books to assemble in his own preferred sequence. This is difficult with paper but easy with electronically published lessons.

Value of PLATO-Based Instruction

The value to an institution of the broad range of services offered by a PLATO system cannot be easily quantified. It is particularly difficult to measure the value of the direct instruction provided by PLATO since there is an enormous number of variables involved. It is also difficult to make a direct comparison with other teaching methods, partly because little quantitative data exist of the effectiveness of traditional teaching methods and, also, because some components of a PLATO-based course do not exist in traditional courses (one-to-one dialogues and simulations of physical phenomena, among others). Nevertheless, it is useful to summarize some basic observations about PLATO-based science instruction.

First, students do as well or better in PLATO-based science courses compared with similar courses that do not use PLATO. They turn in more work: nearly all students complete all assigned instructional lessons, and nearly all students turn in all assigned homework exercises. In a physics course on classical mechanics, 400 students taught by traditional methods and 200 PLATO students took the same 3-hour final exam. The median score of the PLATO students was slightly higher but not statistically significant, and the distributions of scores were very similar. Comparable results were obtained in the previous semester, with half as many students involved.

Second, students like PLATO-based science instruction, as reported consistently in formal questionnaires and in informal comments. Since many students have multiple contacts with PLATO-based courses, and since such courses typically involve several hours of PLATO use per week, it seems likely that student approval of science instruction with PLATO is not due simply to its novelty. Students report that they believe that PLATO instruction is helpful in learning the material.

Third, faculty like PLATO-based science instruction. Discounting the enthusiastic authors of the materials, other instructors who have had the opportunity to use PLATO materials in their courses say that they and their students find the materials useful. This is true not only at the University of Illinois but also at the many other universities and community colleges around the country where these materials are in regular use.

It must be emphasized that these encouraging results have been obtained during a period when the techniques for using this new medium have only begun to be exploited. The interactive PLATO medium is quite different from previous passive media such as movies, television, and lectures, and it may take many years to develop this new medium to its full potential.

Costs of PLATO Services

Because basic research and development costs are intertwined with the cost of providing direct instruction on the experimental PLATO system, it is difficult to estimate the cost of providing classroom instruction alone. However, the major components that contribute to the cost of the operation of the system can be identified and used as a guide to potential costs in other environments. These are the terminals (*19*), the central computer facility (*20*), maintenance, and salaries for the computer center staff. In addition, terminals that are located far from the central computer have extra costs for telephone connections, while local terminals use a microwave system (*21*). The actual cost of delivering instruction with such a system will depend on the current price of these components, the fraction of the facilities which is devoted to other activities such as batch computation, and the organization operating the system.

Although the PLATO system requires a large computer, the cost of such an installation is offset by heavy usage of more than a million terminal hours per year (*22*). Last year the average usage was 1300 hours per terminal, averaged over all terminals in many different environments. Taken as a whole, the 300 terminals at the University of Illinois averaged about 40 hours of use per week, but the two semesters last a total of only 30 weeks, and summer use by students is light. Some terminals at the University have utilization rates as high as 2000 hours per year.

The costs of establishing additional PLATO systems are also affected by rapid changes in technology. The Control Data Corporation Cyber computer in use by PLATO is basically unchanged from its introduction 10 years ago so that more modern technology could result in substantial cost reductions. The terminal, which is also a major factor in the cost, represents new technology in small-scale production, so there exists the potential for cost reductions in this area.

How PLATO Works

The terminal now being used with the PLATO system uses a plasma display panel (*7*) that has a grid of 512 by 512 electrodes at whose intersections a neon discharge can be ignited or extinguished. Text is written on these screens at the rate of 180 characters per second. Graphs and line drawings are displayed at the rate of 60 connected lines per second. Since any part of the display can be changed independently of the rest of the screen, it is possible to use animations to illustrate important concepts in lesson material. The plasma panel has inherent memory and does not require repetitive replotting of the screen as is necessary with normal cathode-ray tubes. The flat plasma panel also serves as a screen for the rear projection of color photographs that can be superimposed on text and drawings generated by the computer.

The fact that the PLATO system handles hundreds of graphical display terminals is the result of an unusual structure (*23*). In standard time-sharing systems, users' programs are swapped in and out of the computer to an electromechanical storage file (disk or drum). PLATO, on the other hand, uses Control Data Corporation's Extended Core Storage as the swapping medium. A unique operating system (which includes the TUTOR language) takes advantage of the much higher performance capabilities of this electronic memory, whose transfer rate is a hundred times faster than that of disks or drums, and whose access time is a thousand times shorter than the waiting time to retrieve information from disks or drums. This makes it possible to handle hundreds of graphical display terminals, with a response time of one-eighth second.

Summary

The PLATO computer-based teaching system provides individualized instruction to hundreds of students simultaneously. Lesson material can include natural language dialogue, graphics, numerical and algebraic responses, and color photographs. There now exist more than 3500 hours of tested materials in more than 100 subject areas. There is also a wide range of tools available for managing courses oriented to PLATO. Communications facilities include public forums, electronic mail, and on-line consulting. The system can be connected to laboratory equipment for on-line data collection and analysis.

There already exist three PLATO systems (*3*). It is expected that additional systems will be set up on a regional basis, with electronic intersystem connections to assure a high level of communication, including nationwide access to curriculum materials.

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24. Many people have made significant contributions to the development of the PLATO system described here. None of the work would have been possible without the interest and help of D. L. Bitzer, director of the Computer-Based Education Research Laboratory at the University of Illinois. The work was supported by the University of Illinois, the National Science Foundation, the Advanced Research Projects Agency, and the Control Data Corporation.

NEWS AND COMMENT

Sulfur Pollution: Charges That EPA Distorted the Data Are Examined

The charges were very serious—they impugned the professional integrity of a fast-rising government health official and the validity of a government antipollution program.

On 29 February the Los Angeles *Times* published a story asserting that a former research administrator at the Environmental Protection Agency (EPA) deliberately distorted research reports "in an effort to prove that pollution from sulfur-bearing fuels had an adverse effect on human health."

The investigative article, written by reporter W. B. Rood, pointed the finger at John F. Finklea, currently director of the National Institute for Occupational Safety and Health but previously the head of EPA's Human Studies Laboratory in North Carolina. In his former capacity Finklea was a key figure in managing the EPA program known as CHESS (Community Health and Environmental Surveillance System), a series of epidemiological studies in communities around the country aimed at determining the health effects of exposure to relatively low levels of pollutants. The program was designed to evaluate whether existing air quality standards are adequate, to obtain data for new standards that might be needed, and to document any health benefits that might result from controlling air pollution.

In the spring and summer of 1972, Finklea was in charge of preparing the early drafts of a monograph analyzing data from the first year of the CHESS program, 1970–71. That monograph, which was eventually published in 1974, purported to find that sulfur pollutants (notably sulfur dioxide and suspended sulfates) were associated with a variety of adverse health effects, including aggravation of asthma and heart and lung disease in the elderly.

The L.A. *Times* reported that "extensive interviews" with government and nongovernment scientists and others had disclosed that, in preparing this monograph,

> Dr. John F. Finklea rewrote the work of agency scientists, often deleting what the researchers felt were important qualifiers on experimental results;
>
> Finklea deleted material from the reports that did not show a connection between sulfur pollution and adverse health effects;
>
> Finklea screened statistical analyses to downplay evidence tending to weaken or contradict the case against pollution; and
>
> Finklea overrode agency scientists' objections to publishing estimates of the health impact of pollution which were either statistically dubious or unsupportable.

The article viewed the consequences as serious. "Relying heavily on the disputed CHESS studies," it said, "EPA has called for controls on sulfur pollution that would cost power companies and ultimately American consumers billions of dollars."

The evidence to support these charges consisted largely of quotes from individ-