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ABSTRACT

The development of computer-assisted instructional lessons on the following three topics is discussed: 1) the mole concept and chemical formulas, 2) concentration of solutions and quantities from chemical equations, and 3) balancing equations for oxidation-reduction reactions. Emphasis was placed on developing computer routines which interpret student answers in their normal chemical form and tell the student what, if anything is wrong with them. Among the forms of answers for which routines were developed are labeled numerical answers, chemical formulas, and chemical equations. For each topic lessons were developed in each of the following three styles: 1) instructional sequences, 2) practice problems, and 3) quizzes with forced review of week areas. The combination of the three lesson styles was successful in providing each individual student with a unique educational experience. The effectiveness of these lessons was determined by analyzing the data generated by the students while using these lessons and by comparing the exam results for students who had computer-assisted lessons with those who did not. (Author)

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AN INVESTIGATION OF THE USE OF COMPUTER-AIDED-INSTRUCTION IN TEACHING STUDENTS HOW TO SOLVE SELECTED MULTISTEP GENERAL CHEMISTRY PROBLEMS

ROBERT C. GRANDEY

Computer-based Education Research Laboratory

University of Illinois Urbana Illinois

AN INVESTIGATION OF THE USE OF COMPUTER-AIDED-INSTRUCTION IN TEACHING STUDENTS HOW TO SOLVE SELECTED MULTISTEP GENERAL CHEMISTRY PROBLEMS

BY

ROBERT CLIFFORD GRANDEY
B.S., Indiana University of Pennsylvania, 1965
M.S., University of Illinois, 1968

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Urbana, Illinois

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ABSTRACT

The development of computer-aided-instructional lessons on the following three topics is discussed: 1) The mole concept and chemical formulas, 2) Concentration of solutions and quantities from chemical equations, and 3) Balancing equations for oxidation-reduction reactions.

Emphasis was placed on developing computer routines which interpret student answers in their normal chemical form and tell the student what, if anything is wrong with them. Among the forms of answers for which routines were developed are labeled numerical answers, chemical formulas and chemical equations.

For each topic lessons were developed in each of the following three styles: 1) Instructional sequences, 2) Practice problems, and 3) Quizzes with forced review of weak areas. The combination of the three lesson styles was successful in providing each individual student with a unique educational experience.

The effectiveness of these lessons was determined by analyzing the data generated by the students while using these lessons and by comparing exam results for students who had experience with these lessons and those who did not.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

A. Nature of Multistep Problems

Problems which require the student to use several steps or a combination of concepts are among the most difficult for beginning chemistry students. If the student does not understand the use of any one step in the sequence he may fail to see a path from the given data to the desired results. The difficulty at any one step can be of two types: either the student can't do the manipulation required or he doesn't understand the purpose of the step. The very nature of these problems presents two tasks for the educator: 1) to make sure that the concept of each step is understood and 2) to make sure that the student understands the relationship of the steps.

The most common teaching procedure is to work a few examples in lecture and then to assign homework problems. If students do not understand the concepts and procedures presented during the lecture, there is little hope for them to get help. Many students will hesitate to interrupt the lecture by asking questions while examples are being done. They may be discouraged by the lecturer or may fear incurring the disgust and ridicule of their fellow classmates. Others may boldly ask questions often and the instructor will be faced with the decision of taking valuable class-time away from the majority of students in order to answer one student's question or of giving a quick and incomplete answer and continuing with the example. Because the instructor is usually required to maintain a prearranged schedule of topics he often can't afford the time to answer many questions in class.

As a result quite a few students may become confused and frustrated during the lecture period and be lost for the remainder of the lesson. A student may elect to talk to the instructor during his office hours or to ask questions during the quiz section, but he may find that the instructor will be available only when he, the student, has other commitments or that a number of students are seeking help during the office hours or quiz section and again there is no time for his individual questions.

When doing his homework problems, the only aid available to the student is a worked out example in his textbook or lecture notes or a friend who understands the procedure and is willing to spend his study time helping to do the problems. Those without such friends or those who have friends that are too busy are often out of luck. Thus it is quite possible for a student to be so confused that he cannot attempt to solve the problems, or if he misunderstands any step he may do all the problems with the same misconception and thus make similar errors on all his homework problems. The student may not realize that he has made any errors until his graded homework is returned to him several days later. By this time the error may be a habit.

Because the students have trouble with different concepts and procedures, what is really needed is an individual tutor for each student: a tutor that can present the concepts and procedures of each step in detail; make sure that the student understands each step before continuing to the next; provide encouragement when the student is correct; decide where the student is having trouble and provide help, hints, and needed review; tell the student why his answer is wrong; and in general make sure that the student doesn't reach a point from which it is impossible for him to continue.

B. Programmed Instruction Strategies

The use of programmed instruction in the form of texts and audio-tutorial tapes has been valuable in developing procedures for presenting material in small steps, allowing students to proceed at their own rate. The term programmed instruction has traditionally implied three necessary characteristics: 1) material is presented as a sequence of small units or frames, 2) students actively respond to questions, and 3) after responding, students are immediately informed of the correct answer. The idea that students learn by making an active response to a stimulus was proposed by Pressey in the 1920s but remained dormant until revived by B. F. Skinner, a Harvard psychologist, in the 1950s. Skinner believed that a student's knowledge that his answer was correct would act as a positive reinforcement, and as a result programs were expected to be effective if they produced low student error rates. Norman Crowder conceived the idea that the program sequence could be dependent upon the individual responses of the student and thus the sequence of frames could be different for those who made different errors on criterion problems. To control the branching he used multiple choice questions which contained common logical errors as possible answers.[11,14,16,21,37]

A series of guidelines concerning how to write individual frames, including types of prompts, criterion questions, and editing have been the result of much educational research.[7,11,21,28,37,38] In addition to procedures for writing individual frames, strategies for presenting material have been developed. These include: 1) presenting a rule or example and then drill concerning it, 2) presenting examples and leading the student to develop the rule, 3) presenting new material as an extension of old material, and 4) presenting a simple idea and then extending it to more complex situations.[19,21,22,37]

Although programmed instruction is often called tutorial instruction, in the form of texts and audio-tutorial tapes it lacks the ability to be truly responsive to the student. For example, if the student is required to write an answer and to compare it with that of the author all he knows is that his answer does or doesn't match. There may be several different forms of the right answer but the author will most likely include only one or two. The student is left to make the decision of whether his answer is close enough to be considered correct. Even if the author includes a brief explanation of the correct answer, the student may not be able to decide specifically what he did wrong. If the question is multiple choice, it is possible that the student will arrive at an answer that isn't in the list and then not know what to do about it. This is particularly true if the question involves several mathematical steps.

Unlike a tutor, programmed instruction in the form of texts or audio-tutorial tapes provides no means of interpreting a student's answer. If the student's response is not among those listed by the author, he cannot be shown why his answer is incorrect, nor can help or review be provided. There is no opportunity for the student to correct his own error on the basis of a hint provided by the program. With text programmed instruction the sequence of instruction can be determined only on the basis of the results of a single question; there is no way to make the sequence determining decisions on the basis of the results of several questions dealing with the same concept.

C. Computer Capabilities

The digital computer system's ability to store data and to be programmed to make decisions makes it a logical tool for achieving true individualized tutorial instruction. The computer can be programmed to interpret a student's answer, determining whether it is correct or not, and if not, what is wrong with the answer. Computer controlled programmed instruction becomes responsive to the student's activity when decisions about the program sequence are made on the basis of the analysis of results of one or more questions. Thus it is possible to program the computer to act much like a tutor, giving students hints and specific help with individual problems and wider concepts.

Because the computer can be programmed to manipulate the student's answer, analyzing it for proper form and content, it is not necessary to list all the possible or most probable correct answers or errors to provide specific feedback to the student. To be most effective as a tutor for chemistry lessons, the computer must be able to accept input from the student in the same form as the student would normally use when writing on a piece of paper. There must be no constraints in the way chemical symbols and data can be presented. The computer must be able to quickly interpret the student's input and provide a variety of types of feedback.

Recent publications of the uses of computers to simulate chemical laboratory experiments and to aid in the instruction of chemistry problem solving indicate that the computer holds promise for the development of new strategies for teaching.[33,36,42,44]

II. STATEMENT OF THE PROBLEM

This research was designed to be a general investigation of the use of a computer-aided-instructional system in the teaching of chemistry material, particularly for the solution of problems which require several steps.

Of special interest is the development of programs which enable the computer to 1) interpret typical forms of chemistry lesson materials such as numerical data including appropriate labels, chemical formulas, and equations, and 2) control teaching strategies which are generally difficult or impossible to apply in other methods of instruction.

An effort will be made to evaluate the overall effectiveness of the lesson materials developed as a combination of teaching strategies.

It is hoped that the uses of the computer and the techniques developed in this study will be of such a general nature that they can be used extensively in future research and instruction.

III. PROCEDURE

A. The Computer System

The materials used in this study were prepared and used on the PLATO III system at the Computer-based Education Research Laboratory at the University of Illinois.[4,5] The system consisted of a CDC 1604 computer, a student terminal containing a cathode ray tube and a keyset, a slide selector for photographic material, a storage device to maintain the display, and peripheral equipment such as disk drives on which lesson materials were stored, tape units on which student data was collected and a line printer on which authors made hard copies of their materials (see Figure 1).

The system could accommodate twenty people at a time; any terminal not in use by a student could be used by a lesson author. It was possible to super-impose computer generated graphics and photographic materials.

In addition to the regular characters available on a standard typewriter, the PLATO keyset provided a number of characters which are of special interest to chemists. These included subscripts, superscripts, plus, minus, arrows right ($\longrightarrow$), left ($\longleftarrow$), and equilibrium ($\rightleftarrows$), and a large portion of the Greek alphabet. As shown in Figure 2, in addition to the keys which plotted characters on the terminal screen, the PLATO keyset contained a number of clearly marked keys which the students used to initiate the judgment of their answers or the erasure of them, to request help, additional information, definition of terms or the correct answer, and to go back to previous material. The conditions under which these keys were operational and their results were specified in the computer program developed by the lesson author. Appendix A contains the written instructions given to each student when he arrived at the PLATO classroom.

The materials used in this study will also be used on the new PLATO IV system presently under construction. The new system will replace the storage device and cathode ray tube of PLATO III with a plasma panel and

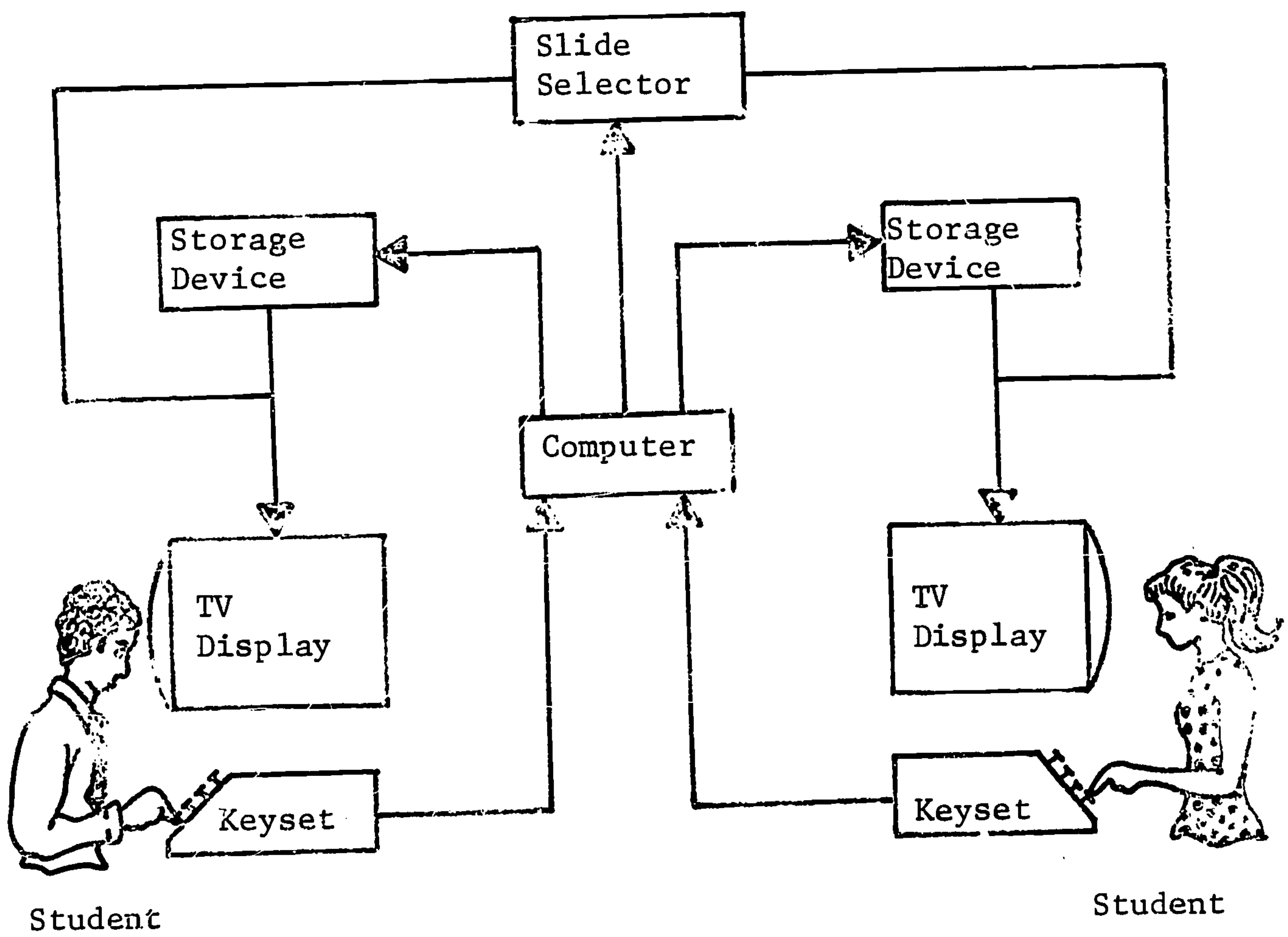


Figure 1. Equipment Diagram for PLATO

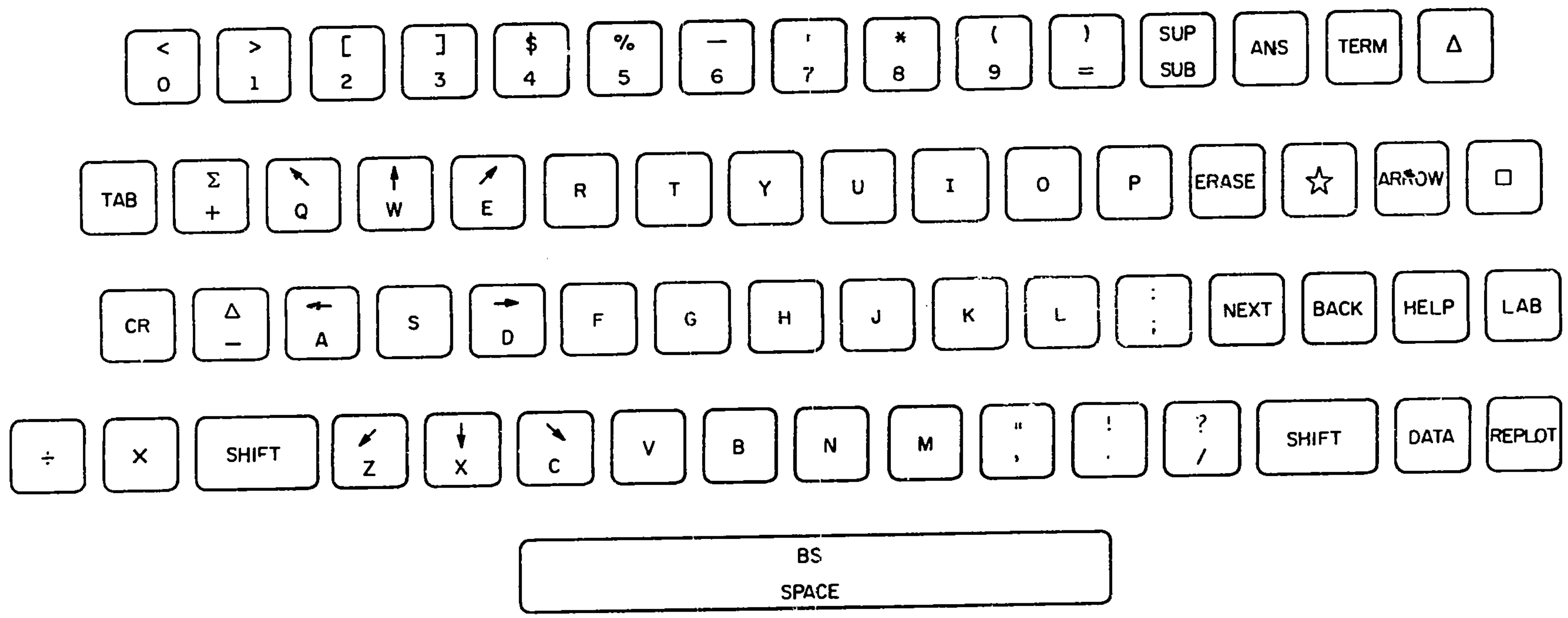


Figure 2. Standard Keyboard

will be capable of providing instruction to as many as 4000 students.[6]

B. Lesson Development

1. Selection of Topics

The following three topics, all of which involve solving a complex problem by following an orderly sequence of steps, have been chosen for this study: 1) Determination of chemical formulas, 2) Calculation of concentration of solutions and quantities from chemical equations, and 3) Balancing equations for oxidation-reduction reactions. These topics were chosen because they are among the most difficult for beginning chemistry students and because the form of answers to questions on these topics include most of the characteristics that are typical of many chemistry lessons and are different from the usual English language. Special routines have been developed to interpret numerical answers including a tolerance and unit label and to interpret answers in the form of chemical formulas and equations (see page 16).

In an effort to eliminate any mathematical deficiencies a separate lesson was prepared in the form of a diagnostic quiz on mathematical skills necessary to solve these problems (see Appendix B). The student was forced into an instruction and practice section on any skill for which he missed more than 40% of the questions on the quiz (one or two problems). The topics included multiplication of fractions, conversion factors, percent, and ratios. The student was able to choose to work any section in which he felt additional review was needed.

2. Purpose of the Lessons

The purpose of the chemistry lessons was to provide an individual tutor for each student by presenting new material, making sure the student didn't get frustrated by giving him specific help when he had trouble, aiding the student with a series of practice problems, in some cases even problems supplied by the student, and analyzing the student's progress and providing review of weak areas.

The lessons for each topic were developed in each of the following styles:

1) instructional sequences
2) practice problems
3) diagnostic quizzes

The central theme of the presentation of material to students who were unfamiliar with the topic was to get the student actively involved in the development of the procedure needed to solve each problem. At the beginning of each instructional sequence, the student was told the purpose of the problem and the form of the available data. He was then guided through at least one complete problem before he was shown a list of steps. Unlike most textbooks, the student was not shown a completely worked out example.

Emphasis was placed on the concept and purpose behind each step as well as the relationship between the steps. At all times the student was cautioned to observe what information was known and what he was trying to determine. In most cases when a mathematical conversion was involved, the student was required to use a conversion factor. For example, when determining how many grams of sulfuric acid are needed to react with sodium chloride to produce 3.65 grams of hydrogen chloride, the student was required to convert 3.65 grams of hydrogen chloride to moles of hydrogen chloride. He was shown the following display and required to fill in the space at each of the three arrows:

$$3.65 \text{ g HCl} \times \frac{\rightarrow}{\rightarrow} = \rightarrow \quad \text{moles HCl}$$

The correct answer was a conversion factor of the form:

$$\frac{1 \text{ mole HCl}}{36.5 \text{ g HCl}} = 0.1 \text{ moles HCl}$$

The material in the instructional sequences was designed to be used by students who wished to review specific areas as well as by those who had no previous experience.

The lessons in the style which permitted students to practice solving problems provided specific help for students who had trouble. The student was encouraged to solve the problem on his own and to type his final answer. If he requested help he was either shown a list of steps as for balancing oxidation-reduction equations or he was actually guided through the problem step by step. At any point in the help sequence the student could return to the original problem and type the final answer. In the lessons on chemical formulas and quantities from chemical equations, the students were able to supply their own problems.

The quizzes were designed to permit the student to determine how well he understood the material and to provide help with any weak areas. After each quiz the student was shown his score and was forced to review any weak areas. The review consisted of either help with the quiz problems that he missed or material from the instructional sequence which was related to the weak areas.

3. General Strategies for Presenting Material

Because of the multistep nature of the selected topics, many of the educational strategies developed by research in programmed instruction for presenting new material were combined with the unique capabilities of the computer. For example, when solving for the chemical formula from the percentage composition by weight, the mole concept was introduced by presenting the laboratory analysis of a compound as 75% carbon and 25% hydrogen. The student was asked to predict from a list what the formula would be. Most students predicted C_3H, then were told that the only way that could be correct would be if the atom ratio were the same as the weight ratio. This would be possible only if the atoms of hydrogen and carbon had the same weight, which they do not. Thus the need for the mole concept was illustrated before it was introduced.

Other new concepts were introduced as extensions of previous material. For example, the concept of expressing the concentration of solutions as molarity, which is the number of moles of solute per liter of solution, was introduced by first asking students to calculate the weight of one mole of sodium hydroxide (40 grams), a task with which they were familiar. Then they were asked how many moles of sodium hydroxide would be in a solution which contained 40 grams of sodium hydroxide in enough water to make one liter of solution. The use of molarity as a conversion factor to convert moles to volume of solution or volume of solution to moles was then stressed by several problems.

Another method of introducing new steps was to start with a simple illustration and to allow the student to expand the concept. For example, most students were able to grasp the concept of balancing simple equations rather easily. The knowledge that the coefficient represents a mole ratio was easy to understand. Armed with this information, the student then realized that the original and final data for quantities from a chemical equation problem can be in any units which can be converted to moles. Thus the procedure for solving problems involving data given in concentration of solution, grams, or liters of gas was developed by combining prior knowledge (i.e. the conversion to moles) and the newly learned concept of determining the mole ratio from the balanced equation.

After completing a problem, the student was occasionally required to begin a sequence which extended the concepts, such as in the extension from simplest chemical formulas to molecular formulas. In other cases the student was asked to solve additional similar problems, often with less and less guidance through the steps or he was asked the purpose and sequence of steps for a given situation.

If a student had trouble with these lessons, an effort was made to help him by providing hints, detailed explanations, examples, review of previous steps or guidance through problems in smaller steps. For example, when the student was asked to convert grams to moles, he was either reminded that the atomic weight was needed or was shown how to use a conversion factor.

If students had trouble determing the formula for phosphorus(V) oxide from the mole ratio they were guided through the problem in smaller steps, while those who had difficulty calculating the formula weight of compounds such as sulfuric acid, sodium chloride, or teflon were guided through similar calculations for potassium phosphate and then forced to return to the original problem.

4. Computer-based Strategies

Although the above strategies for presenting material have been used in several educational media, the capability of the computer to be programmed to interpret the student's answer and to make decisions on the basis of a combination of data provides more flexibility in giving the student specific help and guidance.

The computer was programmed to analyze a student's response in the form of chemical formulas and determine what was wrong without matching it against a list of logical errors. For example, if the student typed "Ca_3Cl" for the formula of calcium chloride, $CaCl_2$, the computer was able to determine that both calcium and chloride were in error.

The computer's ability to be programmed to permit the student to have more than one attempt at the same question allows the number of incorrect attempts as well as the type of error to be used to make a sequence determining decision or to determine the type of help the student needs. In the lesson on chemical formulas, the students were required to determine the simplest formula of phosphorus(V) oxide from the mole ratio. On the first two unsuccessful attempts the student was told what was wrong with his answer and was given a chance to try again, while after the third unsuccessful attempt he was guided through the problem step by step.

Decisions were made on the basis of previous data as well as on the results of the most recent question. In the first multistep problem of the lesson on chemical formulas the students who made four or more errors converting their data from weight to moles of atoms were forced to review the use of moles as a conversion factor, but the review was delayed until after they had completed the remainder of the steps and determined the formula of the compound.

The ability of the computer to store information makes it an ideal medium for administering diagnostic quizzes. For the diagnostic quizzes in this study the computer was programmed to permit a limited number of attempts at each question, to determine the type of response to be made for incorrect answers, and to determine the student's review sequence after the quiz. The student was usually given two chances per problem unless the question was the multiple choice type; then only one chance was permitted. The student was shown the correct answer to the questions he missed only on the quiz on balancing oxidation-reduction equations.

Because the computer can make decisions on the basis of the results of several questions, it was possible to include a number of questions dealing with the same concept, compare the student's results with a set achievement level, and decide if review of that concept was needed. The review sequences for math skills and chemical formulas consisted of material that was not in the quiz while the review for concentration of solutions and quantities from chemical equations involved receiving help with the same quiz problems that the student missed.

In addition to providing unique strategies for presenting material and analyzing student's abilities, the computer was programmed to actually solve chemistry problems. Once the computer had been "taught" how to do the chemistry problems, the student was permitted to supply his own problems in addition to those supplied by the author. Thus to each student the computer appeared to act like a teaching assistant during office hours giving him individualized assistance with his own problems.

C. Program Development

A computer-aided-instruction lesson involves two interrelated aspects: the lesson content including the teaching strategies and the computer program which controls the operation of the lesson. The computer program specifies the rules for the presentation of material, the acceptance of answers, the interpretation of student responses, and the control of feedback. In this study, emphasis was placed on developing general routines which enable the computer to act like a chemist. Once these routines were written, they were used over and over again in specific lessons. Execution of each routine by the computer was fast, taking less than one second even when the classroom was occupied by twenty students at the same time.

1. TUTOR Language

The programs developed in this study were written in a computer language, TUTOR, developed by the staff at the Computer-based Education Research Laboratory at the University of Illinois for a computer-based educational system utilizing graphical screen displays.[3] This language was designed to be easily used by a lesson author who is an authority on his subject matter and who has a feel for the teaching strategies which will be most useful, but knows little of the interworkings and intricacies of the computer. An effort has been made to impose few constraints on the way the author uses this language, thus permitting him to concentrate on the specific nature of the lesson content and teaching strategies.

The language presently consists of more than eighty commands each of which designates a system-level routine that performs a specific function. The system-level routines were designed to do complicated things that are useful in many lessons. By using the appropriate command, the lesson author can tell the computer to perform a complex function without the author having to know how the computer does it. For example, to have the sentence "What is the chemical formula of amonium sulfate?" appear on the screen the author types the command WRITE, and then the sentence. A system-level routine then does all the work required to display that sentence on the screen. Similarly, by using another command, SEN, the author can specify how the student's answer in the form of a sentence is to be judged. The author simply types the command and the words that a student's answer must contain, those that it cannot contain, and those that are not necessary but permissable. A system-level routine interprets the student's answer and automatically provides the following feedback: If the student's answer does not contain all the required words, the letters IC for incomplete are placed beside the answer, while if the student includes words that are not permitted, the computer places slashes through the unacceptable words. By using the additional commands SPELL, ORDER, and NODUP, the author may specify that the computer underline misspelled words, indicate words that are not in the correct order and note if the answer is a duplicate of a previous one.

Although each of these commands is general in nature and can be used in a number of different lessons in different subject areas, by combining the commands in the appropriate sequence the lesson author can design his own specific routines.

2. Routines for Judging Students Answers and Providing Standard Error Messages Related to Chemistry

To be an effective chemistry tutor the computer must be programmed to analyze a student's response not only in the normal English language but also to interpret it as a chemist would. It must be able to determine specifically what is wrong with a student's answer as well as whether it is correct or not. For example, if the student types NH_3OH for the formula of ammonium hydroxide, he should be told that the hydrogen is not correct and not that he has a misspelled word.

The answers to questions in chemistry lessons are often in particular forms that are specific to chemistry. Emphasis was placed on developing routines that would permit the student to communicate with the computer in the same form as he would with an instructor. Routines were developed that could be easily used by the author to provide a large amount of feedback to the student and still place no artificial restraints on the form of the student's answer.

In order to judge a student's answer as a chemist would, these computer routines were written to extract specific information from the answer. Thus in addition to judging a student's answer, the author was able to use part of these routines to simply translate data from a chemical form to a form that could be used by the computer.

The following routines are representative of those developed:

a. Numbers ± tolerance (NUMJUDG)

Often answers to chemical questions are numerical in form and may be the result of several calculations. Thus it is imperative to permit a student's answer to be judged correct if it is within a specified tolerance of the correct value. It is also desirable to tell the student whose answer is not within the prescribed tolerance whether his answer is too high or too low.

When the development of these lessons began, the only way to determine if a student's numerical answer was correct by using a single system level routine was to directly match it with a list of answers supplied by the author. If a student's response between 14.4 and 14.8 (14.6 ± .2) was to be judged correct, and if he used only three significant figures, the author's list would contain the following five entries: 14.4, 14.5, 14.6, 14.7, 14.8. When the student was required to use four significant figures and the correct answer was 14.63 ± .20, the list of acceptable answers would contain forty-one entries: 14.43, 14.44, 14.45, . . . , 14.83. If the author permitted the student to use either three or four significant figures the list would be forty-six entries long. A larger tolerance would require even more entries.

It was clear that an easy to use routine was needed to do the calculations to determine whether or not the student's answer was within the proper range, and if not, whether it was too high or too low. The routine called NUMJUDG was developed to perform this function. It required the author to list only the correct answer, the permitted tolerance, and the position on the screen for the error message.

When a student's answer was judged by this routine, a counter was set to 0 if the answer was correct and to -1 if it was incorrect. This counter could then be used to control additional functions which were contingent upon the student's answer. For example, depending on the value of the counter, a student could be given a hint or additional help, or be congratulated for getting the correct answer. This counter could also be used to keep scores and in the making of sequence determining decisions.

This routine has found such general use in fields other than chemistry that with the exception of the information concerning the direction of error, it has been made a system-level routine under the name of ANSV.

b. Number ± tolerance in Scientific Notation (EXPJUDG)

Although the routine NUMJUDG judges numerical answers and was used extensively in many areas, it does not permit the use of scientific notation nor does it provide specific error messages for decimal errors. The routine EXPJUDG was developed for this reason. It, like NUMJUDG, in addition to providing student error messages returns a counter which can be used to control other functions.

In this routine the author was required to specify only the power of 10, the coefficient between 1 and 10, the tolerance, and the position of the error message on the screen. He had the option of permitting the student to use coefficients less than one and greater than 10.

For the answer 6.02×10^{23}, the author specified a tolerance of .01, a power of 23, and a coefficient of 6.02. Table 1 shows the judgment and feedback for some student responses in the two cases a) where proper scientific notation form was required, and b) when any answer equivalent in value to the correct answer was permitted.

c. Combination of Numerical Answers and Appropriate Labels (GRAMS, LITERS, MOLES, etc.)

Many times in chemistry lessons students are required to include units with their numerical answers. If the author had to list all the possible correct answers, he would have to list each correct numerical answer with each possible abbreviation for the correct units. For example, if the correct answer was $14.63 \pm .20$ grams, the author would have to list each of the forty-six acceptable numerical answers with each of the ten forms of the unit (gram, grams, g, g., gm, gm., gs, gs., gms, gms.) for a total of 460 entries.

An attempt was made to treat this as a two word sentence, with the first word being the number and the second the units. The system-level routine which was designed to judge sentences required separate lists of all the synonyms for each word. Any student response which used one word from each list was considered a correct answer. To use this routine for the above example, a list of the forty-six numerical values was provided along with the list of the ten abbreviations for grams. However, the computer interpreted the student's answer as a three word sentence with the decimal point separating two words, thus requiring three lists: A list with the single entry of fourteen, another with the forty-six possible numbers after the decimal, and a third containing the abbreviations for grams. To prevent 63.14 grams and other answers with the two parts of the numerical answer interchanged from being judged correct, the additional command ORDER was used. However, this attempt also failed because many students did not put a space between the number and the abbreviation for grams, thus the computer interpreted their answer as two words: 14 and 63grams.

This problem was solved by writing routines which used a combination of the system-level routine to determine if the units were correct and

Table 1. Examples of Student Responses and the Resultant Judgment and Feedback Provided by the EXPJUDG Routine

a) Proper scientific form required $(6.02 \pm .01) \times 10^{23}$

Response	Judgment	Feedback
6.02×10^{23}	ok	very good
6.03×10^{23}	ok	very good
6.02×10^{24}	no	your power of ten is wrong
6.05×10^{23}	no	your answer is too high
6.00×10^{23}	no	your answer is too low
60.3×10^{22}	no	improper form of scientific notation
0.603×10^{24}	no	improper form of scientific notation
0.604×10^{24}	no	improper form of scientific notation

b) Any answer equivalent in value to the correct answer, $(6.02 \pm .01) \times 10^{23}$

6.02×10^{23}	ok	very good
6.03×10^{23}	ok	very good
6.02×10^{24}	no	your power of ten is wrong
6.05×10^{23}	no	your answer is too high
6.00×10^{23}	no	your answer is too low
60.3×10^{22}	ok	very good
0.603×10^{24}	ok	very good
0.604×10^{24}	no	your answer is too high

either NUMJUDG or EXPJUDG to judge the numerical part. This combination provided all the standard error messages of NUMJUDG and EXPJUDG, plus specific messages when the student failed to include units or when the units were incorrect.

To use these routines the author simply specified the information needed for NUMJUDG or EXPJUDG and the name of the unit routine he desired (GRAMS, LITERS, MOLES, etc.). The author was able to also supply additional words that were to be permitted or required in the student's answers; thus a student's answer, 14.63 grams of carbon, was judged to be correct if the lesson author had specified the number, 14.63 $\pm$ .20, the additional words of, carbon, atoms, and used the routine called GRAMS.

A similar routine called WTUNIT was written to accept a student's answer in any valid unit of weight. The author specified the answer in grams, and this routine then determined the units specified by the student, converted the student's numerical answer to what it would be in grams, and then used NUMJUDG. For example, for the question "How much does one mole of zinc atoms weigh?" the author specified 65.4 $\pm$ .1 grams and a student response of 654 decigrams or 0.0654 kg or any other equivalent answer was judged to be correct. Similar routines could be developed for volume and length.

d. <u>Chemical Equations for Form and Balance (EQTJUDG)</u>

When balancing equations, it is important that the students write the correct chemical formulas as well as the correct coefficients. Capitals, subscripts, superscripts, parenthesis, and arrows were available on the PLATO keyset so that anytime a student was asked to type an equation, it looked just as it would in the chemistry classroom, or in any chemistry textbook or on the student's homework paper.

Because chemists write equations in a very specific form, there are certain rules with which a balanced equation must comply and these rules can be programmed into the computer. Thus the computer can be "taught" the requirements for any balanced equation. After the computer has been programmed to automatically detect all errors in format and all unbalanced elements, it can provide far more feedback to the student, in the form of error messages, than the lesson author could possibly list. To have the computer determine if a student's chemical equation is correct for a given reaction, the lesson author would need only to specify the specific species required (see page 26).

A routine, EQTJUDG, was written to interpret any chemical equation, determining not only if it was balanced by both mass and charge, but also if it was in the proper form according to the following rules:

1. Only valid chemical symbols are permitted
2. All coefficients must be immediately followed by a valid chemical symbol
3. All parenthesis must be immediately followed by a subscript
4. All subscripts must be integers
5. All superscripts must include a + or - sign
6. All superscripts can contain only integers and + or - signs.

A violation of any of the above format rules was indicated by the proper error message, such as "improper chemical symbol", "improper use of subscripts", or "improper use of parenthesis". The student was shown a list of any elements that were not balanced and was also told if the charge was not balanced.

In addition to judging if the equation was balanced, the routine also determined which elements were in the equation, and if they were unbalanced, on which side the excess occurred and how large the excess was.

In keeping with the philosophy that no artificial restraints should be placed on the student, this routine did not require any specific spacing. Charges could be written as superscripts with the number preceding the sign, the sign preceding the number, or as a string of signs. Thus, when superscripted +3, 3+, and +++ were accepted as equivalent. The student could use a mixture of these forms in the same equation. All proper forms of chemical formulas were permitted, including hydrates. Thus this routine interpreted 12 $CuSO_4.5H_2O$ as containing 12 copper atoms, 12 sulfur atoms, 108 oxygen atoms, and 120 hydrogen atoms. This routine also permitted the use of arrows pointing upward to indicate gases and arrows pointing downward to indicate precipitates. The use of e^- to designate electrons was permitted so that oxidation-reduction half equations could be judged. Equations containing any of these three types of arrows were permitted: $\rightarrow$, $\leftarrow$, $\rightleftarrows$.

The following are some examples of equations that were judged to be correct:

a) $2\ H_2 + O_2 \rightarrow 2H_2O$

b) $O_2 + 2H_2 \rightarrow 2H_2O$

c) $H^+ + OH^- \rightleftarrows H_2O$

d) $H^+ + OH^- \rightleftarrows HOH$

e) $CuSO_4 . 5H_2O \rightarrow CuSO_4 + 5H_2O$

f) $2H_2O \rightarrow 2H_2 + O_2$

g) $Cr_2O_7^{-2} + 14H^+ + 6I^- \rightarrow 2Cr^{3+} + 3I_2 + 7H_2O$

The following are some examples of equations that were judged to be incorrect and the error message displayed to the student:

Equation	Error message
a) $2Hy_2 + O_2 \rightarrow 2HyO_2$	Improper chemical symbol
b) $2H_2O + O_2 \rightarrow 2(H_2O)$	Improper use of parenthesis
c) $H_2 + O_2 \rightarrow 2H_2O$	The following are not balanced: H
d) $2H^+ + OH^- \rightarrow H_2O$	The following are not balanced: H charge

The equation judging routine worked in the following way. The equation with all spaces removed was searched character by character from left to right. The search stopped immediately with the first occurrence of any violation of the format rules (see page 21) and the appropriate error message was displayed. If there were no format errors the search continued through the entire equation and all elements which were not balanced were determined.

Two lists of information were generated in the computer by this routine, one containing the symbols of the elements and another containing the corresponding count of the atoms. Each time an elemental symbol was found in the equation a check was made to see if that element had been found before. If not, a new entry was made in the list.

The elements that were not balanced were determined by keeping a running total of the number of atoms of each element; counting the occurrence in the reactants as positive and those in the products as negative. If the equation was balanced the final value of the counter for each element was zero. The number of atoms of each element was calculated just as the student would by multiplying together the values of the coefficient, subscripts, and subscript after the parenthesis. Before adding this value to the running total for the element, the number of atoms was multiplied by +1 if found on the reactant's side and by -1 if on the product's side.

Thus to count the number of atoms, four variables were needed: one each for the coefficient, subscript, subscript after a parenthesis, and one to indicate the side of the equation being searched. In the absence of a coefficient, subscript, or parenthesis the value of the appropriate variable was set equal to 1.

For example, the equation $2NH_4OH + H_2SO_4 \longrightarrow (NH_4)_2SO_4 + 2H_2O$ was interpreted in the following way. The variables for the coefficient, subscript, and subscript after a parenthesis were initially set to 1 and were changed only when an appropriate character was found. The value of the variable designated for the coefficient was then changed to 2 and the capital N was found. The next character was examined to see if it was an a, d, e, p, i, or b, characters which would have made a valid two letter symbol of an element starting with a capital N. Finding that the next character was not one of those letters but a capital H indicated that the first located symbol of an element was the valid symbol for nitrogen. The capital N was placed in the first spot in the list of elements and the number of nitrogen atoms was calculated by multiplying the coefficient, 2, times the value of the subscript 1, and the value of the subscript after a parenthesis, 1, and the value of the variable indicating that this was the reactant's side of the equation.

The next elemental symbol found was that for hydrogen. After determining that it was a valid symbol, the list of elements already found (N) was searched to determine if any other hydrogen had been found. Failing to find any additional hydrogen in the list, the symbol H was placed in the second spot in the list of elements. The value of the variable for subscripts was changed to 4 and the number of atoms of hydrogen, 8, was calculated in the same manner as those of nitrogen. At this point the two lists in the computer looked like this.

Elements	Number of atoms
N	2
H	8

When the symbol for the next element, oxygen, was found the value of the variable designated for the subscript was reset to 1 and a similar procedure was used to add the oxygen to the list of elements.

When the symbol of the next element, H, was determined, it was found that hydrogen was already in the list of elements, thus the number of atoms calculated at this point, 2, was added to the number of atoms already found, giving the following lists:

Elements	Number of atoms
N	2
H	10
O	2

The value of the variable designated for the coefficient was then reset to 1 when the plus sign was found and the search continued in the same way until the arrow was found. At this point the list contained the count of the number of atoms of each element in the reactant's side of the equation:

Elements	Number of atoms
N	2
H	12
O	6
S	1

When the arrow was found the variable indicating the side of the equation being searched was changed to minus one, the other three variables were set to 1 and the search continued. After finding the left parenthesis, a special search was made for the right parenthesis and when it was found, the value of the appropriate variable was set equal to the value of the following subscript, 2. The original search then continued as before, finding the capital N, verifying it as a valid chemical symbol, calculating the number of atoms and then multiplying that value by -1 because the capital N, was found on the product side of the equation. The list of elements already found was searched for N and the number of nitrogen atoms was decreased from 2 to 0.

The search continued in the same way until the right parenthesis was encountered again and then the value of the variable designating the subscript after the parenthesis was reset to 1. When the search reached the plus sign between $(NH_4)_2SO_4$ and $2H_2O$ the list of information looked like this:

Elements	Number of atoms
N	0
H	4
O	2
S	0

When the search indicated that there were no more characters the values of the number of atoms of each element was checked for any that were not zero:

Elements	Number of atoms
N	0
H	0
O	0
S	0

In this case all were zero, the equation was judged to be properly balanced, and the student was congratulated.

When the routine EQTJUDG was used to interpret the unbalanced equation $H_2 + O_2 \rightarrow H_2O$, the following lists were generated:

Elements	Number of atoms
H	0
O	1

In this case the equation was judged incorrect and the student was told that oxygen was not balanced. The additional information that the excess oxygen was on the reactant's side and that the excess was one atom was readily available to the author.

If superscripts were used to indicate charged ions, this routine was able to determine if the charge, as well as the mass, was balanced. When the superscripted 2 was found in the following equation, $FeBr^{2+} \rightarrow Fe^{+3} + Br^{-}$, a search was made for a superscripted plus or minus sign, the word charge was entered in the same list as the symbols for the elements, and the value of the charge, +2, was placed in the corresponding place in the same list as the count of the number of atoms. The charge found on the product side was treated in the same way after being multiplied by -1. If there had been a coefficient preceding any of the ions, the total charge would have been calculated as the product of the coefficient and the value of the superscript.

e. Chemical Equations for Specific Species (SEARCH)

A number of situations arise in chemistry lessons when it is important to determine if the formula of a given chemical species is present in a chemical equation. When judging balanced chemical equations for a specific reaction and when solving stoichiometry problems are only two such cases.

At times it is important to indicate to the student not only what he left out of an equation, but also what he put in that should not be there. For example, when writing the balanced half equation for an oxidation-reduction reaction which occurs in acid, it may be necessary to include H^{+} and H_2O and electrons would be required, but it would be very improper to include OH^{-}.

The routine called SEARCH was developed to determine the presence or absence of the formula of a particular chemical species in a chemical equation. By using this routine in combination with EQTJUDG the author had a very effective equation judger. Instead of specifying the complete balanced equation he could simply specify the species that were required and those that were prohibited and the computer would supply the proper error message when necessary.

It was found that to insure that each student typed the correct equation for a specific reaction, the author generally needed to list only a few of the required species. If only most of the species required in the reactants and one that was required in the products were specified, it was very seldom that the student was able to type an equation which satisfied all the conditions of both SEARCH and EQTJUDG without being exactly the equation the author desired.

This routine searched the equation for each species in the order in which the author listed them. The first violation of the required conditions ended the search and generated the appropriate error message. To use this routine the author needed to specify only the chemical formula of the species and whether it was required or prohibited.

In the lesson on oxidation-reduction equations, special subroutines were set up to specify the common species such as H^+, OH^-, and H_2O which were required to balance equations for reactions which take place in acid and in base. Special routines were established for half reactions where e^- was required and for complete equations where e^- was prohibited. Thus, to specify an oxidation-reduction equation the author had to list only a few specific species such as the oxidizing and reducing agents and then use the proper routine to specify the desired presence or absence of H^+, OH^-, H_2O and e^-.

The following is a list of student responses, the judgments and the error messages for the equation for the reduction of nitrate ions to nitric oxide. The author specified that H^+, e^-, and NO were required and that OH^- was prohibited. He then used the combination of the SEARCH and EQTJUDG routines to interpret the student's response.

a) $4H^+ + NO_3^- + 3e^- \rightarrow NO + 2H_2O$ ok

b) $NO_3^- + 4H^+ + 3e^- \rightarrow 2H_2O + NO$ ok

c) $3H^+ + NO_3^- + 3e^- \rightarrow NO + H_2O$ no

The following are not balanced:

H O charge

d) $4H^+ + NO_3^- \longrightarrow NO + 2H_2O$ no

e^- cannot be found in your equation

e) $4H^+ + NO_3^- + 3e^- \longrightarrow NO + 2OH^-$ no

OH^- should not be in your equation

f. Chemical Formulas (JUDGFM)

Students' answers in the form of chemical formulas were interpreted and judged by a routine called JUDGFM. In order to be judged as a correct answer the students' formula had to conform to a proper format that a chemist would use and contain the symbols of the correct elements and the proper subscripts. As in the other judging routines, special attention was paid to determining what was wrong with the student's answer and telling him about it.

The first part of the routine JUDGFM was the same as the first part of the routine that was used to interpret the format of the chemical formulas and to count the number of atoms of each element in a chemical equation (EQTJUDG). This generated lists of the symbols of the elements present and the corresponding number of atoms of each element. Any violation of the normal format of a chemical formula halted the judging procedure and the proper error message was displayed.

If the formula was found to be in a proper form, the number of atoms of each element was compared with that of the correct answer, which had been stored in a separate list. The symbols of any elements which are not correct were listed on the student's screen. Additional messages were displayed if the student failed to include an element that should have been in the formula or if he included additional elements.

To specify the correct answer the author generated a list of the symbols of the elements and a corresponding list of the number of atoms of each element. The easiest way to do this was to type the correct formula, generate the lists by using the same routine that interpreted the student's answer and then to direct that the information be stored in the appropriate place. In addition to automatically providing for a large amount of feedback to the student when his answer was not correct, the use of this routine also permitted a student's answer to be judged correct as long as it was written in a form that chemists would use, even if it was not in exactly the same form as that provided by the author.

For example, if the author specified that the correct answer was to be the formula for acetic acid, CH_3COOH, and the student typed an equally acceptable form of the same answer, $HC_2H_3O_2$, the student's answer would be judged as correct. The order of the elements in the student's answer was not required to match that of the author supplied answer. In this case the list of elements generated in the computer for the author's answer was in the following order: C,H,O, while that generated for the student's answer was H,C,O.

3. Routines to Solve Chemistry Problems

Chemistry problems of a given type are all solved the same way. Once the computer has been programmed to actually solve a problem the way a chemist would, that program routine could be used over and over again to solve similar problems. By allowing the computer to actually solve the problem step by step and thus generate the information required for the answer, the author can spend more time on designing the teaching strategies. He can decide if the student is to be required to solve the complete problem on his own or if his work is to be checked at each step. No matter what strategy or strategies the author decides to use, the problem solving routine should be able to supply all the information needed to decide if the student's answer is correct. By combining the problem solving routines and the answer judging routines, the author can supply a large number of problems and provide for very specific error messages without even solving the problems himself.

The problem solving routines have three common phases: 1) the input of information needed to solve the problem, 2) the problem solving procedure, and 3) the output of the results.

In this study emphasis was placed on developing routines which would accept the data in the form in which it is normally written in a text or on a homework paper. The idea was to have the machine conform to the way chemists do things, and not to force the chemistry student to conform to the way the machine works. An effort was made to require only the minimal amount of input, thus permitting the student as well as the author to supply the problems. The computer was programmed to interpret this information and to translate it into forms that could be used to display the data as well as to solve the problem.

The actual problem solving routines were designed so that the results of each step as well as the final results were available to the author, thus permitting him to use a variety of teaching strategies.

The results of the calculations were placed in a form that could be used directly by the standard answer judging routines, and could be used to generate the proper display of the answer.

a. Determining the Empirical Formula of a Compound from the Known Composition by Weight

The data required were the chemical symbols of the elements and the composition by weight expressed either in percent or as a weight ratio. The data for each problem could be supplied by either the author or the student. The computer was programmed to recognize proper elemental symbols and to provide the appropriate atomic weights. The data, including the atomic weights were stored in a form that permitted their display on the student's screen and that could be used by the computer to solve the problem.

The problem solving routine which determined the relative number of atoms of each element in the compound and expressed the results in a ratio of smallest possible integers was designed so that the results of each step as well as the final answer were available to the lesson author. The relative number of atoms of each element was determined by converting the given weight data to moles of atoms of each element by dividing by the appropriate atomic weight.

The mole ratio was reduced to smallest whole numbers by first expressing the number of moles of each element as a multiple of the number of moles of the least abundant element as determined on the basis of the number of moles of each element in the compound. The resulting of the mole ratio were then searched for values which were not integers. Any decimal portion greater than .1 and less than .9 was interpreted as a decimal equivalent of a fraction and all the numbers of the ratio were then multiplied by the denominator of the appropriate fraction. The resulting numbers were searched again and the process continued until all the numbers were integers. At this point the problem was solved.

For example, the formula of benzoic acid, C_6H_5COOH, was determined from the following composition by weight: 68.8% carbon, 4.9% hydrogen, and 26.3% oxygen. The given data was divided by the respective atomic weights, giving 5.74 moles of carbon atoms, 4.90 moles of hydrogen atoms, and 1.64 moles of oxygen atoms. The number of moles of each element was expressed as a multiple of the number of moles of oxygen atoms by dividing each number by 1.64 yielding the following ratio: 3.5 carbon atoms:3 hydrogen atoms:1 oxygen atom. When the numbers were searched for non-integer values, the 3.5 carbon atoms was found and the .5 was recognized as the decimal equivalent of one half. All the numbers were then multiplied by 2 and the answers searched again for non-integer values. Finding no other non-integer values the problem was solved. Thus the empirical formula of benzoic acid required 7 carbon atoms, 6 hydrogen atoms, and 2 oxygen atoms.

The results of the calculations were stored in a form that could be used either as the author supplied answer for the formula judging routine (see page 28) or to create a proper display of the answer as a series of chemical symbols and appropriate subscripts. In the above example the list of elements and number of atoms of each element were stored as C,H,O and 7,6,2 respectively and a correct form of the answer was generated as $C_7H_6O_2$.

b. Calculation of the Percentage Composition by Weight of a Chemical Compound from the Known Chemical Formula

The information needed to calculate the percentage composition of a compound was the symbols of the elements present, the atomic weight of each element, and the number of atoms of each element.

In keeping with the philosophy that the input of data should be easy and natural for both the student and the author, the routine which calculated the percentage composition of a compound required only that the input be a valid form of a chemical formula. The computer then determined the necessary information. The same routine that was used to determine the number of atoms of each element in a chemical formula when judging a chemical formula or equation (see pages 20-26) was used to generate the list of elements and the respective number of atoms. Another list containing the respective atomic weights was also generated.

The formula weight of the compound was determined by summing the products of the number of atoms of each element and the respective atomic weights. The percentage composition was then determined by dividing the weight of each element by the formula weight and multiplying by 100.

The answers to each individual step and the final answer was easily expressed in a form that could be used by the numerical answer judging routines, NUMJUDG and EXPJUDG (see pages 16 and 17), and could also be displayed to the student.

To calculate the percentage composition of sulfuric acid, the student or author simply typed H_2SO_4 and the computer interpreted the following information:

Element	Number of atoms	Atomic weight
H	2	1.00
S	1	32.06
O	4	16.00

The calculation routine then solved the problem, finding that sulfuric acid is 2.0% hydrogen, 32.8% sulfur, and 65.3% oxygen.

c. Calculation of Quantitative Relationships from Balanced Chemical Equations

A routine was written to determine the mass of any species involved with a given mass of another species in a chemical reaction which proceeds to completion. The initial data and the final answer could be expressed in any of the following units: kilograms, pounds, grams, decigrams, centigrams, and moles. In keeping with the idea that to specify a problem the author or student should have to supply only the bare minimum of information and that the computer should do the work of setting up the data in the proper form to be used to calculate the answer, the author or student was required to type only the information that was required to display the question: 1) the balanced equation for the reaction, 2) the chemical formulas for the two species, 3) the known mass of one species, and 4) the desired units for the answer. The computer was programmed to analyze this information for the other specific facts needed to solve the problem, such as the formula weights of the species and the mole ratio.

The problem "How many grams of sodium sulfate will be produced by reacting a solution of 20 grams of sodium hydroxide with an excess of sulfuric acid?" was specified in the following manner. First the balanced equation was typed in the same form as it would appear in a chemistry text or on a homework paper, $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$. The computer routine EQTJUDG was used to make sure the equation was properly balanced and that the formulas were written correctly. Because only reactions which proceed to completion were permitted, the use of the equilibrium arrow would have provoked an error message.

Then the formulas of the two species, NaOH and Na_2SO_4 were entered. The computer routine SEARCH was used to make sure that both species were in the equation and to find the proper coefficients. Each formula was also interpreted to determine how many atoms of each element were present and the atomic weight of each element. The same routine that was used to calculate the formula weight of a compound when determining the percentage composition was used to determine the formula weight of each species. In this case the results were 40 for NaOH and 142 for Na_2SO_4. The last information entered was the known mass of one species and the desired units of the answer. In this case 20 grams of sodium hydroxide and grams of sodium sulfate.

The calculation sequence was dependent upon the units of the given data and the desired units of the answer. If the known mass of one species was not originally expressed in grams, the first step was to convert it to grams. The number of grams was then divided by the formula weight to give the number of moles. The number of moles was then multiplied by the mole ratio of the two species as determined by the coefficients found in the equation. The result was the number of moles of the second species. If the answer was to be expressed in moles the problem was solved, but if the answer was to be in other units, the number of moles was converted to grams by multiplying by the formula weight of the species. If other units were desired the proper conversion from grams was made.

The final answer as well as the result of each step was numerical in nature and was easily placed in a form that could be displayed on the student's screen or used as a correct answer for the NUMJUDG or EXPJUDG routines.

4. Student Convenience Routines

These routines which permitted the student to perform special functions were available at all times. The two most frequently used routines were those that permitted a student to use the computer as a calculator and that permitted the student to type any comment he desired.

a. Calculations

The calculation routine performed complex calculations including trigonometric functions and square roots as well as simple addition, subtraction, multiplication and division. The student simply typed his expression using the standard operational signs and the computer calculated the value of it. The author could specify the number of significant figures to be used when displaying the result.

b. Comment

Students were quite free with their comments about the lessons. If the teaching assistant was busy or if the student felt shy about making a comment to the instructor's face, he could type his comment on the screen and have it recorded. The student's name, the comment, the time, and the place in the lesson were all recorded. This information was printed for the author and instructor after the class session.

5. Programs to Control Lesson Presentation

The lesson author communicated to the computer exactly what was supposed to happen and under what conditions by developing computer programs to control the presentation of material and the teaching strategies or series of strategies used in the lesson. These lesson control programs were a composite of general systems level routines designated by the proper TUTOR commands (see page 14) and the special routines written to perform specific functions as a chemist would perform them (see pages 15-34).

Before the lesson author wrote any programs or typed anything into the computer, the lesson topic was selected, the objectives were specified, the program style was determined, and specific strategies were developed for presenting material, providing additional help, accepting student responses and providing feedback. When determining the program style the type of lesson material, the lesson objectives, and the background of the students were considered. The program style depended upon whether the lesson was to be used to present new material, as a review and drill of already familiar material, or as a test.

After the program style was determined, consideration was given to the specific characteristics of the teaching strategies. These included the order of presentation of material and the design of the displays, the form of questions, the availability of additional information, the information to be stored and used to make sequence determining decisions, and the computer's reaction to a student's response.

In the lessons designed as instructional sequences or quizzes, the strategies for providing feedback to the student, providing additional help, and determining the sequence of material often varied from one question to another. Thus the lesson programs consisted of a series of program segments each designed to control the presentation of specific information or individual questions. For example, consider two consecutive quiz questions, one of which required the student to type a numerical answer including the proper units and another which required the student to type only the letter corresponding to the correct answer in a list of possible answers. In the first case the student was to be given two chances before the problem was counted wrong but in the second case only one chance was permitted. The student was told what was wrong with his answer to the first question but no feedback was available for the second question. In this case the lesson control program consisted of the program segment which controlled the student-computer interaction for the first question and then another program segment to control the second question and so on for the entire quiz.

In the lessons designed to permit the student to practice solving problems, the strategies for each question of the same type was constant; therefore, unlike the above situation, the same program sequence was employed for a number of problems with the appropriate data and answer supplied each time.

The lesson control programs were continually revised and redesigned when the author desired to change the teaching strategy and sometimes when changes in system-level routines provided more convenient and efficient ways of doing things. Emphasis was placed on adding help sequences where needed, revising any sequences that appeared to be confusing and providing specific interpretation of students' incorrect answers. It was found that to avoid frustrating the student, it was important that the answer judging routines recognize all proper forms of the correct answer. Any time a student supplied a form of a correct answer that the computer had not been programmed to accept, the program was immediately revised to accept it.

Most of the revisions were based on an analysis of student data and comments. The most helpful information was the list of incorrect answers and the requests for help.

The following examples illustrate specific strategies which could be used in a computer-assisted-instruction lesson and the computer program that would be used to control them. First the situation is presented as the author would conceive it, then the list of TUTOR commands and author supplied information that constitutes the computer program is given, and finally the function performed by the commands is explained. For the purpose of emphasizing the strategies, the same question is used in each of the first three examples, with the strategies for providing feedback to the student, for providing additional help, and for determining the sequence of material becoming more complicated with each example. The last example illustrates the situation which often occurs in drill and practice lessons where the strategies for accepting student responses, providing additional help, and determining the sequence of material are constant but the specific questions and answers change.

Example 1:

The situation: The question "How much does 0.25 moles of sodium sulfate weigh? ______g" was to appear on the screen. Any student response between 35.3 and 35.7 was accepted as correct. No additional information or help was available and the answer was judged as correct or incorrect without additional comment. The next display was not presented until this question was answered correctly.

The Program:

TUTOR Command	Author supplied information
UNIT	QUEST1
NEXT	QUEST2
WHERE	301
WRITE	What is the weight of 0.25 moles of sodium sulfate? ________g
ARROW	501
ANSV	35.5,.2

Analysis of the Program:

The command UNIT was used to specify a name for the following series of commands. The command NEXT indicated that after the student had answered the question correctly the next display was to be generated by the series of commands (UNIT) called QUEST2. The command WHERE 301 and the WRITE command indicated that the question was to appear on the student's screen beginning on the third line, the first space. The arrow at 501 indicated that when the student typed his answer it was to appear on the screen at the fifth line, the first space. The correct answer and the permitted tolerance were supplied by the author with the command ANSV 35.5,.2.

Example 2:

The situation: The same question as in Example 1 was to be displayed but this time help was available at the student's request. The help was available at all times but the student wasn't told about it until he typed an answer which wasn't even close to the correct value. In addition to determining if the student's answer was correct or incorrect, special messages provided by the author were displayed when the student's answer was within plus or minus two tenths of the correct answer, within plus or minus four tenths of the correct answer but not close enough to be considered correct, and when the student's answer was off by more than four tenths. The next display was not presented until the student answered this question correctly.

The Program:

TUTOR Command	Author Supplied Information
UNIT	QUEST2
NEXT	QUEST3
HELP	HELP1
WHERE	301
WRITE	What is the weight of 0.25 moles of sodium sulfate? _______g
ARROW	501
ANSV	35.5,.2
WHERE	601
WRITE	very good
ANSV	35.5,.4
WHERE	601
WRITE	You're close but not close enough, try again
JUDGE	No
WRONG	
WHERE	601
WRITE	You seem to be off the track. Help is available
UNIT	HELP1
WRITE	First calculate the weight of 1 mole of sodium sulfate, Na_2SO_4, by multiplying the number of atoms of each element by the respective atomic weights and summing the results. Then calculate the weight of 0.25 moles.

Analysis of program features not described in Example 1:

The HELP command indicated that the display specified by the commands in the unit entitled HELP1 was to appear on the student's screen if the student pressed the key marked HELP. The series of WHERE and WRITE commands which appear after an ANSV command were performed only if the student's answer matched the conditions of the ANSV. Thus any student's answer between 35.3 and 35.7 was judged correct and the words "very good" were written on the student's screen starting at the first space of the sixth line. The message "you're close but not close enough, try again" was displayed when the student's answer was between

35.1 and 35.3 or between 35.7 and 35.9. With the command JUDGE NO, the author designated that any student's answer in this range was to be judged incorrect and the student was forced to try again. The command WRONG followed by a blank indicated that <u>any</u> answer other than those above was judged incorrect and the student was told "you seem to be off the track. Help is available."

Example 3:

The situation: The same question as described in Examples 1 and 2 was displayed but the strategy was contingent on whether the question was used on a quiz or as part of an instructional sequence. If a quiz question, no help was provided and the next display was another quiz question. After two errors the problem was counted incorrect and the student forced on to the next question. If the question was used as part of an instructional sequence, perhaps as a review after the quiz, the student was told that help was available and the next display was a graph rather than another question. After two errors the student was forced to the help sequence which was a series of questions to guide the student to the answer. In both cases any answer between 35.3 and 35.7 grams was to be accepted. The student was required to label his answer with the word grams or an appropriate abbreviation. Error messages were displayed for any answer which was unlabeled, mislabeled, or numerically too high or too low.

The program:

```
TUTOR      Author supplied
Command    Information

  UNIT     SETUP1Q
  CALC     I1=I3=0
  CALC     I2=-1
  JUMP     PROB1

  UNIT     SETUP1I
  CALC     I1=I2=0
  JUMP     PROB1

  UNIT     PROB1
  NEXT     I2,SETUP2,GRAPH1
  HELP     I2,X,FORMWT
  WHERE    201
  WRITC    I2,You have only two chances at this problem,
           Help is available
  WHERE    401
  WRITE    How many grams does 0.25 moles of sodium sulfate weigh?
```

```
ARROW  701
INHIB  ANSWER
STORE  F4
CALC   F5=35.5
CALC   F6=0.2
CALC   I7=801
JOIN   GRAMS
JOIN   I8,ADD1,X
WHERE  901
WRITC  I1,,,,You missed this problem twice,,
NEXT   I1,X,X,X,SCORE

UNIT   SCORE
JUMP   I2,X,FORMWT
ADD1   I3
CALC   I1=0
JUMP   PROB2

UNIT   ADD1
ADD1   I1

UNIT   SETUP2
CALC   I1=0
JUMP   PROB2

UNIT   FORMWT
WHERE  201
WRITE  You need some help.
       Let's solve the problem in smaller steps.
       What is the chemical formula for sodium sulfate?
       What is the formula weight of sodium sulfate?
```

Analysis of the program:

The unit SETUP1Q sets the proper counters for the question when it was used as a quiz question while SETUP1I does the same for the use of the question as part of an instructional sequence. The counter I1 was used to count the number of errors on the problem and I3 was used to count the number of problems marked wrong on the quiz; I3 was set to zero only at the beginning of the quiz. When the value of I2 was equal to -1, it indicated that the question was being used as part of a quiz; when the value of I2 was set equal to 0 as in SETUP1I, the question was part of an instructional sequence. All these variables were set instantaneously and the student noticed no delay as the control was immediately "jumped" to the unit PROB1 which displayed the question. In the unit PROB1 several of the commands were followed by a counter and a list of information separated by commas. If the value of the counter was -1 the function designated by the first item in the list was to be performed, while values of 0,1,2 indicated that the second, third, or fourth items in the list were to be performed. An X indicated that nothing was to be done.

The NEXT command followed by I2, SETUP2, GRAPH1 indicated that after the student answered the question correctly the next display was dependent on the value of I2. If I2 was -1, indicating a quiz question, the next series of commands to be executed was UNIT SETUP2, but when I2 was equal to zero, the next unit was GRAPH1. Similarly the availability of help was determined by the value of I2. The message written at the second line was "You have two chances at this problem" or "Help is available", depending again on the value of I2 as designated by the command WRITC.

The INHIB ANSWER command made it impossible for the student to obtain the answer by pushing the key marked ANS.

The next four commands beginning with STORE F4 were used to set up the proper values for the use of the special routine, GRAMS, which accepted a numerical answer within a specified tolerance and required that the answer be labeled by a proper abbreviation for grams (see page 18). This routine automatically provided the error messages the author required. The student's answer was stored in a variable designated as F4, the correct answer was placed in F5, and the permitted tolerance was placed in F6. The variable I7 was set equal to 801 to indicate the position on the screen where an error message was displayed if needed. The routine GRAMS automatically provided error messages if the student's answer was unlabeled, mislabeled, or numerically too high or too low.

When the routine, GRAMS, judged a student's answer, the counter I8 was set equal to zero if the answer was correct and to -1 if the answer was incorrect. Thus the counter I1, used to count the number of incorrect attempts at the problem, was incremented by 1 in the unit ADD1 every time I8 was set equal to -1. In addition to the standard messages provided by the routine, GRAMS, the author designated that the student be told when he missed the problem twice by writing the appropriate messages on the ninth line when the value of I1 reached 2.

The NEXT command at the end of the unit indicated that when the student had made two errors (the value of I1 = 2), the screen was erased and the next series of commands indicated by the unit named SCORE was performed. UNIT SCORE transferred control immediately to the help sequence, FORMWT, if the value of I2 was zero, but if the value was -1 the counter I3, which was used to count the number of problems missed, was incremented and the next quiz problem displayed.

The unit SETUP2 was used to set the value of the counter used to count the number of attempts at a given problem back to zero and to transfer control to the next problem.

The unit FORMWT indicates a typical type of help sequence where the student was guided through the problem in smaller steps. The program which would control the acceptance of the student's answers has been omitted from this example.

Example 4:

The situation: As in a practice sequence, the same lesson control strategies were used for a number of problems. In this case the student was required to balance four oxidation-reduction equations. The unbalanced equation was displayed and the student was required to type the complete balanced equation. The student could attempt the equation as many times as he desired. Help in the form of a list of rules and procedures for balancing equations was available. After requesting help once, the student was able to see the correct answer by pressing HELP a second time. The number of times the student requested the answer was stored for use in making sequence determining decisions later in the lesson. The next question was not presented until the student correctly balanced the equation or requested to see the answer. Extensive feedback was provided to the student when his equation was not in proper form, when he included species which should not be in the equation or excluded species which should have been there, and when the equation was not balanced by mass and charge.

Although some equations were for reactions which occur in acid while others were for reactions which occur in base, the requirements for the judging routines and the additional information available by pressing the key marked HELP were similar enough that the same routine could be used with only minor modifications. These modifications were specified by setting counters to appropriate values.

The Program:

```
TUTOR     Author Supplied
Command   Information

  UNIT    SETUP
  CALC    I1=I4=0
  CALC    I2=1
  JUMP    BALEQT

  UNIT    BALEQT
  NEXT    I2-4,BALEQT,THATSAL
  WHERE   201
  WRITE   Balance this equation:
  JOIN    I2,X,X,EQT1,EQT2,EQT3,EQT4
  HELP    I1,X,SHORULE,SHOANS
  WHERE   101
  WRITC   I1,,,You may see the answer by pressing HELP.
  ARROW   601
  CALC    I84=801
  JOIN    I2,X,X,EQT1ANS,EQT2ANS,EQT3ANS,EQT4ANS

  UNIT    EQT1
  WHERE   401
  WRITE   Cr2O7 2- + H+ + I- --> Cr3+ + H2O + I2 (acid)
  CALC    I3 = -1

  UNIT    SHORULE
  JOIN    I3,ACIDRUL,BASERUL
  CALC    I1 = 1

  UNIT    SHOANS
  ADD1    I4
  WRITE   The balanced equation is:
  JOIN    I2,X,X,ANS1,ANS2,ANS3,ANS4
  ADD1    I2
  ZERO    I1
  NEXT    I2 - 5,BALEQT,THATSAL

  UNIT    EQT1ANS
  JOIN    ACID
  CALC    I82 = -1
  PACK    I100,A95,Cr2O7 2-
  JOIN    SEARCH
  GOTO    I81,END,X
  JOIN    EQTJUDG
  GOTO    I91,X,ADD1

  UNIT    ADD1
  ADD1    I2
  ZERO    I1
```

```
UNIT   ACID
JOIN   STOREQT
CALC   I82 = -1
PACK   I100,A95,H+
JOIN   SEARCH
GOTO   I81,END,X
CALC   I82 = 0
PACK   I100,A95,OH-
JOIN   SEARCH
GOTO   I81,END,X
CALC   I82 = 0
PACK   I100,A95,e-
JOIN   SEARCH
GOTO   I81,END,X
```

Analysis of the program features not previously described:

The unit SETUP was used to initialize the values of the counters, I1 for the form of help, I4 for the number of requests for the answer, and I2 for the problem number.

In unit BALEQT the units EQT1, EQT2, EQT3, and EQT4 displayed the unbalanced equation and set I3 equal to -1 if the reaction occurred in acid and to zero if the reaction occurred in base. The command NEXT followed by I2-4,BALEQT,THATSAL indicated that until the value of I2-4 became zero, the next display was generated by the same unit BALEQT. The unit THATSAL presented different material and evaluated the progress of the student after all four equations were attempted. When the student pressed HELP the first time, for each equation, the appropriate rules designated by the command JOIN I3,ACIDRUL,BASERUL in the unit SHORULE were displayed and the value of I1 was set equal to 1. If I3 was -1, the rules for reactions which occur in acid were shown, but if I3 was equal to zero the rules for balancing equations for reactions which occur in base were displayed. The message "You may see the answer by pressing HELP" appeared on the screen only after the student had pressed HELP once and the value of I1 was set to 1. If the student never pressed HELP he was unable to request the answer. When the student requested to see the answer, the commands in the unit SHOANS were performed incrementing the count of the number of times the student requested the answer, I4, displaying the proper equation, adding 1 to the problem number I2, so that the next equation would be shown, and resetting the value of I1 to zero.

The commands necessary to judge the equation were specified in the units EQT1ANS, EQT2ANS, EQT3ANS, and EQT4ANS. The unit ACID and a similar one called BASE were used to search the student's equation for the presence or absence of the specific species, OH^-, H^+, and e^-. The value of I82 set equal to -1, required the next species to be in the equation and I82 set equal to zero prohibited the presence of the following species. The general routine SEARCH (see page 26) was used to determine if the proper conditions were satisfied. The value of I81 was set equal to -1 if a species was found when it was prohibited or if it was not found and it was required. In these cases the judging was stopped by the unit END and the appropriate error message displayed. In the first equation the author further required the presence of $Cr_2O_7^{2-}$ with the commands CALC I82⇐-1, PACK I100,A95,$Cr_2O_7^{2-}$ and JOIN SEARCH which were in the unit EQT1ANS. The general routine EQTJUDG was used to interpret the student's equation and provide error messages if any elements or charge were unbalanced (see page 20). If the equation was judged to be correct the routine EQTJUDG set the value of I91 equal to zero and in the unit ADD1, the equation number, I2, was incremented by 1 and the value of I1 was reset to zero. The next equation was then presented.

IV. CURRENT CONTENT OF THE LESSONS

A. Math Skills

This lesson consists of two parts: 1) a quiz to determine weakness in four of the math skills necessary to solve stoichiometry chemistry problems, and 2) instructional sequences including explanations, examples and problems in each of the four skills. The student is given two chances per quiz problem and no help is provided. After the quiz the student is forced into the instructional sequence for any skill for which he missed 40% or more of the quiz questions. He may also choose to do the instructional sequence for any topic. On the quiz there are three problems on multiplication of fractions, five problems on percentage, five problems on conversion factors (sometimes called factor dimensions), and four problems on ratios.

After the quiz and instructional or review sequences the student should be able to: 1) Multiply by fractions and express the answer in decimal form, 2) Given x and y, calculate what percent the number x is of the number y, and/or what is x percent of y, 3) Use conversion factors to express a quantity in different units, and 4) Express ratios in small whole numbers.

A flow chart for this lesson is presented in Figure 3 and the quiz questions are found in Appendix B.

B. Chemical Formulas

A series of lesson materials containing instructional sequences, practice problems and a quiz has been developed. The objectives of these lessons are that the student should: 1) Recognize the information contained in a chemical formula, 2) Be able to convert laboratory data expressed as the composition of a compound by weight either in percent or weight units to the simplest formula by a) using the definition of a mole of atoms as a conversion factor; b) recognizing the equivalence of the mole and atom ratio, and c) expressing the atom ratio in small whole numbers; 3) Calculate the formula weight from the chemical formula and recognize the formula weight in grams as a mole of formula units; 4) (if previously prepared) Determine the molecular weight from the

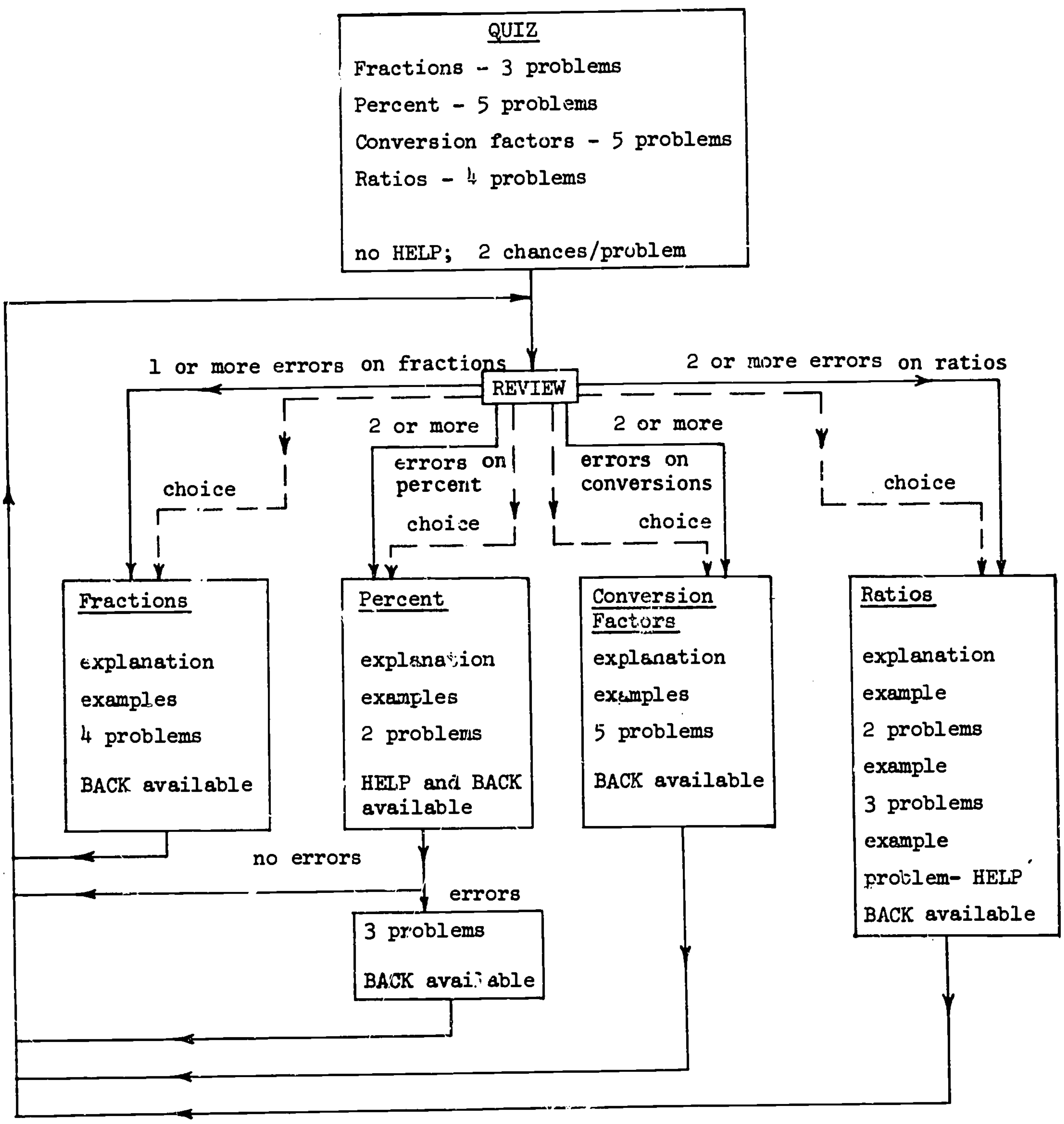


Figure 3. Flow Chart of Math Skills Quiz and Review.

volume and weight of an ideal gas; and 5) Determine the molecular formula and molecular weight.

1. Instructional Sequence

In the instructional sequence the importance of each individual step is stressed. The student is first introduced to the meaning of a simplest (empirical) formula in terms of an atom ratio. Typical laboratory data on the composition by weight of a compound is then presented as 75% carbon and 25% hydrogen. After the student has predicted the simplest formula, the mole concept is introduced as a relation between weight of an element and the number of atoms. At this point the student can choose to review the use of conversion factors. After correctly answering questions about using the mole as a conversion factor, the student is required to use the mole concept to convert his data, 75 grams of carbon and 25 grams of hydrogen, to moles. If the student makes four or more errors or requests help in this section, which requires six separate answers, he is forced to practice using the mole as a conversion factor after completing the carbon-hydrogen problem.

After converting his data to moles, the student is told that the mole and atom ratios are equivalent because of the constant number of atoms per mole of any element. The student then expresses the atom ratio in small whole numbers and types the final formula, CH_4. He is then shown a summary of the steps that he has just completed. At this point on the basis of his previous results he may be forced to practice using the mole as a conversion factor.

The student is then required to determine the simplest chemical formula of four additional compounds. He is guided through each problem with emphasis placed on different steps. For the first problem, carbon dioxide, the student is given data in grams and is required to convert the data to moles. A fuller explanation of the equivalency of the mole and atom ratio is available at the student's request. The student then expresses the atom ratio in smallest whole numbers and types the formula.

The second problem is used to demonstrate that the atom ratio may not always be expressed in small whole numbers in one step. The data is given as 0.46 moles of phosphorus and 1.15 moles of oxygen. The student is asked to type the simplest formula. If he makes three errors, he is forced to a sequence which helps him do the problem step by step. This help sequence is also available at his request. Extensive feedback is provided for wrong answers. Specific messages are provided for these and other errors: using K as the symbol for phosphorus, $PO_{2.5}$, P_5O_2, and O_5P_2.

The next problem is analogous to the original CH_4 problem with the data presented as 30 grams of oxygen and 70 grams of iron. Emphasis is placed on the need to convert weight data to moles. The student is required to pick the simplest formula from the following list: Fe_3O_7, Fe_3O_2, Fe_7O_3, Fe_2O_3, $Fe_{70}O_{30}$, and "can't tell." If the student chooses any answer other than Fe_2O_3, the next display shows him the data again and a specific message depending upon his original answer. He is then required to solve the problem again and type the formula. He cannot return to the original list of answers. If the student has more trouble he can request step by step help. The student who initially chooses Fe_2O_3 is congratulated and shown a review of the correct steps.

Unlike the other problems, the data for the fourth problem, teflon, is supplied as the percentage composition. In addition to the added step of converting the percentage to weight units, the student is required to specify the next step. This question makes sure that the student has not lost sight of the final goal while doing each individual step. Finally the student determines that the simplest formula of teflon is CF_2.

The last part of the lesson extends the concept of chemical formulas from empirical formulas to molecular formulas. The student is told how to calculate the formula weight from the chemical formula and is required to do three problems. If he requests help he is shown an example.

If the student has had previous experience solving problems with gas laws, he is required to calculate the molecular weight of teflon from the known density and the fact that one mole of ideal gas occupies a volume of 22.4 liters at standard conditions of temperature and pressure. If the student has not solved gas problems, he is told that the molecular weight must be determined in the laboratory.

The student must determine the molecular formula by comparing the simplest formula weight of teflon with the molecular weight. He then verifies that the formula weight calculated for the molecular formula equals the molecular weight determined in the laboratory. The lesson ends when the student has determined the molecular formulas from the molecular weight and simplest formula of three different compounds.

The material on each individual step or objective is designed so that it can also be used as an independent review sequence. The following subtopics are available for review: 1) conversion factors, 2) meaning of formulas, 3) the mole concept, 4) calculating simplest formulas, 5) formula weights, and 6) molecular formulas.

The student may be allowed to select areas for review or he may be forced to review on the basis of the quiz results. In a few cases the review sequence is slightly different than the normal instruction sequence. In the review sequence for moles, the concept is introduced with a definition without the CH_4 problem and the four problems using the mole as a conversion factor are required. In addition to the introduction to chemical formulas, the review sequence on chemical formulas includes two additional problems.

The various paths through the major sections of this lesson are displayed in Figure 4.

2. Practice Problems

The student is able to practice calculating the percentage composition from the chemical formula and determining the simplest formula from the known composition by weight for any number of problems. Problems may be chosen from a list supplied by the author and displayed on the student's screen or they may be supplied by the student. A summary of the steps and an example of each kind of problem is available.

a. Determining the Simplest Formula from Known Composition

The list of problems supplied by the author contains data in percent for the composition of the following compounds: sodium hydroxide,

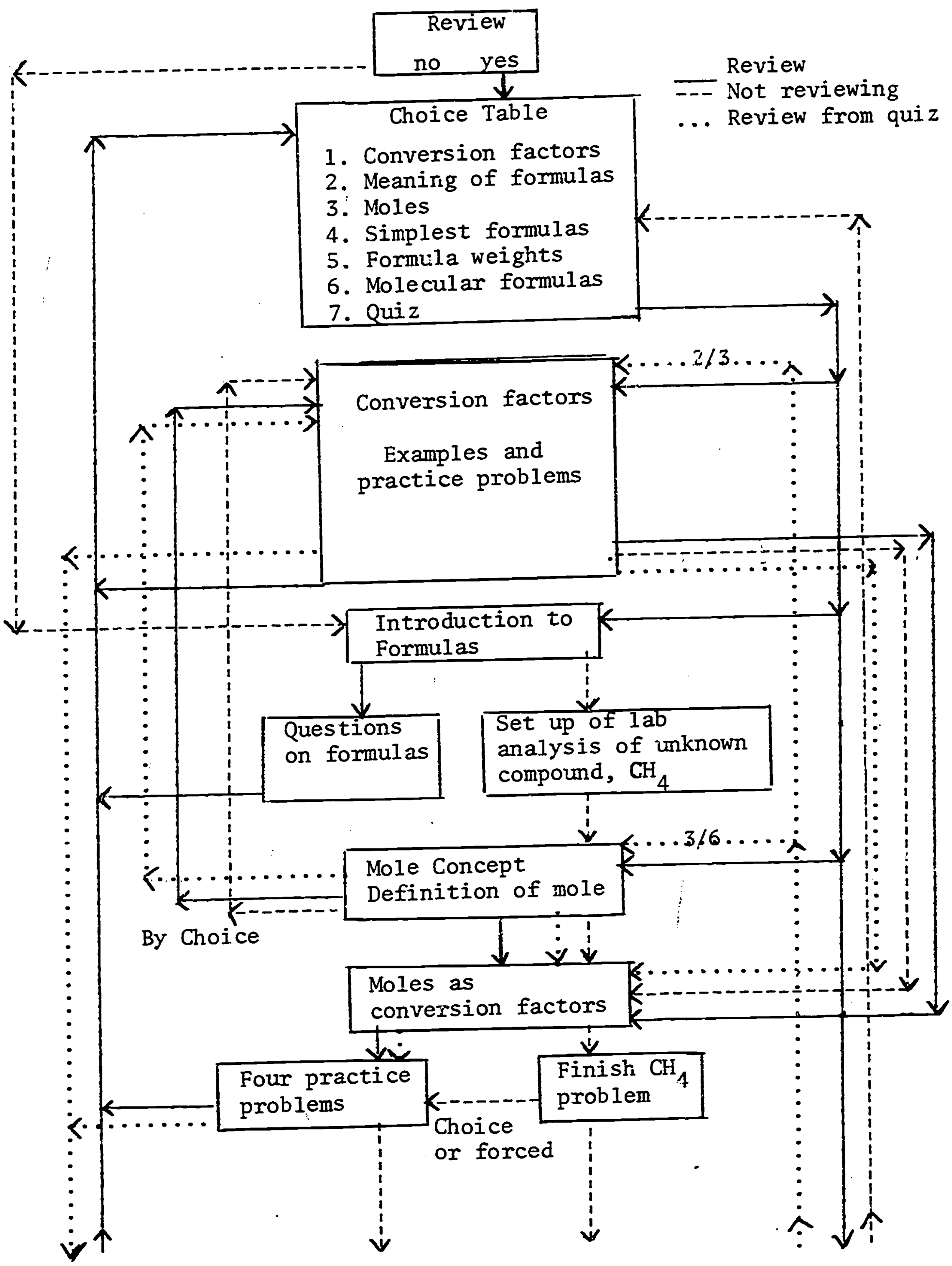
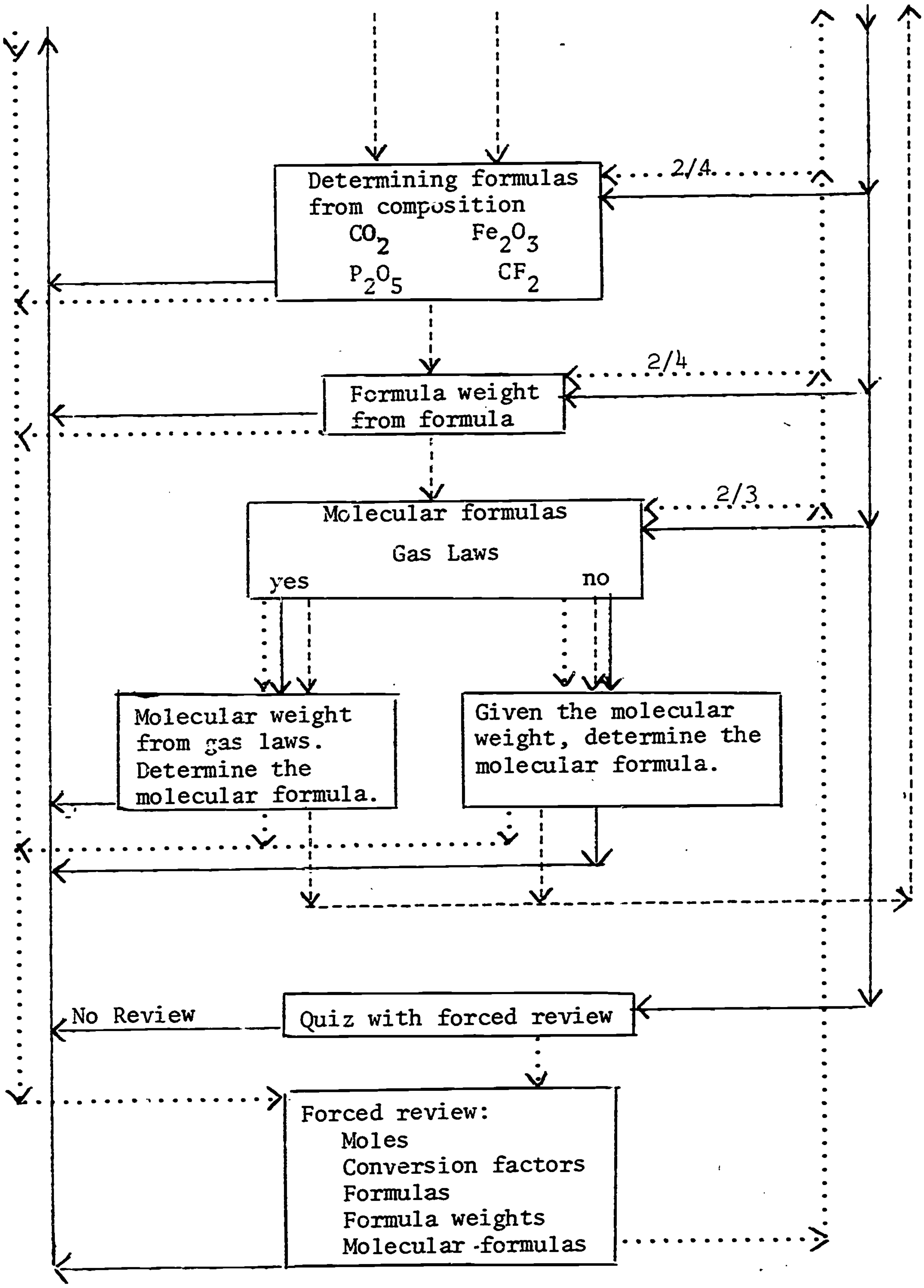


Figure 4. Flow Chart of Lessons on Chemical Formulas.


Determining formulas from composition
CO_2 Fe_2O_3
P_2O_5 CF_2
2/4
Formula weight from formula
2/4
Molecular formulas
Gas Laws
yes
no
2/3
Molecular weight from gas laws. Determine the molecular formula.
Given the molecular weight, determine the molecular formula.
No Review
Quiz with forced review
Forced review:
Moles
Conversion factors
Formulas
Formula weights
Molecular formulas

zinc nitrate, hexane, ammonium sulfate, chromium(III) sulfate, and 1,3-propanediol. To supply his own data the student first specifies how many elements are in the compound and whether his data are in grams or percent. Then he types the chemical symbols and the data for each element. The computer will accept only valid symbols of the elements and if the data is in percent, the computer will make sure the total is approximately 100 before solving the problem. If the student makes an error he is told why the data are not acceptable.

The computer calculates the correct answer to the problem in less than one second, displays the data for the student and asks for the student's answer. The student may use the computer as a calculator at any time and may also request to be guided through the problem step by step. The computer analyzes the student's answer and tells the student which elements are not correct or if he has improperly used subscripts or parenthesis. If he makes two errors on the problem he must decide to try again, ask for help, or see the answer. If he asks for the answer the data is displayed and the computer generates the display of the correct formula in the form of symbols and subscripts. The student then can work through the problem step by step or choose another problem.

In the step by step sequence, if the data are in percent, the student is told how to convert to grams by assuming a 100 gram sample and the computer does the conversion. With the data in grams the student is asked to complete the following statement: "Moles of atoms equals weight in grams divided by the ____?" The computer then does the calculations and displays the results. The symbols and the number of moles of each element are then displayed and the student decides what number to divide by to express the ratio in the smallest whole numbers. Again the computer does the calculation and displays the results. The student is then asked to type the correct formula.

To encourage the student to use the step by step procedure only when he is having trouble and to return to the original problem when he finds his trouble spot, he must indicate after each step whether he wants the next step or wants to return to the problem. The sequence of of frames is shown in the flow chart in Figure 5.

b. Calculating the Percentage Composition from the Formula

The following eight compounds are in the list provided by the author: ammonium sulfate, formaldehyde, calcium phosphate, N-bromopropylamine, sodium aluminum sulfate, potassium stearate, acetic acid and 2-butanone. To supply his own data the student simply types the chemical formula. The computer checks for correct symbols and proper use of subscripts and parenthesis.

The computer analyzes the formula, calculating the weight of each element, the formula weight and the percentage composition immediately. The student, shown the chemical formula and a list of the elements, is required to type the percentage composition beside the appropriate symbol. If the student's response is incorrect he is told if it is too high or too low. Again the student may use the computer as a calculator and request to do the problem step by step.

In the step by step sequence the student is first asked to calculate the formula weight. If he makes two errors he is shown the chemical formula, the symbols, and number of atoms and atomic weight of each element in the formula. He is then required to calculate the weight of each element and the formula weight. With the formula weight and weight of each element calculated, the student is next required to calculate the percentage of each element.

As when solving for the chemical formula from the composition, the student is forced to decide to try again, ask for help, or see the answer after making two errors and may return to the main problem at any point in the step by step sequence.

3. Quiz

The quiz consists of questions directly related to the objectives outlined on page 46. Major emphasis is placed on the details of each step. To see the quiz questions, refer to Appendix B.

The student is given two chances per problem unless it is a multiple choice question; then he has only one chance. The quiz consists of six

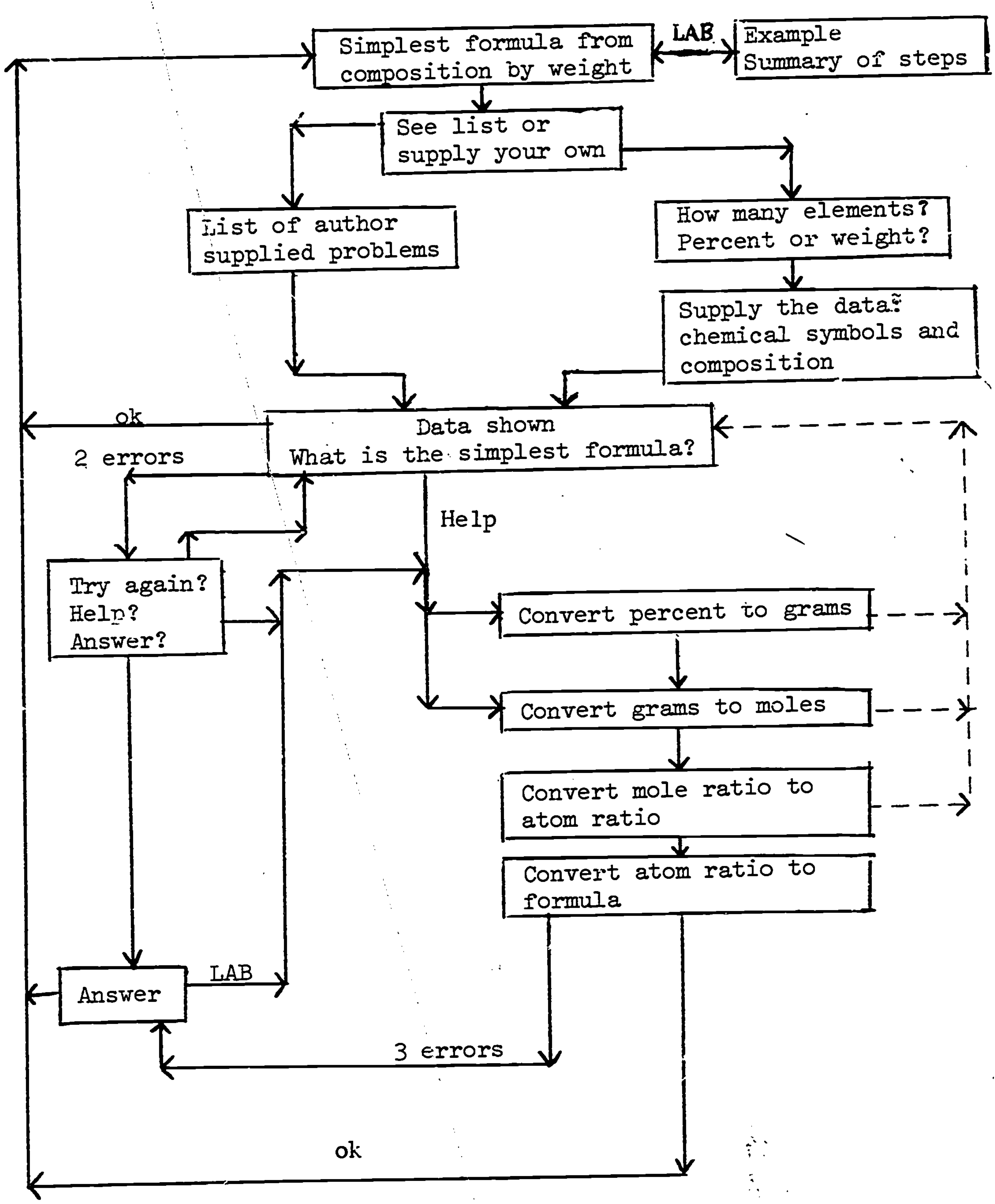


Figure 5. Flow Chart for Practice Problems on Determining the Simplest Formula from Composition by Weight.

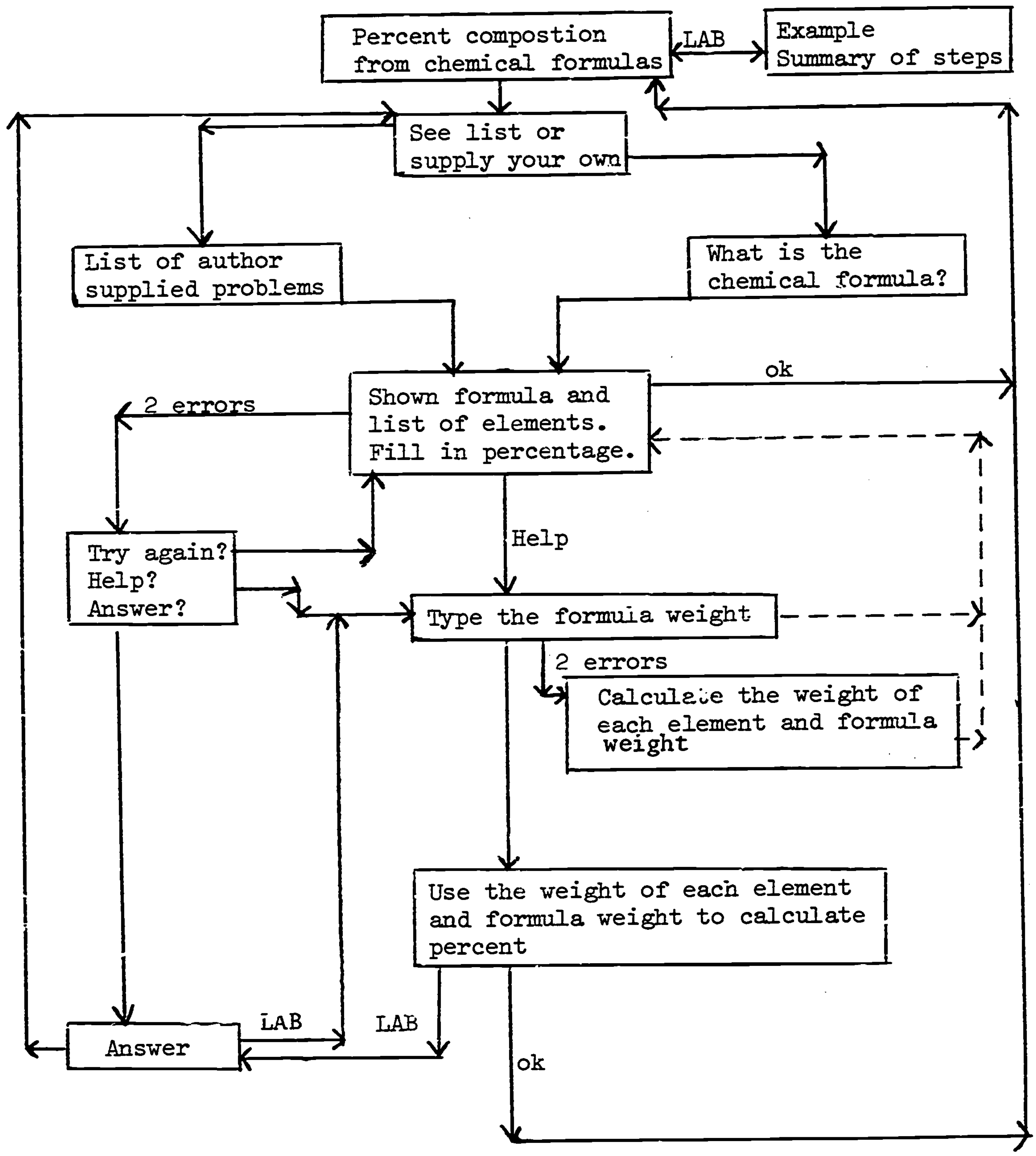


Figure 6. Flow Chart for Practice Problems on Determining the Percent Composition from Chemical Formulas.

questions on moles, three on conversion factors, four on simplest formulas, four on formula weights, and three on molecular formulas. Only five of the twenty problems are multiple choice. If the student fails to get the correct answer on 40% or more of the problems in any area he is forced to review the instructional sequence for that area.

C. Concentration of Solutions and Quantities from Chemical Equations

The objectives of this series of lessons are that the student should be able to: 1) Use the definition of molarity and moles to calculate any of the following, given the other two: a) concentration of solution in molarity, b) volume of solution, and c) moles or grams of solute, and 2) Use the quantitative relationship of a chemical equation to determine quantities of reactants and products for reactions which proceed to completion by a) balancing simple equations, b) determining mole ratios from the equation, c) converting the data given in concentration of solution, liters of gas, or grams to moles, d) using the mole ratio as a conversion factor, and e) converting moles to the desired units.

1. Instructional Sequence

The idea of expressing concentrations of solutions as moles per liter is introduced, then the student is asked to calculate the weight of one mole of sodium hydroxide. If the student has trouble, he receives a review of the method and an example. After establishing that the weight of one mole of sodium hydroxide is 40 grams, the concentration of one liter of solution containing 40 grams of sodium hydroxide is expressed as one mole per liter. The concept of molarity is then introduced as the number of moles of solute per liter of solution, using sodium hydroxide as an example.

The student is then guided through the steps in the determination of the weight of ethanol in .5 liters of a one molar solution. The use of the definition of molarity as a conversion factor to determine the number of moles in a given volume of solution is emphasized by an example and then the student is required to calculate the number of moles of sodium chloride in .4 liters of .25 molar solution. Extending the concept one more step, the student is required to calculate how many grams of potassium chloride are required to make 300 milliliters of .2

molar solution.

The next problem on concentration of solutions requires the calculation of the volume of .3 molar hydrochloric acid that can be prepared from 25 milliliters of 6 molar hydrochloric acid solution. The student is instructed to first determine the number of moles of hydrochloric acid in the 6 molar solution and then to set up a ratio to solve for the final volume of .3 molar solution. More detailed help is available.

The last problem requires students to calculate the molarity from the volume of solution and the number of moles of solute. The problem uses the same data as the previous one and upon completion of the problem the student is encouraged to compare the two problems; one calculating the volume from the knowledge of the number of moles of solute and concentration and the other calculating the concentration from the knowledge of the volume and number of moles of solute.

The second portion of this lesson concerns using balanced chemical equations to determine quantitative relations. The concept of balanced equations is introduced by first emphasizing that in order to write an equation, it is important that all the formulas for both reactants and products must be properly written. The student then decides where coefficients are needed to balance the equation for the formation of water. He is cautioned that when balancing an equation the subscripts in the formula remain unchanged.

The student is then asked to fill in the coefficients for the equation for the reaction of zinc metal and hydrochloric acid. This balanced equation is used to introduce the idea that the coefficients can be used to represent the mole ratio between the species in the reaction. The student is asked several questions such as "If you wanted to produce two moles of zinc chloride, how many moles of zinc metal would you need?" Then he is presented the general equation $2A + 3B \rightarrow 5C + D$ and is asked to use the mole ratio as a conversion factor to determine how many moles of "A" are needed to produce 15 moles of "C". Now that the student is familiar with the importance of the mole ratio the data can be given in any units that the student can convert to moles.

The next problem asks the student how many grams of sulfuric acid reacting with sodium chloride are needed to produce 3.65 grams of hydrogen chloride. He is guided through this problem step by step with extra help available at his request. He must first balance the equation, use the mole concept as a conversion factor to convert 3.65 grams of hydrogen chloride to moles of hydrogen chloride, and use the mole ratio as determined from the balanced equation as a conversion factor to determine how many moles of sulfuric acid are required. Then using the weight of a mole as a conversion factor again, he converts the moles of sulfuric acid to grams. At this point the student is shown a diagram summarizing the steps.

The next three problems are designed to allow the student to practice solving problems by taking some steps away but providing them again if he has trouble. Each problem is a little different in the form of the data given or in the answer required.

The student is told that potassium perchlorate decomposes to potassium chloride and oxygen and is asked to fill in the coefficients that will balance the equation. The problem is to determine how many liters of oxygen measured at standard conditions, at which one mole equals 22.4 liters, can be produced by decomposing 2.45 grams of potassium perchlorate. The student may request help in the form of step by step guidance immediately or be forced into the step by step sequence after one error.

The next problem provides a review of the concentration of solutions presented earlier in the lesson and ties the two parts of the lesson together. The problem is to determine how many grams of barium sulfate can be produced by adding sulfuric acid to 100 milliliters of a one-tenth molar solution of barium chloride. The student is given the balanced equation and is asked to analyze the problem. He is asked to type the formula of the species for which he knows quantitative data and the formula of the species for which he is to calculate the quantity. If he fails to answer correctly he is told why his answer is incorrect. For example, if he responds that he knows the quantity of sulfuric acid, he is told that sulfuric acid is in excess and that the reaction will stop before all the acid has reacted.

The next step is to convert quantitative data for barium chloride to moles. If the student fails to answer correctly, he is reminded of the definition of molarity. After converting to moles of barium chloride, the student is guided through the remaining steps using the mole ratio and converting the moles of barium sulfate to grams.

The last problem in the lesson requires the student to calculate the weight of oxygen that must react with zinc sulfide to produce 1000 grams of zinc oxide. The student must first supply the coefficients that will balance the equation and then analyze the problem in terms of what species' quantitative data are known and for what species the quantity is to be calculated. Step by step help is available only if the student requests it.

If this material is being used as review, the student has the option of doing the first part on concentration of solutions, the introduction and step by step solution of quantities from chemical equations including the problem of potassium perchlorate, or the last two problems.

2. Practice Problems

The purpose of this lesson segment is to give the student practice determining quantitative relations by using balanced chemical equations. The student may request to see a summary of the steps and an example before attempting each problem. The problems may be chosen from the list provided by the author or the student may supply his own data. Data in most common mass units such as grams, kilograms, centigrams, decigrams, pounds, and moles are accepted.

Problems concerning the following reactions have been provided by the author: 1) The decomposition of calcium oxalate, 2) The production of nitric acid from nitrogen dioxide and water, 3) The combustion of ethane, 4) The reaction of aluminum sulfide and water to produce aluminum hydroxide, and 5) The oxidation of iron(II) oxide by potassium permanganate (see Appendix C).

The student may supply his own problems by typing the balanced equation for the reaction. The computer will determine if the equation is balanced and if it is incorrect will tell the student which elements are unbalanced. The computer also analyzes the equation for proper use of coefficients, subscripts, superscripts, parenthesis, and arrows. The student then types the formula of the species for which he knows quantitative data, "y", and the formula for the species for which the quantity is to be calculated, "x". The computer determines if the formulas as the student typed them are found in the original equation and if so, immediately calculates the formula weight of each. If the formula has been erroneously typed, the computer tells the student it cannot be found in his original equation.

The student is then asked to specify the quantity of "y" including mass units and the units he desires for the quantity of "x". Now that the data has been entered the student proceeds just as he would if he had chosen a problem from the author supplied list.

The balanced equation is displayed as is the given quantity of "y" and the units and the formula for the desired species. The student is asked how many specific units of "x" are involved in the reaction with the given amount of "y". The student may request step by step help immediately. If he attempts the problem, the computer informs him if his answer is ok, too high, or too low. After making two errors, the student must decide to try again, ask for step by step help, or to see the answer. If he asks for the answer he can also do the step by step sequence.

The beginning and end of the step by step sequence depends on the units of the data and the units desired for the answer. If the data is given in units other than moles the student is told that, because the coefficients from the equation represent a mole ratio, he must first convert his data to moles. If the data is not in grams he is told how many grams are equivalent to his unit and is required to convert to grams. When converting grams to moles the student is told the formula weight of the compound but must do the calculation of the number of moles himself. The computer may be used as a calculator at any time.

With the data now expressed in moles the next step forces the student to use the mole ratio to determine how many moles of "x" are involved. If the quantity of "x" was to be expressed in moles the problem is solved. If not, the student must convert to grams and then to other units desired. The computer knows when to stop the sequence and to tell the student "your problem is solved." As in previous practice problems the student must specify if he wants the next step or to return to the original problem. See Figure 7.

3. Quiz

The quiz is designed to help the student determine where he is having trouble if any and to help him solve any problem that he is unable to do correctly.

The three questions on moles of compounds, three problems on concentration of solution, two problems on balancing equations and three problems on calculating quantities from chemical equations are listed in Appendix B. The last three problems are weighted four times as heavily as the others for the purpose of calculating the score. The score is calculated for the student's benefit and not as the basis for assigning a grade.

The student has two chances at each problem. After he has attempted all the quiz problems, his score is calculated and the problems which he missed are presented again. This time the student may request help immediately, solve the problem correctly on the first try, or be forced to a help sequence. The help sequence generally guides him through the individual steps, emphasizing the importance of each one. In each case the student must do the calculations himself.

If the student requests help calculating the weight of 0.5 moles of hydrogen molecules he is asked to type the formula for hydrogen molecules. If he answers incorrectly he is shown a list of elements which occur in nature as diatomic molecules and is encouraged to memorize them. After typing the correct molecular formula, he is asked to calcu-

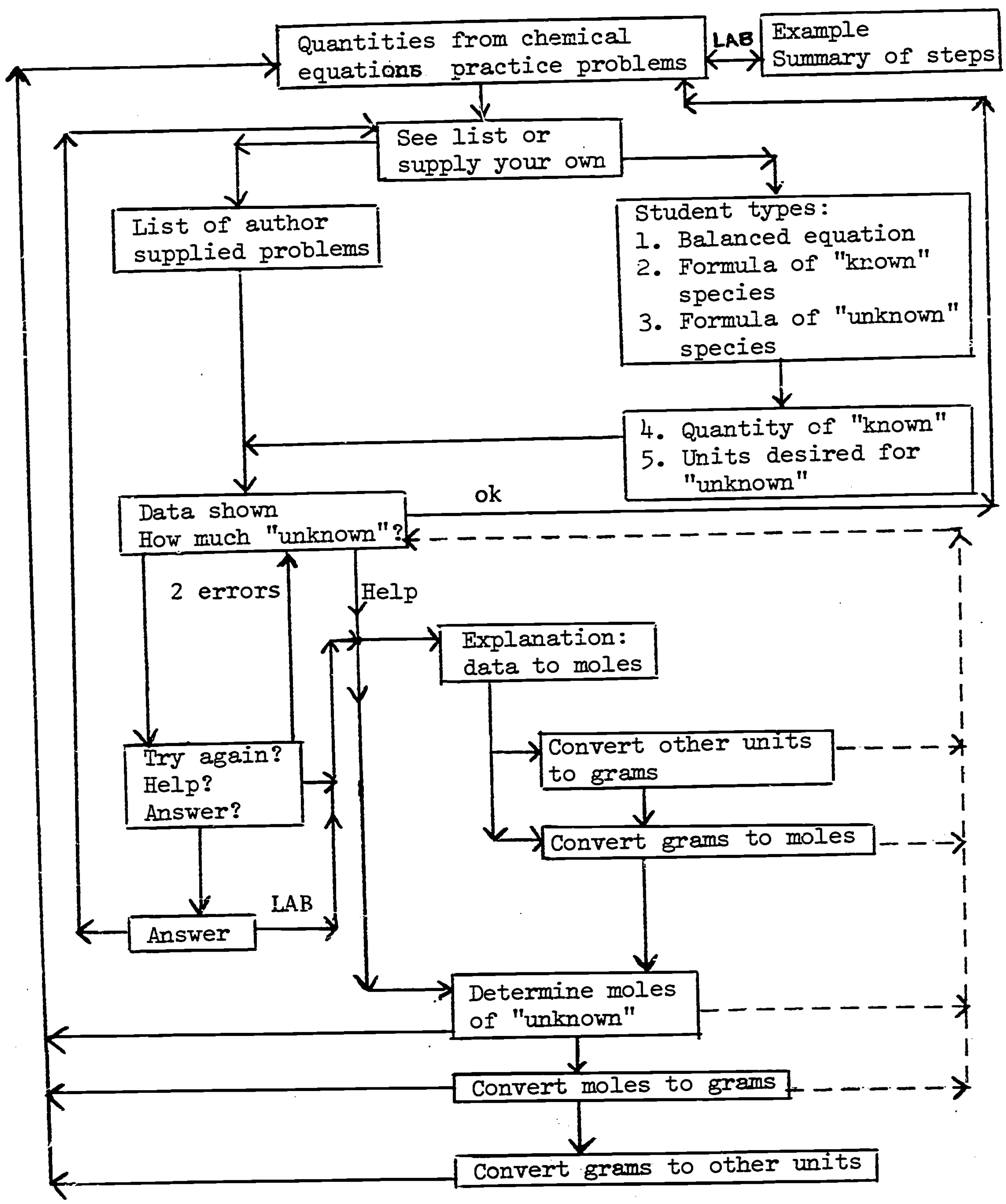


Figure 7. Flow Chart for Practice Problems on Determining Quantities from Chemical Equations.

late the weight of one mole of molecules and then the weight of 0.5 moles.

The help sequence for the problem involving calculating the concentration of a solution containing 40 grams of acetic acid in enough water to make 100 milliliters of solution consists of first requiring the student to express the 40 grams in moles and the 100 milliliters in liters. Then expressing the concentration as moles per liter of solution gives the molarity.

Each help sequence for the three problems on calculating the quantities from a chemical equation emphasizes a different point. In the first one, calculating the amount of magnesium chloride that can be produced by reacting 5.83 grams of magnesium hydroxide with hydrochloric acid, emphasizes the conversion of data to moles. The second problem requires the student to balance the equation and then specify the next step. Although encouraged to use conversion factors to solve each step, the student is required to type only the final answer for each step. In the last problem the data is presented as 82% of 450 grams of sulfur dioxide. The student must first realize that only 369 grams of the sulfur dioxide will react.

D. Balancing Oxidation-Reduction Equations

Balancing equations for oxidation-reduction reactions is considerably different than calculating chemical formulas and quantities from chemical reactions with respect to the amount of mathematical manipulation required at each step. However, the problems are similar as they all require a series of steps to be performed in sequence.

In these lessons on balancing oxidation-reduction equations, a number of new terms are introduced, such as oxidation, reduction, oxidizing and reducing agents, and half reactions. Emphasis is placed on the need to balance charge as well as mass. Continuous reinforcement is provided by using the knowledge of the previous step to develop each new step.

The material in these lessons is grouped around the following objectives: the student should be able to: 1) Assign oxidation numbers to elements according to a set of rules, 2) Identify oxidation-reduction equations, 3) Recognize oxidation and reduction half reactions, 4) Balance oxidation-reduction equations by the half reaction method, 5) Balance equations for reactions that occur in acid solutions by the half reaction method, 6) identify oxidizing and reducing agents, and 7) Balance equations for reactions that occur in basic solutions by the half reaction method.

1. Instructional Sequence

The lesson begins with the rules for assigning oxidation numbers. At the very beginning the student is told that the purpose of assigning the oxidation number does not necessarily mean that the atom has a charge. The first three rules dealing with assigning oxidation numbers to elements in their elemental forms, hydrogen, and oxygen are presented one at a time. After each rule the student is required to assign oxidation numbers to the elements in five compounds. The student is forced to use the knowledge of these first three rules to verify the next two rules.

The fourth rule, that the sum of the oxidation numbers in a neutral compound is zero, is demonstrated by the student assigning oxidation numbers to hydrogen and oxygen for the compound water, and summing them. This concept is extended to other compounds by calculating the oxidation number of sulfur in sulfuric acid. The student assigns and sums the total oxidation numbers for hydrogen and oxygen and subtracts from zero. He is then asked to assign oxidation numbers to every element in three additional neutral compounds.

The last rule dealing with assigning oxidation numbers to elements in an ion is introduced in exactly the same way by using the phosphate ion and dichromate ion as examples. The student then assigns oxidation numbers to all the elements in three more ions.

Now that the student has practiced using each rule individually, he is required to assign oxidation numbers to every element in a mixture of species, some ions and some neutral molecules and elemental forms.

He may go backwards through the rules as a review if he desires. To summarize the procedure for assigning oxidation numbers, the student is next required to fill in the blanks left in a presentation of each rule.

The next section of the lesson defines an oxidation-reduction reaction as one in which there are changes in oxidation numbers and that everytime there is oxidation, there must also be reduction. By assigning oxidation numbers to all the elements in every species of the reaction between silver nitrate and sodium chloride, the student discovers that not all reactions are of the oxidation-reduction type. The terms oxidation and reduction are introduced after the student has assigned oxidation numbers to each element in the reaction of magnesium metal with hydrochloric acid and has determined which elements increased or decreased in oxidation number. Reduction is defined as the gain of negative charge, electrons, or a reduction of the oxidation number. From a list of four half equations the student is required to pick out the two that represent reduction, and is told to note that for a reduction half reaction the electrons will always be on the reactant's side. The concept of reduction is reinforced by asking the student how many electrons are needed to reduce a silver(I) ion to silver metal and to reduce two iron(III) ions to metallic iron. Oxidation is identified as the opposite of reduction or the loss of electrons and the student is required to pick the two half reactions that represent oxidation from a list of four half reactions.

Now that the student can assign oxidation numbers and understands the definitions of oxidation and reduction, the procedure for balancing an equation is developed by first choosing a simple example, the reaction of zinc metal with hydrogen ions. The student assigns oxidation numbers and determines that zinc is oxidized and the hydrogen ions are reduced. He is then instructed to set up separate half reactions for oxidation and reduction by determining the product of oxidation, zinc ions, and the product of reduction, hydrogen molecules.

The procedure for balancing both mass and charge is explained for both half reactions with the student supplying the answers to questions. After the individual half reactions have been balanced, the student makes sure that the number of electrons lost equals the number gained and adds the half reactions together. Cautioned that although the procedure might at first appear to be a lot of work but that most equations are much more complex than the reaction of zinc and hydrogen ions, the student is shown a list of steps he has just followed.

The next section of the lesson develops the procedure of balancing half reactions when the reaction takes place in acidic solution. The example used is the oxidation of iron(II) ions with manganate ions in the presence of acid. First the student is required to use the material from the earlier part of the lesson to assign oxidation numbers and determine the reactants oxidized and reduced and the products of oxidation and reduction. He then balances the oxidation half reaction, adding an electron to the product side, $Fe^{2+} \rightarrow Fe^{3+} + e^{-}$. The reduction half reaction is not so easily balanced. After the student has determined the reactant and product for the reduction half reaction he is shown the balanced half reaction, including the additional hydrogen ions and water molecules. The rule for balancing excess oxygen is presented and the student determines how many hydrogen ions to add. Now that the mass is balanced the student is guided through the procedure of adding electrons to balance the charge. To balance the number of electrons lost with the number of electrons gained, the student multiplies the oxidation half reaction by five and adds the half reactions together, cancelling out species which occur on both sides of the arrow. The student is now shown a summary of the procedure for balancing the excess oxygen and hydrogen, the only new step introduced in this section.

The student is next required to balance two reduction half reactions which occur in acid. The first, reduction of dichromate ion to chromium (II), by answering questions at each step and the second, reduction of arsenic trioxide to arsenic hydride, by typing complete equations. After each half reaction has been balanced, the student is asked whether it is oxidation or reduction.

The final equation for a reaction which occurs in acid is the reaction of copper metal with concentrated nitric acid to produce nitrogen dioxide. The student is asked to pick out the oxidation and reduction half reactions and to type the balanced equation for each. The oxidation of copper metal to copper(II) ions is easily balanced in one step by adding two electrons to the product side, but the reduction of nitrate ion to nitrogen dioxide requires several steps. For each step the student is required to type the correct equation, first balancing the oxygen, then the hydrogen, and finally the charge. The student is then asked for the next step. After answering that the next step is balancing the electrons lost with the electrons gained, he specifies that the reduction half reaction must be multiplied by two. The next display presents the two half reactions being added together, and the equation is balanced when the student fills in the blanks on the product side.

The terms oxidizing and reducing agents are defined and applied to the last equation with the student selecting the proper species. A table of the terms oxidation, reduction, oxidizing agent and reducing agent, and their change in oxidation state and accompanying change in electrons is displayed.

The last part of the lesson extends the concepts learned earlier to reactions which occur in basic solutions. The student is told that the only change in the procedure is in the method of balancing the oxygen and hydrogen. After the student sees a description of how to balance the oxygen, he is required to complete an equation. The same procedure is used for presenting the method of balancing the hydrogen.

The last equation in the lesson is one for the oxidation of zinc metal by nitrate ions in the presence of base. The student assigns the oxidation numbers and determines the species in the oxidation and reduction half reactions. He must then apply the rules for balancing mass for reactions that occur in base. The only help available is the option of going backwards to the rules. For each half reaction the student must fill in the blank spaces in the equation to balance the oxygen and answer questions about balancing the hydrogen and the charge. The electrons lost and gained are balanced, and the half reactions are added together and the equation is balanced. The lesson ends with the student receiving a summary of the general steps in balancing an oxidation-reduction equation and then specific steps to balance hydrogen and oxygen for reactions which take place in acid or in base.

Very little help is available in the way of extra sequences; however, the student can generally see a list of the steps he has performed and may go backwards in the lesson. Many frames, particularly those requiring the typing of equations, have extensive error messages.

The section of this lesson dealing with the reduction of dichromate ions, reduction of arsenic trioxide, and the oxidation of copper metal by nitric acid is used as a review if the student cannot do the practice equations for reactions that occur in acid.

The entire last section dealing with balancing equations for reactions which occur in base is also used as a review if the student has trouble with the practice equations.

When using this lesson as a review, the student may select topics from the following list. All the sequences are the same as those described above: 1) Assigning oxidation numbers, 2) Types of reactions, 3) Oxidation and reduction defined, 4) General steps for balancing oxidation-reduction equations, 5) Balancing equations for reactions which occur in acid, 6) Practice balancing half reactions which occur in acid, 7) Oxidizing and reducing agents defined, and 8) Balancing equations for reactions which occur in base.

2. Practice Equations

The student is required to balance three equations for reactions which occur in acid and three equations for reactions which occur in base. The student must work on the equations in the order presented by the author and he may not supply his own.

For each equation the student is shown the skeleton equation and is required to type the final completely balanced equation. The only help available is a list of the steps, including how to balance any hydrogen and oxygen.

An extensive variety of errors are detected and pointed out to the student. If the reaction occurs in acid, the presence of hydroxyl ions or the absence of hydrogen ions or hydronium ions in the student's equation invokes an appropriate error message. The equation is checked for balance of both charge and mass and the student is told every element which is not balanced. After the student has missed an equation twice, he may choose to try again or to see the answer. If he requests to see the answer he is shown the balanced half reactions as well as the final answer.

If the student asked to see the answer to any one of the three equations for reactions which occur in acid, he is forced to review the balancing of the half reactions for the reduction of dichromate ions and arsenic trioxide and the oxidation of copper metal. Similarly for the reactions which occur in base, the student must review the oxidation of zinc metal by nitrate ions in the presence of base. The review is not presented until the student has attempted all six equations.

3. Quiz

The quiz on balancing oxidation-reduction equations is divided into two parts; the first is a series of fifteen questions on the concepts, terms and procedures presented in the lesson, and the last part consists of equations for two reactions which occur in acid and for one reaction which occurs in base (see Appendix B). The student is given no help or error messages for the first fifteen questions. He has two chances per question unless the question requires two answers or is a multiple choice question in which case he has three chances and one chance respectively. The student is shown the answer to any question which he missed the maximum number of times.

For the last three equations, each of which counts three points when determining the final score, the student is given two chances. Very extensive error messages are provided. After the quiz the student must do the equations that he missed again. This time the student may request help immediately or be forced into the step by step help sequence after two errors.

The help sequence is the same for each question. The student is shown the skeleton equation and is asked to select the reactant that is oxidized, the reactant reduced, and the products of oxidation and reduction. Additional help in the form of the definitions of oxidation and reduction is available at the student's request. He may also see a list of the rules for assigning oxidation numbers. After noting the oxidation and reduction half reactions, the student is required to type the balanced half reactions. If he chooses he may see the procedure for balancing oxygen and hydrogen for reactions which take place in acid or in base. Again the student has the benefit of an extensive variety of error messages. The student is next asked a question about making sure that the number of electrons lost and gained are equal and is then shown the correctly balanced equation. After each balanced equation is shown, he is encouraged to double check that it is balanced by both charge and mass.

V. RESULTS

A. Student Selection and Attendance

The lessons were designed primarily for students who have had no prior experience with the topics, thus students were chosen from the Chemistry 100 course at the University of Illinois.

In the Fall of 1968 and Spring of 1969 the major function of student trials was to test the operation of the programs, thus they were scheduled when the author desired information about the program and not necessarily when the topic was being covered in class. The lessons were then revised in content, style, and program features on the basis of these student results. The students were volunteers, however, the teaching assistants would often strongly recommend that those who were having trouble with the course and wanted some extra work join the PLATO group. No effort was made to have the same number or the same students at each trial.

In the Fall of 1969 and Spring of 1970 an attempt was made to have the same students attend all the PLATO sessions, which were scheduled to coincide with the lectures. Because the students were asked to attend PLATO in addition to the normal class sessions and because the PLATO sessions were held in the evening, students were not forced to attend. However, all students in the selected quiz sections were strongly encouraged to attend PLATO and six extra points were added to the quiz average of those who attended PLATO regularly. The maximum effect this could have on the final course average was one point out of 100 (see page 96).

In the Fall of 1969 forty-two students from two quiz sections meeting at the same time were enlisted to attend PLATO. For each topic the students were able to work for two hours on Monday evening and for another hour on either Tuesday or Wednesday afternoon. Two additional Monday evenings were reserved for quizzes and review.

The attendance as indicated in Table 2 varied depending upon the scheduled activity and the occurrence of conflicting activities. Attendance was particularly good on the evenings when a new topic was presented, October 13 and 20, and November 10. The afternoon sessions were available for those who had not finished the instruction or who felt they needed to review. On both evenings when the quizzes were presented there were conflicting campus activities.

Of the forty-two students who originally agreed to attend PLATO, five did not attend. Three of the five dropped the course. Of the thirty-seven students who attended at least one PLATO session, twelve attended all eight sessions, fourteen attended all five evening sessions and an additional fourteen were absent only one evening. Only four of the thirty-seven or 11% of those who attended at least one session on the first two topics did not attend any sessions on oxidation-reduction and can be considered drop-outs.

Table 2. PLATO Attendance Fall 1969

Date	Topic	Attendance
Oct. 13	Math review Formula instruction	35
Oct. 14,15	Finish instruction and/or review	31
Oct. 20	Concentration of solutions and quantities from chemical equations	33
Oct. 21,22	Finish instruction and/or review	30
Nov. 3	Quizzes on chemical formulas and quantities from chemical equations and concentration of solutions	26*
Nov. 10	Oxidation-reduction instruction	31
Nov. 11,12	Finish instruction and/or do practice equations	23
Nov. 24	Oxidation-reduction quiz	19**

*Conflict with English Department movie.

**Thanksgiving Week.

In the Spring 1970 the computer was available four hours on Monday evening and one hour each on Tuesday and Thursday afternoons. The following changes in the schedule were made: to provide more time for the formula instruction the math review was given one week earlier; students were given ample time, four hours, to finish the instruction on Monday evening; the afternoons were used to do practice problems which were not available in the Fall; each quiz was given on a separate night two weeks after instruction; and an additional opportunity to take two of the quizzes was provided at the end of the semester. Thus instead of five evening sessions, eight were now available (see Table 3).

Twenty-two students were enlisted from one of two quiz sections taught by the same teaching assistant. Three of these students did not attend PLATO and one transferred quiz sections after one session. Originally the students were told only that they would be required to attend the lessons dealing with chemical formulas, concentration of solutions and quantities from chemical equations. Later in the semester when given a chance to volunteer to attend sessions dealing with oxidation-reduction, thirteen of the eighteen who attended at least one of the previous sessions eagerly agreed to attend these sessions too.

The attendance once again was particularly good on the Monday evenings when new topics were presented. The only exception was for balancing oxidation-reduction equations for which some students were confused about the date. At least three students showed up at the PLATO classroom the week after the instruction had taken place. As indicated in Table 3, three of the eighteen students were unable to attend the afternoon sessions because of conflicts with other classes. Six students attended all the evening sessions and eleven missed no more than two sessions. The quiz and review of concentration of solutions and quantities from chemical equations were given the day classes were to resume after spring vacation. Several students said they did not return to campus in time to attend the PLATO sessions.

Table 3. PLATO Attendance Spring 1970

Date	Topic	Attendance
Mar. 2	Math skills	18
Mar. 9	Chemical formulas instruction	17
Mar. 10,11	Practice problems	12 (3 excused)
Mar. 16	Concentration of solutions and quantities from chemical equations instruction	16
Mar. 17,19	Practice problems	9 (3 excused)
Mar. 23	Formula quiz and review	14
Apr. 6	Concentration of solutions and quantities from chemical equations quizzes and review	9*
Apr. 13	Oxidation-reduction instruction	10**
Apr. 14,16	Practice equations	5 (3 excused)
Apr. 27	Oxidation-reduction quiz	9
May 18	Special review session	13

*First day after spring vacation. Classes started for students at noon. Students had not been in chemistry class for two weeks.

**Schedule mixup. At least three students appeared on the wrong night.

Tables 2 and 3 indicate that fewer students attended PLATO quizzes and practice sessions than attended the instructional lessons. Some students may have felt that it was not worth the time and effort to come to these lessons on material which they had already studied. However, the attendance figures for both semesters, as summarized in Table 4, for the nights when new material was presented show that attendance dropped only 11% between the first and third week of PLATO experience. In spite of the fact that PLATO was available in the evening when other activities are often scheduled and that the PLATO facility is located across campus from most dormitories, twenty-eight of the thirty-seven or 76% of the students were absent for no more than one of the five evening sessions in the Fall and 11 of 18 or 61% of the students in Spring missed no more than two of the eight evening sessions, even though the last three were not originally scheduled. It is hard to imagine that the students would maintain such interest over a seven or eight week period for the sole purpose of gaining one extra point on their final average.

Table 4. Summary of Attendance for Evenings When New Material Was Presented

Topic	Fall 1969		Spring 1970	
	number (37)	percent	number (18)	percent
Math review	35	95%	18	100%
Chemical formulas	35	95%	17	94%
Concentration of solutions and quantities from chemical equations	33	89%	16	89%
Oxidation-Reduction	31	84%	10 (optional)	56%

B. An Analysis of Student Data

Every time the student pressed one of the functional keys on the keyset, a record of his activity was stored on a magnetic tape. This record included the student's name, the time elapsed since he started the lesson, the name of the unit or frame and the number of the question on which he was working, the result of the judgment of the student's answer or his request for a special feature such as help, and the student's response. The computer was used to sort the data and to print out a list of the activity of each student. The list was ordered by student names and by unit names. In the first case the list contained all the data for student 1 and then all the data for student 2, etc., while in the second case, the results of all students on question 1 were listed before the results on question 2, etc. The following analysis of part of the student data gives an indication of the wide variety of individualized instruction achieved by these lessons and some trends in student performance. The individuality was achieved not only in the amount of time that a student spent on given material but also by the sequence of material, the amount of help and the specific error messages that he received.

1. Instructional Sequences

In the Fall 1969 the students were given two hours on Monday evenings in which to work on the instructional sequence for each of the three topics and an additional hour was provided on Tuesday or Wednesday for those students who needed it. In the Spring 1970, however, four hours were provided on Monday evenings and no additional time to complete the instructional sequence was available as the time on Tuesday and Thursday was used to solve practice problems. At all sessions students were permitted to leave at any time whether they had completed the work or not.

The sequences used in the Fall and Spring were identical except for the lesson on chemical formulas in which another problem was added and the opportunity was provided for the student to practice using moles as a conversion factor. In the Fall the use of each instructional sequence was preceded by the lecture but because of the hour exam schedule in the Spring only the lesson on concentration of solutions and quantities from chemical equations was preceded by a lecture. The only other difference in the use of the instructional sequences in the Fall and Spring was that the lesson on chemical formulas was available on the same night as the math quiz in the Fall but in the Spring the math quiz and instruction on chemical formulas were presented at separate times. In both semesters only the faster students were able to complete the lesson on balancing oxidation-reduction equations, however all students were encouraged to complete at least the portion of the lesson concerning reactions which occur in acid solutions.

Table 5 shows the number of students from both groups that completed the lessons and the average amount of time they required. The data for the lesson on chemical formulas for the Spring excludes the time spent on material which was not available in the Fall.

The evidence indicates that the students who were required to work on a lesson for a long stretch of time in the Spring performed less efficiently that those who were permitted to work for two shorter periods in the Fall. For every lesson the average time of those who completed the lesson in the Spring was higher than for those who completed the lesson in the Fall. This is particularly interesting when it is noted that the percentage of the Spring group which completed each lesson was lower than the percentage of the Fall group, even though the total time available to the Spring group was one hour longer than for the Fall group. Each of the students who failed to complete the lessons on chemical formulas and concentration of solutions and quantities from chemical equations in the Fall 1969 worked for the full time available to them while five of the eight who did not complete the oxidation-reduction lesson were absent on the second day.

Table 5. Number of Students Who Completed the Instructional Sequence and the Time They Required

a) Chemical Formulas

	# of students who started	# of students who finished	% of students who finished	Average time for those who finished (minutes)
Fall	35	33	94	60
Spring	17	14	82	77

b) Concentration of solutions and quantities from chemical equations

Fall	33	29	88	92
Spring	16	13	81	104

c) Balancing equations for oxidation-reduction reactions

Fall				
(acid)	31	23	74	101
(base)	31	18	58	107
Spring				
(acid)	11	7	64	134
(base)	11	5	45	138

In the Spring none of the students worked the full four hours available to them. The longest time that any student worked was three and a half hours while the longest time put in by a student who did not finish the lesson was only two hours and fifty-one minutes. Those that did not finish in the Spring simply got tired and quit or had to leave for some other appointment. The average time used by those who did not finish was one hour and forty-seven minutes. It appears that the maximum length of time that a student can effectively work is approximately two hours and that the most efficient use of the lessons would be provided by a schedule that permitted the student to come and go as often as he pleased.

The fact that the difference between the mean times for the two groups was higher for the lessons on chemical formulas and balancing equations for oxidation-reduction reactions than for the lesson on concentration of solutions and quantities from chemical equations as shown in Table 6 indicates that the lack of lecture before the use of the

Table 6. Comparison of the Average Times to Complete the Instructional Sequences by the Spring and Fall Groups

a) For all students who finished

	Fall 1969		Spring 1970		
Topic	Percent that finished of the total group	Mean time (min.)	Percent that finished of the total group	Mean time (min.)	Difference between the means (min.
Chemical formulas	94	60	82	77	17
Concentration of solutions and quantities from chemical equations	88	92	81	104	12
Balancing oxidation-reduction equations	74	101	64	134	33

b) Considering only the times for the same percentage of the students who completed the lesson in the Fall as the percentage of those who completed the lesson in the Spring

Topic	Percent that finished of the total group	Fall mean time (min.)	Spring mean time (min.)	Difference between the mean times	Difference expressed as percent of Fall mean
Chemical formulas	82	56	77	21	37
Concentration of solutions and quantities from chemical equations	81	88	104	16	18
Balancing oxidation-reduction equations	64	94	134	40	43

instructional sequence also affected the rate.

In order to make a fairer comparison only the times for the same percentage of students who completed the lesson in the Fall as the percentage of those who completed the lesson in the Spring should be considered. When only the values for the first 82% of the Fall group to finish the lesson on chemical formulas were used to calculate the mean, the difference between the mean time for the Fall and Spring groups was twenty-one minutes. This difference expressed as a percent of the Fall mean shows that the average time required for the same percentage of students to complete this instructional sequence in the Spring was higher than in the Fall. Part b of Table 6 shows that similarly on the average the Spring group required 18% more time to complete the lesson on concentrations of solutions and quantities from chemical equations and 43% more time for the lesson on balancing oxidation-reduction equations. A comparison of these values shows that the instructional sequence for chemical formulas and balancing oxidation-reduction equations which were not preceded by a lecture required nineteen and twenty-five percent more time on the average than the instructional sequence for concentration of solutions and quantities from chemical equations which was preceded by a lecture.

One of the most important features of individualized instruction is the ability to permit the student to work at his own rate. The data presented in Table 7 indicated that the time required to complete each instruction sequence varied widely from student to student.

For the lesson on chemical formulas and the lesson on concentration of solutions and quantities from chemical equations, each of which had a completion rate of over 80% in both the Spring and Fall, the range of times for those who completed the lessons indicated that the slowest students required approximately three times as long as the fastest student in every case. The slowest students who completed the lesson on balancing equations for oxidation-reduction reactions required more than twice as much time as the fastest student. This spread would no doubt have been much larger if a higher percentage of students had completed the lesson.

Table 7. Summary of Time Required to Complete Instructional Sequences (Minutes)

a) Chemical formulas

Date	Range	Median	Standard deviation	Mean	% of students who finished
Fall 1969	40-125	58	16.5	60	94
Spring 1970(*)	40-121	70	25.7	77	82
(**)	55-187	84	36.8	99	82
b) Concentration of solutions and quantities from chemical equations					
Fall 1969	52-145	88	28.5	92	88
Spring 1970	64-187	92	35.5	104	81
c) Balancing equations for oxidation-reduction reactions					
Fall 1969					
(acid)	60-154	94	30.9	101	74
(base)	71-158	102	28.6	107	58
Spring 1970					
(acid)	90-200	118	45.7	134	64
(base)	96-209	128	42.1	138	45

*Same material as in Fall 1969.
**Including material added after Fall 1969.

In addition to the large difference between the times for the fastest and slowest students indicated by the ranges, the high standard deviation from the mean indicates that the times required by the majority of the students were not bunched around the mean but scattered. In each case the standard deviation was approximately 30% of the value of the mean.

Each of the instructional sequences not only permitted the students to work at their own rate but also provided individualized instruction in terms of specific feedback to student responses and variations in the presentation of material. At times the student was able to directly control the sequence of material such as the use of a help sequence, review of previous material, and the presentation of additional problems, while at other times the presentation of material was predetermined on the basis of an analysis of the student's performance. This flexibility throughout the lessons provided the means for the student to receive individualized instruction as indicated by the data for the few examples which follow.

For the problem which required the student to determine the simplest formula for phosphorus(V) oxide the student was automatically forced into a help sequence after he made three errors, however, prior to making three errors he could use the help sequence at his own request. Twenty-five of the fifty-two students who solved this problem in the Fall or Spring required no help, eleven or 21% of the students were forced into the help sequence and thirteen students requested the help.

In the Fall eighteen of the thirty-five students took advantage of the option to review the use of conversion factors as did seven of the seventeen students in the Spring. On the basis of their performances on the first problem in the lesson on chemical formulas three students were forced to practice using moles as a conversion factor while an additional five of the seventeen students in the Spring group chose to do this practice.

When help was available some students requested it immediately while others made several attempts before asking for help. The students were told that help was available for the problem requiring them to calculate the weight of oxygen needed to react with zinc sulfide to produce 100 grams of zinc oxide. Six of the forty-four students who solved this problem did so without requesting help, twenty or 46% of the students asked for the step by step help before attempting the problem, nine or 20% made one incorrect attempt, two students made two incorrect attempts, four students made three incorrect attempts and one student made ten incorrect attempts before requesting help. Two other students requested the correct answer.

Some students requested help quite frequently while others only infrequently. An analysis of the data of the students in the Spring group shows that in the lesson on chemical formulas, one student requested help on eight different problems, another requested help on seven problems while five students requested help only once. The other students requested help between two and five times throughout the lesson.

The analysis of the data for each of the three lessons shows that although the students were generally required to solve the same problems, the provision of help sequences, specific feedback for incorrect responses, opportunities to review previous material or to branch to additional practice and the opportunity for the student to work at his own pace were successful in providing each student with a unique instructional experience.

2. Quizzes

The students were aware that the scores on these quizzes would not affect their course grade and that after the quiz they would either receive help with any problems which they missed or be given additional instruction in the areas in which they did poorly. In this way the amount of review work as well as the type of material each student received was determined by his results on each quiz. For example, after the quiz on the four math skills in the Spring 1970, one student needed to review three skills, two students needed review in two areas, three students needed to review only one area and the remaining twelve of the eighteen students required no review. The most frequently reviewed area was percent while no one needed to review multiplication of fractions.

In addition to the differences in the review material required by each student, differences were also noted in the amount of time required to complete the quiz questions themselves. For each quiz the range of time between the fastest and the slowest student was quite large as was the standard deviation from the mean time as indicated by the data in Table 8 and the plots of the scores versus time in Figures 8 through 11 for the quizzes when administered two to three weeks after instruction.

Table 8. Summary of Time Required to Complete the Quizzes (Minutes)

	Fall			Spring		
Quiz Topic	Range	Standard deviation	Mean	Range	Standard deviation	Mean
Math	8-67	11.6	18.7	11-49	9.2	20.1
Formulas	14-48	8.4	23.6	17-45	9.2	26.9
Concentration of solutions and quantities from chemical equations	10-63	12.6	35.9	20-72	18.2	41.4
Balancing oxidation-reduction equations	24-111	22.5	46.9	42-87	15.1	61.2

In the Fall the fastest student required eight minutes to finish the math quiz and his score was perfect while the slowest student worked for over an hour and answered only ten of the seventeen questions correctly. In the Spring the students who finished the Math quiz in the shortest amount of time also did better than those who took much longer. The same trend is observed in the results of the quiz on chemical formulas for both the Fall and Spring semesters. On the quiz on concentration of solutions and quantities from chemical equations there appears to be no relation between the score and time as in the Fall both the fastest and the slowest student earned low scores, one and six respectively out of a possible twenty points, while in the Spring the fastest student earned a score of fifteen and the slowest student a score of nineteen.

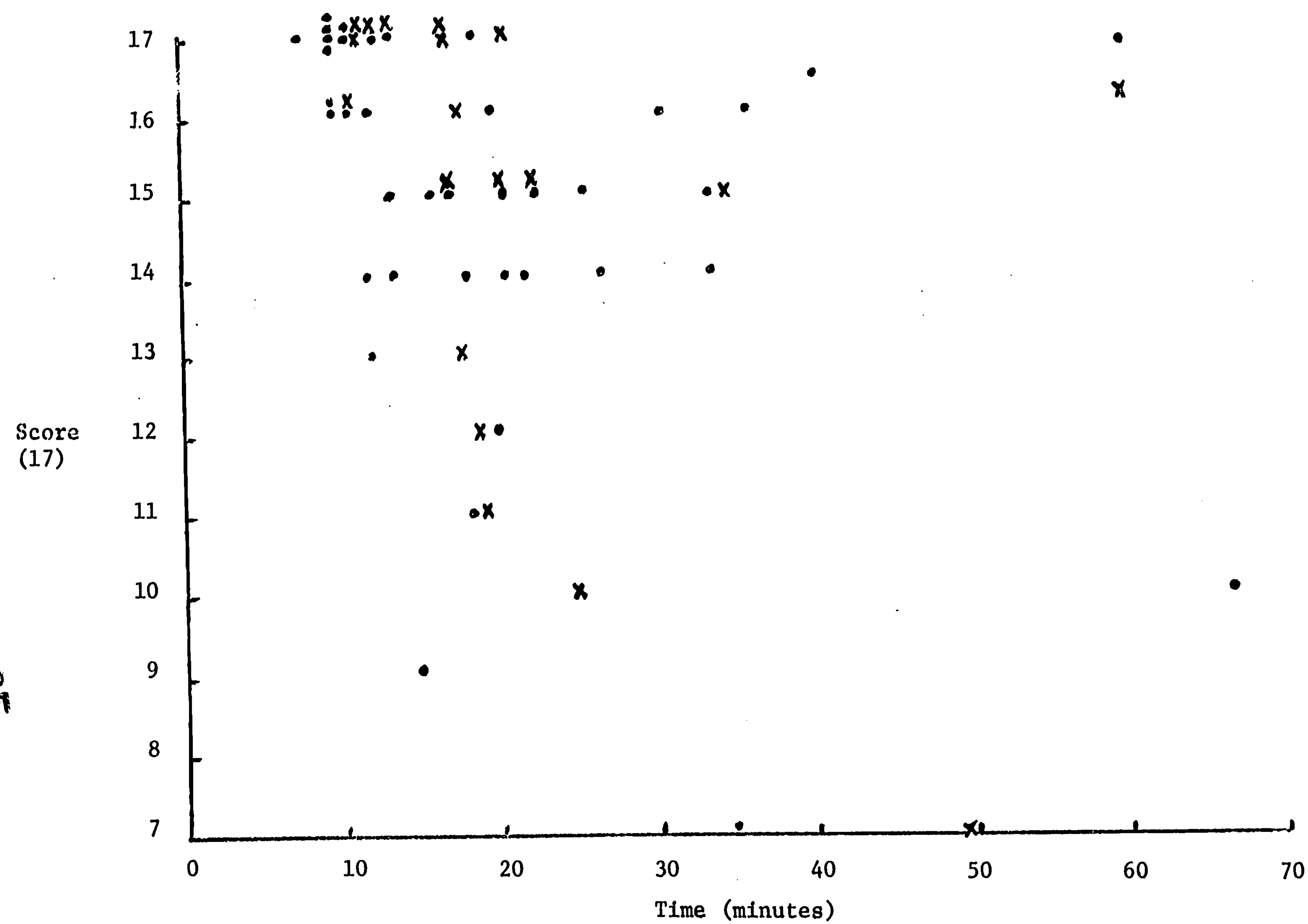


Figure 8. Plot of Score versus Time for Math Quiz.

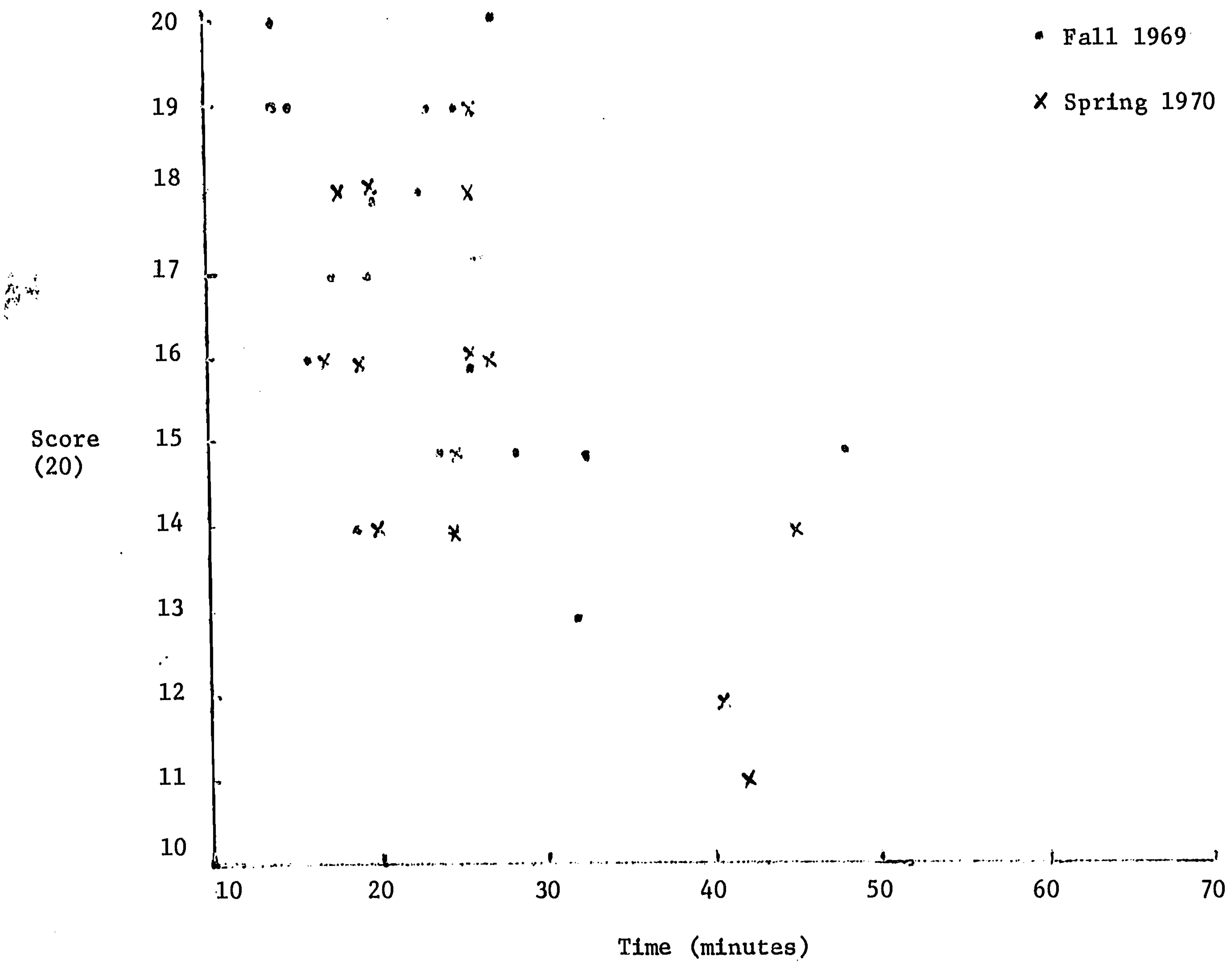


Figure 9. Plot of Score versus Time for Formula Quiz.

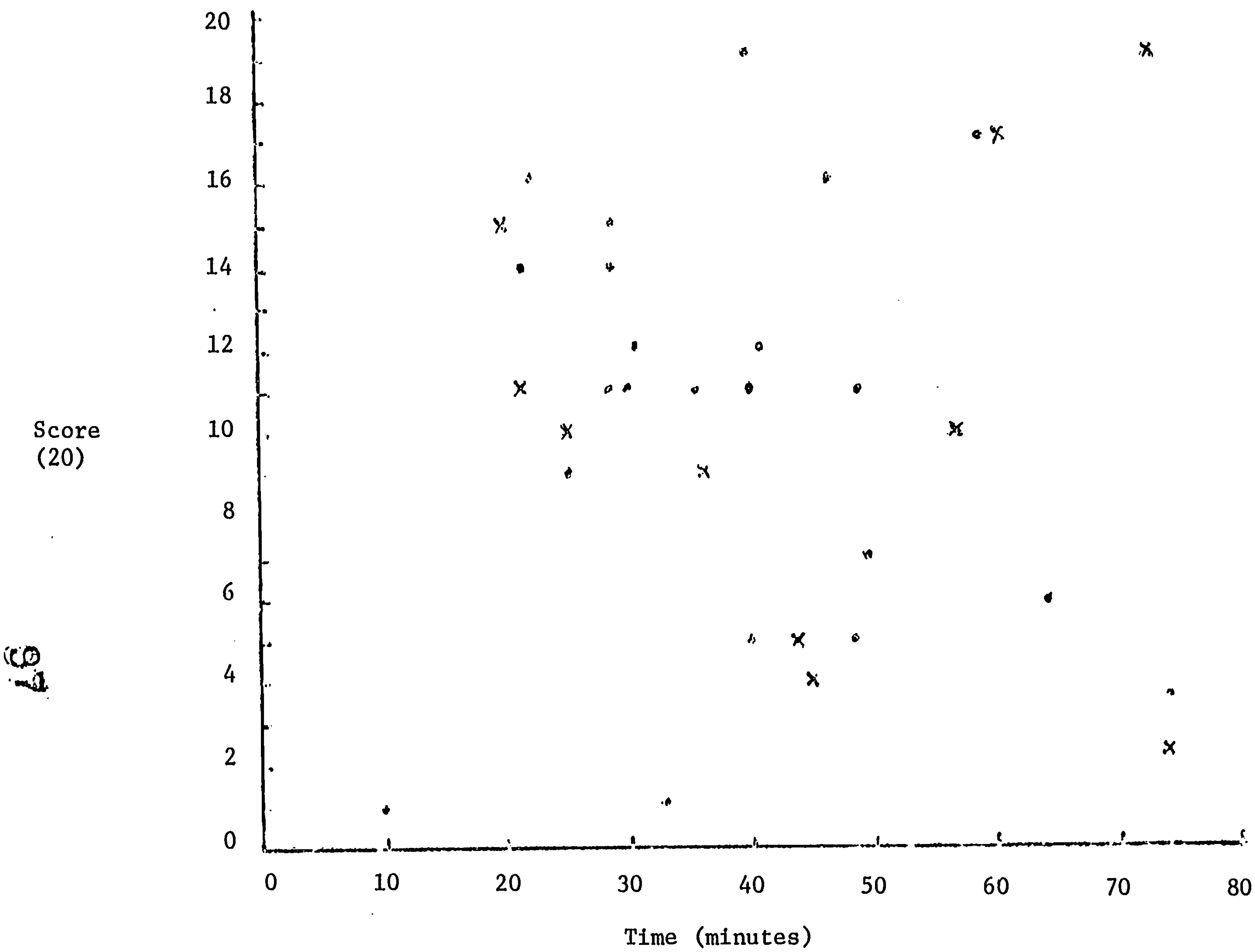


Figure 10. Plot of Score versus Time for Concentration of Solutions and Quantities from Chemical-Equations Quiz.

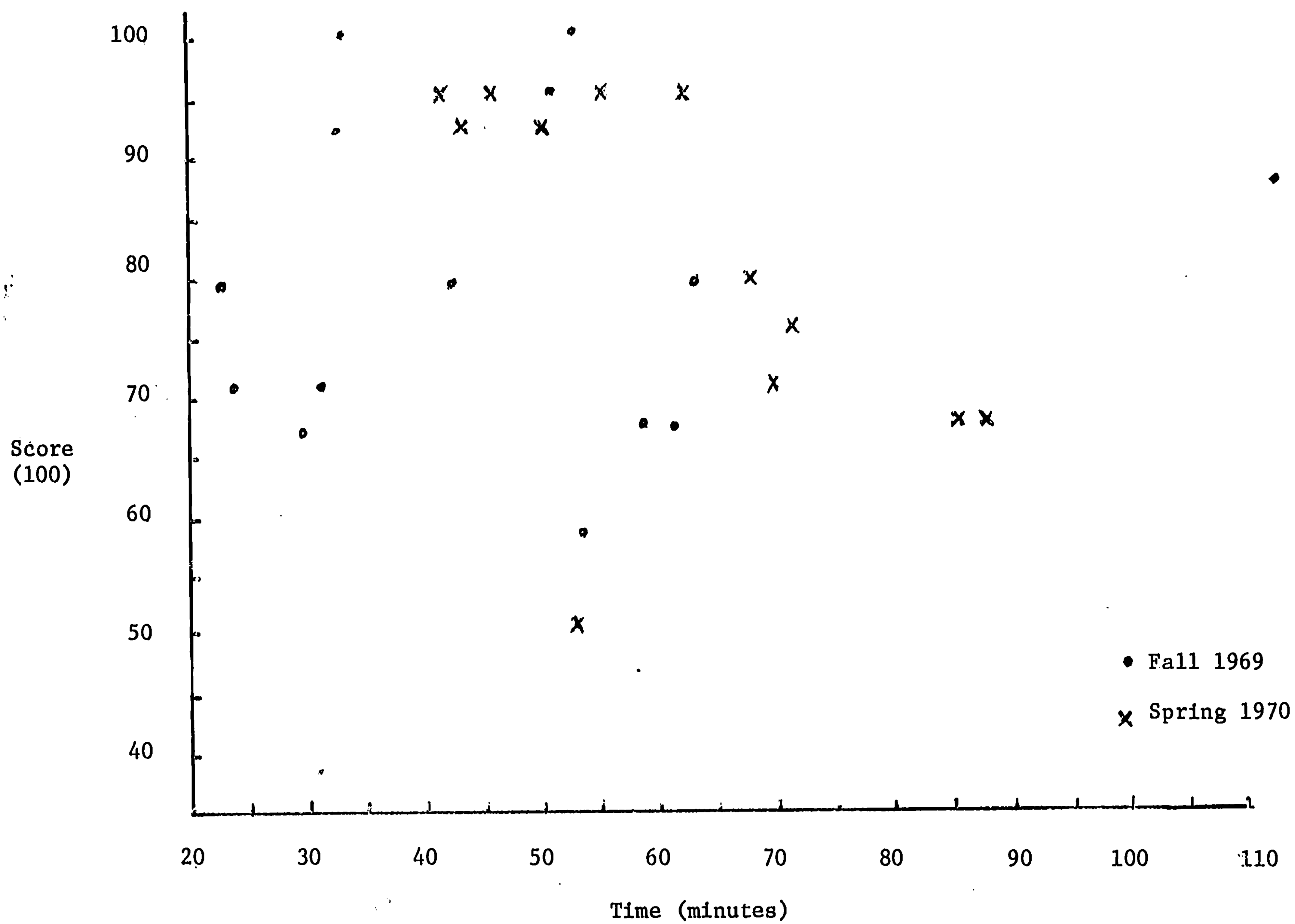


Figure 11. Plot of Score versus Time for Quiz on Balancing Oxidation-Reduction Equations.

Table 9 shows a summary of the correlation between the time and scores for each time the quizzes were administered.

The high negative values of the correlation between the score and time for the math and chemical formulas quizzes indicate that in general the lower scores were earned by those who spent the most time and the higher scores were earned by those who completed the quiz in the shortest time. A t-test of the significance of these correlations shows that the probability of the calculated correlation occurring by chance for the math quiz was less than one chance in 100 for both semesters, while for the quiz on chemical formulas the probability of these correlations occurring by chance was less than 5% in the Fall and less than 2% in the Spring. Both of these quizzes contained questions that required only simple answers or one step calculations.

The correlation between time and score was not significant in either the Fall or Spring semester for the quiz on concentration of solutions and quantities from chemical equations as the probability of the calculated correlation occurring by chance was greater than 70% in the Fall and greater than 30% in the Spring. This quiz contained eight questions requiring simple answers or one step calculations and three problems which required several steps. Evidently the better students answered the first eight questions more rapidly than the poorer students and the poorer students made only superficial attempts or skipped the last three problems while the better students spent considerable time. Thus the correlation between time and score was not significant.

In the Fall the value of the correlation between time and score for the quiz on oxidation-reduction equations was small and positive, +0.19, while in the Spring the value was rather large and negative, -0.57. This discrepancy can be explained by considering the different requirements placed upon the students in the Fall and Spring. The quiz contained fifteen questions which required simple answers and three equations to be balanced which required a considerable amount of time. In both semesters the students were given two chances at each of these last three equations but in the Fall blank answers were counted as an

Table 9. Summary of Correlation of Score and Time on PLATO Administered Quizzes

Topic	Correlation	t_{corr}	Degrees of freedom	Significance
		Fall 1969		
Math	-0.45	2.88	33	$.01 > p > .001$
Chemical formulas	-0.48	2.18	16	$.05 > p > .02$
Concentration of solutions and quantities from chemical equations	+0.08	0.34	19	$.80 > p > .70$
Balancing oxidation-reduction equations	+0.19	0.72	13	$.50 > p > .40$
		Spring 1970		
Math	-0.71	4.03	16	$.01 > p > .001$
Chemical formulas	-0.66	3.03	12	$.02 > p > .01$
Concentration of solutions and quantities from chemical equations	+0.34	0.96	7	$.40 > p > .30$
Balancing oxidation-reduction equations	-0.57	2.19	10	$.10 > p > .05$

attempt while in the Spring they were not. Thus in the Fall poorer students were able to skip equations while those in the Spring were required to attempt each equation twice.

3. Practice Problems

The purpose of the lessons which permitted the students to practice solving problems was to provide help when the student had difficulty and to allow him to work at his own rate. Practice problems for all three topics were available only in the Spring 1970.

After the students had used the instructional sequence on chemical formulas, they were given the opportunity to spend an additional hour solving problems of the following types: Type 1. Calculating the simplest formula of a compound from the known composition by weight, and Type 2. Determining the percentage composition of a compound given the chemical formula. The practice session was completely under the control of the student. He was able to choose his problems from a list supplied by the author (see Appendix C) and to supply his own problems. He was initially asked for the final answer of each problem but could work through the problem in steps under the guidance of the computer by requesting help.

Eight of the twelve students who attended the practice session chose to see an example of the procedure required to solve problems of Type 1 while three chose to see an example of the problems of Type 2. Some students chose to look at the examples before attempting any problems while others waited until they had successfully completed several problems. Every student used the computer as a calculator at least once during the session.

The number of problems completed by each student and the number of requests for help are summarized in Table 10. The total number of problems completed by each student ranged from two to eight while the range for problems of Type 1 was one to five and for problems of Type 2, the range was zero to four. The average number of problems of both types completed per student was five. The list of the total requests for help shows that some students such as students number 3, 5, and 9 requested help with almost every problem while student number one completed eight problems without requesting any help.

Five students supplied their own problems which were generally taken from their course syllabus or homework assignment, while the others used the problems supplied by the lesson author. Two of the five students who supplied their own problems did not solve any of the author supplied problems.

Of the total of sixteen requests for help with problems of Type 1, fourteen were made by students working on author supplied problems and two were made by students working on problems that they had supplied. Five of the eleven requests for help with problems of Type 2 were made

Table 10. Summary of the Number of Practice Problems on Chemical Formulas Completed by Each Student

	Number of problems of Type 1		
Student Number	Author supplied	Student supplied	Requests for help
1	2	0	1
2	1	2	1
3	3	0	2
4	1	0	0
5	2	0	2
6	3	0	1
7	4	0	3
8	1	1	0
9	5	0	4
10	0	2	1
11	4	0	0
12	0	1	1
Total	26	6	16

	Number of problems of Type 2				
Student number	Author supplied	Student supplied	Requests for help	Total # of problems of both types completed in one hour	Total # of requests for help
1	3	0	0	5	1
2	0	2	0	5	1
3	2	0	2	5	4
4	0	1	0	2	0
5	0	0	0	2	2
6	3	0	1	6	2
7	3	0	2	7	5
8	0	3	2	5	2
9	2	0	2	7	6
10	0	2	1	4	2
11	4	0	0	8	0
12	0	2	1	3	2
Total	17	10	11	59	27

by students who supplied their own problems.

The students had no trouble supplying their own problems. The average time required to supply the data for problems of Type 1 and Type 2 was 2.5 minutes and less than one minute respectively and the data for three of the six problems of Type 1 were entered in approximately one minute.

Some students spent as long as twelve or thirteen minutes on the first problem of Type 1 while others were able to solve this problem in two or three minutes. Similar differences in times were noted for the other problems and the number of requests for help varied from one problem to another. The longest time required to complete a problem was 26 minutes and the shortest time was 2 minutes. The average time required to solve problems of Type 1 was seven minutes and to solve those of Type 2 was six minutes.

Another practice session was held after the instructional sequence on concentration of solutions and quantities from chemical equations had been completed. At this time the opportunity to practice a third type of problem involving calculating quantities from chemical equations was made available to the students in addition to the two types of problems concerning chemical formulas. Table 11 shows a summary of the number of problems of Type 3 completed by each student and the number of requests for help. Several students had started an additional problem but were unable to finish within the time for which the computer was available. Step by step help was requested in seventeen or 65% of the twenty-six successful attempts to solve a problem. Again the number of problems completed varied from student to student and some students relied heavily on the help sequence while others required little or no help. Three students completed one or two problems of Type 1 or 2 in addition to those of Type 3 and one student completed two problems of each of the three types.

Two of the nine students successfully completed problems supplied by themselves and a third student was in the process of solving a problem which was not in the author supplied list when the time expired. These students had little trouble supplying the data for their problems by typing the balanced equation, the formula and the weight of one species, and the formula and the desired units of another species in three to four minutes.

The analysis of student activity indicates that these programs did indeed provide the opportunity for the students to control their own practice sessions with each student solving a different series of

Table 11. Summary of the Number of Practice Problems of Type 3 Completed

Student number	Author supplied	Student supplied	Requests for help
1	3	0	2
2	2	0	1
3	2	0	1
4	4	1	3
5	4	0	3
6	1	0	1
7	4	0	2
8	0	3	3
9	2	0	1
Total	22	4	17

problems, in varying lengths of time and receiving help as often as he needed it.

In the lesson that provided an opportunity for students to practice balancing equations for oxidation-reduction reactions the six equations were presented to each student in the same order, however, the students were permitted to take as much time as they wanted and to attempt the problem as many times as they desired. Special emphasis was placed on telling the student specifically what was wrong with each incorrect answer.

The error rates and the types of errors varied greatly from one student to another with some students failing to balance charge and/or elements while others failed to include required species such as H^+ and H_2O. With each equation the performance of most students improved both in time and in number of attempts required to successfully balance the equations.

C. Evaluation

An evaluation of the teaching effectiveness of the lessons can be made by 1) comparing the performance of students who have had PLATO experience with that of those who have not, 2) assessing student evaluation of the lessons and quizzes, and 3) interpreting the results on the quizzes administered by PLATO.

1. PLATO versus No-PLATO

Final course grades for Chemistry 100 have shown that students who have used the chemistry lessons administered on PLATO earn more A's and B's than do those without PLATO experience. In the Fall of 1969, twenty-one or 68% of the thirty-one students who attended PLATO Sessions on at least two of the three available topics received grades of A or B. This compares with 49% of the entire class.

The course grade was determined by first averaging the student's scores on quizzes and laboratory exercises, each based on 100, and then averaging that score with the results of the hour exams and the final exam. Each person who attended PLATO sessions regularly was awarded six extra points on his quiz average, thus raising the maximum value of the combined quiz and laboratory grade from 100 to 103. When averaged with the exam results, the net effect of this bonus was to add one point to the final average. This could be a grade determining factor only in borderline cases which are usually decided on the basis of the final exam grade. However, assuming that this extra point was responsible for a higher grade in every borderline case and reassigning all borderline cases in this group to the next lower grade, lowers the percentage of A's and B's from 68 to 58%. This was still 9% higher than the whole class total.

These data are summarized in the following table:

Table 12. Chemistry 100 Grades Fall 1969

		A	B	C	D	E	Total number of students
Whole class	(number)	19	48	46	18	7	138
	(percent)	14	35	33	13	5	
PLATO	(number)	7	14	7	2	1	31
	(percent)	23	45	23	6	3	
Assuming borderline cases are lower:							
PLATO	(number)	3	15	10	1	2	31
	(percent)	10	48	33	3	6	

In the Spring 1970 two quiz sections taught by the same teaching assistant were given an opportunity to use the PLATO lessons. The students in one quiz section were encouraged to attend all the PLATO sessions on all three topics, while the other section was offered an opportunity to attend only a single evening session late in the semester on which the two quizzes on chemical formulas and quantities from chemical equations were available. Eighteen or 38% of the students in both quiz sections attended PLATO regularly, thirteen or 27% attended only the one session, and seventeen or 35% did not attend any PLATO sessions for one reason or another.

A comparison of the semester grades of the three groups is presented in Table 13. Again the results indicate that a high percentage of those who attend PLATO regularly earn top grades. A total of 22% of those who attended PLATO regularly earned A's in the course while no one in the group that attended only the quiz session earned A's. The combined percentage of A's and B's was approximately equal, 62%, for the two groups, each of which were motivated enough to spend the additional time at PLATO.

Each of the top three grades was earned by a higher percentage of those who attended PLATO regularly than those who had no PLATO experience at all, 22%, 39%, and 22% respectively for the PLATO group compared with 12%, 35%, and 17% respectively for those without PLATO. Members of the

PLATO group earned four of the six A's or 67% while those with only the PLATO administered quiz experience dominated the B's and C's with eight of twenty-one or 36% and five of twelve or 42% respectively. The lower grades were dominated by those who had no PLATO experience.

It is clear that those who attend PLATO sessions regularly earn higher grades but it is impossible to determine from this evidence whether they earn higher grades because of the PLATO experience or because they are more willing to do extra work and probably are more conscientious students. The fact that 22% of those who attended PLATO regularly earned A's while none of those who were given only one chance to attend PLATO earned A's, however, suggests that the PLATO experience may be of significant influence.

Table 13. Chemistry 100 Grades Spring 1970 (two quiz sections only)

		A	B	C	D	E	Total number of students
PLATO instruction and quiz	(number)	4	7	4	2	1	18
	(percent)	22	39	22	11	6	
PLATO quiz only	(number)	0	8	5	0	0	13
	(percent)	0	62	30	0	0	
No-PLATO	(number)	2	6	3	2	4	17
	(percent)	12	35	17	12	24	

It seems unreasonable to expect measurable differences in course grades due to PLATO instruction when only one-fifth of the subject matter of the course is covered by lessons on PLATO. A fairer comparison would involve a separation of material covered in the lessons on PLATO from other course material.

In the Spring of 1970, just prior to the final exam, the two quizzes administered on PLATO dealing with chemical formulas and quantities from chemical equations were given to two groups of 13 students each, one which had used the lessons on PLATO and one which had not. The results of the first hour exam and a portion of the final exam both of which dealt with material not covered in the lessons on PLATO, showed no significant difference between the two groups as shown in Table 14.

Table 14. Comparison of PLATO and No-PLATO Groups on Material not Covered in PLATO Lessons

a) Results of First Hour Exam Spring 1970 (100 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	78.92	7.96
Group with no instruction on PLATO	12	76.25	5.96

t = 0.95 23 d.f. $.40 > p > .20$

b) Results from the Portion of the Final Exam Covering Material not included in the Lessons Administered by PLATO (108 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	61.92	12.87
Group with no instruction on PLATO	13	60.54	11.49

t = 0.29 24 d.f. $.90 > p > .80$

Using the standard deviations (s.d.) of 7.96 for the group receiving instruction on PLATO and 5.96 for the group with no instruction on PLATO and 23 degrees of freedom (d.f.), the t-test of the difference[18] between the two averages ($\bar{x}$) on the first hour exam indicates that the probability (p) of this difference occurring by chance was between .20 and .40.

Similarly the t-test of 0.29 for the portion of the final exam covering material not included in the lessons administered on PLATO indicates that the probability (p) of the difference between the two averages on this part occurring by chance was between .80 and .90.

The group that did not have the lessons on PLATO had used the PLATO system early in the semester for a math drill and thus were familiar with the operation of the terminal. Only four of the thirteen in the group with no instruction on PLATO made typing errors when asked to type a chemical equation. Most other answers were numerical and there were no typing errors by either group. Both groups attended the same lecture and laboratory and had the same teaching assistant for quiz and discussion.

The comparison of the two groups on the 2 PLATO administered quizzes given eight-ten weeks after instruction shows that those who had instruction on PLATO did significantly better on both the chemical formulas quiz and the quiz on concentration of solutions and quantities from chemical equations. Table 15 indicates that on the twenty point chemical formulas quiz the group having instruction on PLATO had an average score ($\bar{x}$) almost three points higher than that of those having no instruction on PLATO. The t-test indicates that the probability of this large difference occurring by chance alone was less than 2 in 100. On the concentration of solutions and quantities from chemical equations quiz the PLATO group had an average score of 13.00 out of 20 points while those in the other group had an average of only 7.23 points. The probability of that difference occurring by chance was less than 1 in 100. The fact that those without PLATO instruction skipped more problems than did those with PLATO instruction is an indication that those without PLATO instruction were less prepared to solve the problems. The number of problems skipped by each student was summed for both groups. On the chemical formulas quiz problems were skipped six times by the group with no PLATO instruction while only twice by the group having instruction on PLATO.

The ratio of the frequency of skipped problems was approximately three to one again on the concentration of solutions and quantities from chemical equations quiz with those without PLATO instruction skipping a problem nineteen times and those with PLATO instruction skipping only seven times.

Table 15. Results of PLATO Administered Quizzes Given 8-10 Weeks After Instruction, PLATO and No-PLATO

Chemical Formulas (20 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	16.39	2.60
Group with no instruction on PLATO	13	13.46	3.02
$t = 2.65$	24 d.f.	$.02 > p > .01$	

Concentration of Solutions and Quantities from Chemical Equations (20 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	13.00	5.99
Group with no instruction on PLATO	13	7.23	3.68
$t = 2.96$	24 d.f.	$.01 > p > .001$	

Additional evidence of the difference between the two groups is the number of students from each group which missed over 40% of the problems in an area in the chemical formulas quiz. The largest difference between the two groups was in the area of moles and molecular formulas as illustrated in Table 16. Notice that more people from the No-PLATO group were forced to review each area than those with PLATO and that summing the number of times areas were reviewed by each group gives seven for those who had instruction on PLATO and twenty-three for those with no instruction on PLATO.

Table 16. Summary of the Weak Areas on Chemical Formulas, PLATO and No-PLATO

Area	PLATO (n=13)	No-PLATO (n=13)
Moles	1	5
Conversion Factors	0	2
Formulas	3	4
Formula Weight	3	5
Molecular Formulas	0	7

On the quiz dealing with concentration of solutions and quantities from chemical equations, every question was missed by more students from the group with no instruction on PLATO than by those from the PLATO group.

Table 17 shows that all the problems dealing specifically with concentration of solutions or quantities from chemical equations were missed by at least five more students without instruction on PLATO than by those who had PLATO instruction.

Table 17. Results from Quiz Dealing with Concentration of Solutions and Quantities from Chemical Equations, PLATO and No-PLATO

Area	Problem Number	Number of Students Making Errors	
		PLATO	No-PLATO
Moles	1	2	4
	2	1	3
	3	3	5
Concentration of Solutions	1	0	5
	2	5	11
	3	6	11
Balancing Equations	1	1	3
	2	1	2
Quantities from Chemical	1	5	11
	2	6	11
	3	7	13

The group having instruction on PLATO may have performed better because they were familiar with the quiz administered on PLATO, however they also scored better on similar material on the final exam. Table 18 indicates that the average score on the area of the final exam dealing with chemical formulas and moles for those having PLATO instruction was approximately fifteen out of twenty-four points while that of those having no instruction on PLATO, on the same areas, was only 10.5. Similarly the data in the same table indicate that the PLATO group scored better than the No-PLATO group in the area of concentration of solutions and quantities from chemical equations on the final exam.

Table 18. Comparison of PLATO and No-PLATO Groups on Final Exam Material Covered on PLATO

Chemical Formulas and Moles (24 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	15.23	7.41
Group with no instruction on PLATO	13	10.46	5.50
$t = 1.86$	24 d.f.	$.10 > p > .05$	

Concentration of Solutions and Quantities from Chemical Equations (16 points)

	n	$\bar{x}$	s.d.
Group receiving instruction on PLATO	13	13.85	2.27
Group with no instruction on PLATO	13	11.38	4.91
$t = 1.64$	24 d.f.	$.20 > p > .10$	

The difference between the means of the two groups on this material was not as significant as on the PLATO administered quizzes, where the probability of the difference between the means occurring by chance was less than 2% for each topic. However, the difference was more significant than on the material not covered in lessons on PLATO.

The two groups were shown to be matched on material not covered by lessons on PLATO on two independent measures, the first hour exam and a portion of the final exam. The probability of the measured difference between the averages of the two groups on these two exams occurring by chance was better than 20% on the first hour exam and 80% on the final exam. However, the probability of the difference between the means of the two groups on the formula part and concentration of solutions and quantities from chemical equations part of the final occurring by chance was less than 10% and 20% respectively.

This evidence plus the fact that those with PLATO experience in less controlled situations also scored higher on material covered on PLATO than those who did not have PLATO experience indicates that the lesson on the mole concept and chemical formulas and the lesson on concentration of solutions and quantities from chemical equations are effective instructional tools.

The effectiveness of the PLATO instruction on balancing oxidation-reduction equations was demonstrated by the results on the oxidation-reduction portion of the 1970 final exam. Eleven of the fifteen students who had used PLATO scored the maximum credit of 10 points. Of the 33 other students who were taught by the same teaching assistant only one scored the maximum credit. The average score of the group that had instruction on PLATO on that area was 8.76 while that of those without PLATO instruction for the same area was 4.82.

2. Student Evaluation

One means of estimating the quality of a teaching method is to ask the students to evaluate it. Those who have used these PLATO materials, particularly in the latest forms, have indicated on questionnaires that 1) they feel they have learned the material on all three topics, 2) they can spend less time on their homework after instruction on PLATO, and 3) PLATO experience prepares them for the hour exams.

The questionnaires were completed before the students left the PLATO classroom after an instructional session. For the first question concerning how well they learned the material the students were told to limit their evaluation to the present topic. The response to the other two questions on homework and exams, however, are an evaluation of the complete PLATO experience to that date.

The students' response to the statement "I feel that I really learned the material in the PLATO lesson" is summarized for each topic in Table 19.

The results of the student evaluation of the instructional sequences on moles and chemical formulas indicate that 50% of the students either strongly agreed or agreed with the above statement in the Fall 1968 and 66% agreed in the Fall 1969. In both semesters no student strongly disagreed with the statement and only seven of the total of fifty students disagreed.

Table 19. Students' Response to the Statement "I feel that I really learned the material in the PLATO lesson"

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
Topic: Moles and Formulas						
Fall 1968*						
(number)	1	8	3	3	0	15
(percent)	7	53	20	20	0	
Fall 1969						
(number)	3	20	8	4	0	35
(percent)	9	57	23	11	0	
Topic: Concentration of solutions and quantities from chemical equations						
Fall 1969						
(number)	1	7	11	7	1	27
(percent)	4	26	40	26	4	
Spring 1970						
(number)	6	7	2	0	0	15
(percent)	40	47	13	0	0	
Topic: Oxidation-Reduction						
Fall 1968						
(number)	2	12	5	0	1	20
(percent)	10	60	25	0	5	
Fall 1969						
(number)	2	16	6	4	0	28
(percent)	7	57	21	14	0	

*Includes early form of concentration of solutions and quantities from chemical equations

The students in the Fall 1969 did not feel they learned the material on concentration of solutions and quantities from chemical equations as well as they had the material on chemical formulas or oxidation-reduction. Only 30% of them could agree with the above statement. Many students commented that the computer was too "picky" about the form of the answer. This program was revised on the basis of the students' results with the major revision allowing more lenient use of spaces in the students' response. When the lesson was evaluated by the students in Spring 1970, they overwhelmingly agreed that the lesson was successful;

40% strongly agreed and 47% agreed with the statement while the remaining 13% were undecided.

The students in both Fall 1968 and Fall 1969 agreed that they had learned the material on balancing oxidation-reduction equations. Thirty-two of the forty-eight students agreed or strongly agreed with the statement while only five disagreed.

The results show that the students did feel that they learned the material in all three of these lessons. A total of only two people strongly disagreed with the above statement for any lesson.

The questions concerning the amount of time needed for homework and the preparation for the hour exam were administered at the completion of the PLATO experience in the Fall 1969 and twice in Spring 1970, once after two-thirds of the instruction and again at the completion. The results are tabulated in Table 20 and Table 21.

Twelve of nineteen students of the Fall 1969 group agreed that their homework took less time after PLATO while only two disagreed. In the Spring 1970 only one person strongly agreed with the statement after two-thirds of PLATO instruction but five strongly agreed after completion of instruction. This indicates that the lesson on balancing oxidation-reduction equations was the most effective in reducing homework time. By the end of the PLATO experience, 70% of both groups agreed that they could spend less time on their homework while only 10% disagreed.

When asked if the lessons on PLATO helped them prepare for the hour exams, 68% of the nineteen students in the Fall 1969 agreed while 100% of those in the Spring 1970 agreed both times they were asked. The students indicated that the PLATO administered quizzes were the most helpful. These results are indicated in Table 21.

Table 20. Students' Response to the Statement "I can spend less time on my chemistry homework if I've had the material on PLATO"

Last topic completed: Oxidation-reduction

Nov. 24, 1969

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	1	11	5	1	1	19
(percent)	5	58	26	5	5	

Last topic completed: Quantities from chemical equations and concentration of solutions

April 6, 1970

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	1	6	1	0	0	8
(percent)	12	75	13	0	0	

Last topic completed: Cxidation-reduction

April 27, 1970

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	5	4	1	1	0	11
(percent)	45	36	9	9	0	

Table 21. Students' Response to the Statement "I feel that PLATO really helps me get ready for the hour exam"

Last topic completed: Oxidation-reduction

Nov. 24, 1969

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	1	10	7	1	0	19
(percent)	5	53	37	5	0	

Last topic completed: Quantities from chemical equations and concentration of solutions

April 6, 1970

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	3	5	0	0	0	8
(percent)	37	63	0	0	0	

Last topic completed: Oxidation-reduction

April 27, 1970

	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Total
(number)	6	5	0	0	0	11
(percent)	55	45	0	0	0	

3. Quiz Results

The quizzes administered by PLATO (see Appendix B) were initially prepared to aid the student by allowing him to test himself so that he could spend his review time most effectively. However, the results of these quizzes given after the instruction on PLATO lessons can also be interpreted as an evaluation of the effectiveness of the instruction.

The results of quizzes given within days of the PLATO instruction most accurately evaluate the effectiveness of the lecture and the PLATO lessons while those given later include the effect of the laboratory, quiz section, and homework experiences. Weak areas that remain several weeks after instruction indicate areas in which both PLATO lessons and the normal procedure need to be improved.

a. The Mole Concept and Chemical Formulas

The quiz consisted of questions directly related to the objectives described on page 46. A student was required to review any area on which he missed at least 40% of the questions.

In Fall 1969 the quiz was administered within two days of the lecture and PLATO instruction. The average score was 76.2%. Table 22 indicates that eleven of the twenty-five who completed the quiz required no review while an additional seven needed to review only one area. Calculation of the simplest formula was the only area in which one-third or more of the students needed review. This suggests that the students understood the individual steps but needed some practice in doing the complete problem.

The quiz was administered three weeks after instruction in Fall 1969 and two weeks after instruction in Spring 1970. In the Fall fourteen of twenty-three and in the Spring eight of thirteen students needed no review as shown in Table 23 and none of the areas were reviewed by more than one-fourth of the students. The average score in the Fall was 85.3% and that in the Spring was 76.4%. Only one person in the combined groups needed to review two areas. The additional practice, including laboratory and quiz section experience over the two or three week period, appears to have eliminated the need to review the calculation of simplest formulas.

Table 22. Results of the Quiz on Chemical Formulas When Administered Within 2 Days of Instruction

n = 25 $\bar{x}$ = 15.24 (76.2%)

Review areas	Students having PLATO instruction and needing review: Number	Percent
Moles	6	24
Conversion factors	0	0
Simplest formula	9	36
Formula weight	5	20
Molecular formula	6	24

Distribution of review areas per person

Number of areas for which students having PLATO instruction need review	Number of students
0	11
1	7
2	2
3	4
4	1
5	0

Thus it is possible to conclude that the lesson on chemical formulas is successful in teaching students the underlying concepts of each step and that reinforced by the laboratory and quiz section experiences the students can calculate the chemical formula from composition by weight with little difficulty.

b. Concentration of Solutions and Quantities from Chemical Equations

The questions on this quiz were designed to emphasize the solution of the complete problem rather than the understanding of each individual step. Most of the problems required more than one step and are more complicated than the questions on the chemical formulas or oxidation-reduction quizzes.

Table 23. Chemical Formulas Quiz Results for Students Who had Instruction on PLATO

Fall 1969

(given three weeks after instruction)

n = 23 $\bar{x}$ = 17.1 (15.3%)

Review Areas	Students Needing Review: Number	Percent
Moles	0	0
Conversion factors	1	4
Simplest formula	3	13
Formula weight	1	4
Molecular formula	4	17

Spring 1970

(given two weeks after instruction)

n = 13 $\bar{x}$ = 15.3 (76.4%)

Review Areas	Students Needing Review: Number	Percent
Moles	3	23
Conversion factors	0	0
Simplest formula	1	8
Formula weight	0	0
Molecular formula	2	15

The quiz consisted of three questions on the mole concept, three on concentration of solutions, two on balancing equations and three problems calculating the quantity from a chemical equation.

When calculating the score, the last three problems were weighted four times as heavily as the others and no partial credit was given. After the quiz the student was forced to try again the problems he missed; the second time help was available. He did not need to review the entire area as he did in the chemical formulas quiz unless he chose to do so.

In Fall 1969 the quiz was given to 18 students within two days of the PLATO instruction and lecture, however, the last two problems were not available. Half the students missed two or fewer problems as indicated in Table 24, and the average score was 65.2%. The most frequently missed problems were 1) the calculation of the weight of 0.5

moles of hydrogen gas, 2) the calculation of the molarity of a solution of acetic acid containing 40 grams of acid in 100 milliliters of solution, and 3) the calculation of the weight of magnesium chloride that can be produced by reacting 5.83 grams of magnesium hydroxide with hydrochloric acid.

Table 24. Results of the Quiz on Concentration of Solutions and Quantities from Chemical Equations When Administered Within 2 Days of Instruction

n = 18 $\bar{x} = 7.83$ (65.2%)

Distribution of problems missed per person

Number of problems missed by students who had PLATO instruction	Number of students
0	1
1	4
2	4
3	5
4	1
5	2
6	1
7	0
8	0
9	0

The percent of students missing the first two of the above problems was 44% and 50% respectively. The third problem which counted four times as heavily as the others was also missed by 50% of the students. Although no other problems in the quiz were missed by more than one-third of the students it appears that the students needed more practice solving problems.

When the quiz was administered two weeks after instruction in the Fall 1969 and Spring 1970, all three problems on quantities from chemical equations were available. Table 25 indicates the frequency with which these problems were missed.

Table 25. Frequency of Errors on Problems Dealing with Quantities from Chemical Equations 2 Weeks After Instruction

Problem number	Fall 1969 n = 23		Spring 1970 n = 9	
	Number missing problem	Percent	Number missing problem	Percent
1	9	39	2	22
2	18	78	6	67
3	13	57	7	78

The students had particular difficulty with the second problem dealing with quantities from chemical equations because the equation as presented was not balanced. Seventeen of the total of twenty-four students who missed this problem had an answer of approximately 511 grams while the correct answer is 1021 grams. This indicates that they used the correct step by step procedure but failed to recognize that the equation was not balanced. This suggests that in the PLATO lesson more emphasis should be placed on the importance of balancing the equation.

The fact that 50% of the students who took the quiz immediately after the instruction missed the first problem dealing with quantities from chemical equations indicated that students need practice solving problems. However, even after two weeks in which to do homework and other practice problems, 39% of the students in the Fall 1969 missed the same problem. In the Spring 1970 PLATO-aided practice problems were available. This time when the quiz was given two weeks later, only one of the seven students who had attended the practice session missed this problem. Comparing the results of these seven students with the results of the twenty-five students who did not have PLATO-aided practice (twenty-three from the Fall and two from the Spring who were absent from the practice session) indicates that of the number of students who missed the second problem for reasons other than failure to notice that the equation was unbalanced, only one was from the group with PLATO-aided practice while seven were from the other group. Both groups had a high error rate on the last problem for which the data, 82% of 450 grams of sulfur dioxide, was presented in a different form than in any other problem in the PLATO lessons and practice problems. These results indicate that at least when the data were presented in the familiar form the students who had PLATO-aided practice problems did much better than those with only the PLATO lesson.

The students who took the quiz two weeks after instruction also had a high error rate on the same two problems on concentration of solutions and moles as those who had the quiz within days of instruction. Evidently the PLATO experience coupled with the homework practice and the experiences in the laboratory and quiz section was not much help with these problem.

An analysis of the errors made on the question "What is the weight of 0.5 moles of hydrogen molecules?" shows that of a total of thirty-five incorrect responses twenty-six were 0.5. Apparently 74% of the students understood the mole concept but were unaware that hydrogen is diatomic and thus calculated the answer on the basis of one atom per molecule. The fact that hydrogen molecules are diatomic was not mentioned in the PLATO lessons and evidently not stressed much in class either.

For the problem "What is the molarity of a solution of 40 grams of acetic acid ($HC_2H_3O_2$) in enough water to make 100 milliliters of a solution?" the student must first convert the 40 grams of acetic acid to 0.667 moles. Then converting the 100 milliliters to .1 liters he can express the molarity as 6.67 M. Sixteen of fifty-one or 31% of the responses which were in error on this problem had the decimal in the wrong place but the numbers in the correct sequence. Evidently these students calculated the formula weight correctly, but either made an error when dividing or more likely didn't know whether to multiply or divide by the volume. Another twelve responses indicated that the students did not try to convert the grams to moles. This indicates that additional attention must be paid to this problem both in the PLATO lessons and in class. Most of the concentration problems currently in the PLATO lessons involve calculating moles from the known concentration and volume of solution. The result of the second problem on concentrations showed that the students could solve problems of this type.

The quiz results indicate that in the PLATO lessons and class procedure additional emphasis is needed on calculating concentration of solutions, the importance of balancing equations, and solving problems in which the data is presented in different forms. The students who had PLATO-aided practice problems did considerably better than those without practice on PLATO. The quiz itself should be improved by removing the ambiguity of presenting both balanced and unbalanced equations and by using compounds for which the molecular formula is given or known when the student is asked to calculate the weight of a mole.

c. Oxidation-Reduction Equations

The quiz on oxidation-reduction equations contained fifteen questions concerning individual steps and three equations which must be completely balanced. The last three equations were counted as three points each when calculating the score. When the student used the maximum number of chances on any of the first fifteen questions without answering the question correctly he was shown the answer. If the student missed any of the last three equations twice he was forced to do it again after the quiz. This time help was available.

The quiz was never administered immediately after the lecture and the PLATO instruction. The results two weeks after instruction on PLATO have been very good, indicating that the combination of the normal class procedure and PLATO instruction was quite effective. As indicated in Table 26 the average score in the Fall 1969 was 76.7% and in Spring 1970, 86.4%.

In the Spring the procedure for balancing equations for reactions which take place in base was covered only on PLATO. Thus even though the quiz was given two weeks after instruction, the results for the questions on balancing equations for reaction in base, numbers 14 and 15 and the second equation (see Appendix C) are an indication of the effectiveness of the PLATO lessons.

Table 26. Balancing Oxidation-reduction Equations Quiz Results for Students Who had PLATO Instruction (given 2 weeks after instruction)

Fall 1969

$n = 15$

$x = 18.4$ (76.7%)

Spring 1969

$n = 8$

$\bar{x} = 20.75$ (86.4%)

Problem Number	Number of students missing problem			
	Fall 1969		Spring 1970	
	(number)	(percent)	(number)	(percent)
1	4	27	0	0
2	2	13	2	25
3	4	27	1	13
4	1	7	0	0
5	0	0	0	0
6	4	27	1	13
7	4	27	2	25
8	9	60	3	38
9	6	40	1	13
10	7	47	0	0
11	6	40	0	0
12	10	70	1	13
13	3	20	0	0
14	5	34	3	38
15	6	40	3	38
Equations				
1 (acid)	5	34	0	0
2 (base)	7	47	0	0
3 (acid)	3	20	0	0

Only two of the eight students missed both the multiple choice equations while two others missed one each. None of these students missed the second equation. However, all four students who were absent the night of the PLATO instruction and who took the quiz, missed at least one of the questions and all of them missed the equation. Evidently the PLATO instruction was effective in teaching students to balance equations.

d. Retention

If the lessons on PLATO are effective teaching devices there should be little if any loss of ability to solve problems even weeks after the instruction. The quiz on chemical formulas and the quiz on concentration of solutions and quantities from chemical equations were administered twice, once two weeks after instruction and again eight to ten weeks after instruction. Students who took the quizzes both times had a higher average score the second time. As would be expected without additional practice in both cases the probability of the gain being due to chance was better than 30%. (See Tables 27 and 28).

For the formula quiz the correlation between scores after two weeks and after ten weeks was significantly high. The probability of such a correlation by chance was less than 1%. This indicates that students who did well the first time also did well the second time and thus retained the knowledge.

Table 27. Comparison of Scores on the Quiz on Chemical Formulas When Administered 2 and 10 Weeks After Instruction

	two weeks		ten weeks
$\bar{x}$ =	16.037		16.548
s.d. =	1.93		2.70
n = 13	t = 0.94	12 d.f.	$.40 > p > .30$
correlation	0.76		
	t_{corr} = 3.86	11 d.f.	$.01 > p > .001$

Table 28. Comparison of Scores on the Quiz on Concentration of Solutions and Quantities from Chemical Equations When Administered 2 and 10 Weeks After Instruction

Spring 1970 20 points

		two weeks	ten weeks
$\bar{x}$ =		11.36	13.45
s.d.		5.94	6.12
n = 11	t = 0.91	10 d.f.	$.40 > p > .30$
correlation 0.21		t_{corr} = 0.64	$.60 > p > .50$

Molecular formulas was the area in which the largest change was noted; after two weeks four people needed review and after ten weeks none needed review. Although the average time, 26.4 minutes, for the second time was better than three minutes less than the first time, there was no correlation between the times. Thus it is not possible to predict the amount of time a student would take the second time on the basis of the first time.

For the quiz on concentration of solutions and quantities from chemical equations the average score the first time was 56.8% compared to 67.3% the second time. The correlation between the scores was very low, 0.21, indicating that some students did considerably better the second time while others did much worse. With the last three problems weighted four points each (one-fifth of the total points), the success or failure on any one problem would greatly affect the score. No partial credit was given. On all problems except two, there were fewer student errors the second time than on the first time. Those two problems were the first one on moles where one student missed it each time and the first quantities from chemical equations problem where three people made errors the first time and four the second time. See Appendix B for a list of the quiz questions.

D. Student Reaction

The general attitude of the students toward the use of PLATO was favorable from the very beginning of the project and became even more favorable as the lessons were edited to permit more flexibility in the form of acceptable answers. The results of student responses to questionnaires and student comments indicate that the students liked the PLATO experience and that they would like to have other chemistry lessons offered on PLATO. They felt that the operation of the machine did not interfere with their concentration on the lessons and that they generally received the help they needed.

The majority of the students who used the earliest forms of the instructional sequences in the Fall 1968 as well as those who used the latest forms in the Spring 1970 felt that when the material was presented on PLATO they learned better and more easily than they would if the material was presented in a lecture, textbook or movie. Table 29 shows that 70% of the students in the Fall 1968 preferred PLATO to any other instructional method and that 67% of the students in the Spring 1970 felt the same way.

Table 29. Comparison of Student Opinion of PLATO and Other Instructional Media

Summary of the number of students who chose PLATO as the answer to the question "Of these methods (PLATO, lecture, text or movie) which do you think you would learn from . . ."

	Fall 1968		Spring 1970	
	Number	Percent	Number	Percent
Best	13	65	14	93
Most easily	12	60	12	75
Personally prefer	14	70	10	67

The students really appreciated the opportunity to work at their own pace and to receive immediate feedback in privacy as evidenced by the following typical responses to the question "What do you like the most about PLATO lessons?"

> Being able to take the time I need to absorb and comprehend the material without inconveniencing another person.
>
> One knows immediately if his answer is correct or incorrect.
>
> I just like doing things on my own without a teacher watching over my shoulder. If I make a dumb mistake I don't feel bad since only the computer knows.

When asked what they found most annoying about PLATO, over one third of the students in the Fall 1968 responded that nothing annoyed them. Most of the remaining comments concerned the lack of flexibility permitted for correct answers. In the Spring 1970, however, only one student complained about the form of acceptable answers. The major complaint in the Spring concerned the scheduled time and place that PLATO was available.

When asked to summarize their feelings concerning PLATO lessons, all the students in the Spring responded that the PLATO experience was worthwhile and that they liked the lessons. One student responded: "I love them."

Appendix D contains the Spring 1970 questionnaires and a summary of the students' responses including the comments.

E. Summary

The lessons developed in this study were successfully used by students who were taking a course to prepare themselves for the normal non-major college chemistry courses. The instructional sequences and quizzes with forced review of weak areas were offered in the evening and an additional hour was available during the following day to finish the instruction or practice solving problems. Attendance was very good every evening when a new topic was scheduled.

Each of the lessons in the form of instructional sequences, quizzes or practice problems provided unique opportunities for students to receive individualized instruction by permitting them to work at their own speed and to receive material in a sequence which was determined on the basis of their performance. When 80% of the students had finished an instructional sequence the amount of time required the slowest students was approximately three times as long as that required by the fastest student.

In the Spring 1970 five of twelve students took advantage of the opportunity to supply their own practice problems for chemical formulas. They had no trouble supplying their own data. They required an average of only 2.5 minutes to supply the information for problems of Type 1 and less than one minute for problems of Type 2. Two students had no trouble receiving help with their own problems on quantities from chemical equations. The number of practice problems on chemical formulas each student completed in an hour ranged from two to eight.

For each student, the PLATO administered quizzes were successful in determining the areas or the problems with which he needed review. In addition to the variation among the students in the scores and in

-0.71 and for the quiz on chemical formulas the value was -0.66. There was no significant correlation between the time and scores on the quiz on concentration of solutions and quantities from chemical equations or on the quiz on balancing oxidation-reduction equations, each of which contained several multistep problems in addition to short answer questions.

An evaluation of the teaching effectiveness of the lessons showed that the students who attended PLATO regularly earned more A and B grades, performed better on PLATO administered quizzes, and scored higher on final exam questions concerning the topics covered by PLATO lessons than students who did not have PLATO experience.

Comparison of the results of those who had PLATO instruction on chemical formulas and those who did not indicates that those with PLATO instruction did significantly better on the quiz administered by PLATO and considerably better on the final exam questions on chemical formulas. On the quiz administered by PLATO, thirteen students with PLATO experience scored an average of 2.92 points or 14.7% better than the thirteen students without PLATO instruction. The probability of this difference occurring by chance is less than 2%. The performance of these two groups was not significantly different on material not covered by PLATO. On the final exam the difference between the averages of the two groups on material not covered by PLATO was only 1.3% while the difference on the questions dealing with chemical formulas and moles was 23.8%.

When the PLATO administered quiz was given within days of the instruction the students did well on the questions involving individual steps. Forty-four percent of the students needed no review while only 28% needed to review more than one concept.

to solve problems as was evidenced by a high correlation, 0.76, between the scores of a group of thirteen students who took the quiz both two weeks and ten weeks after instruction.

The lessons on concentration of solutions and quantities form chemical equations appear to be quite effective. On the PLATO administered quiz students who had PLATO experience h an average score 5.77 points or 29% higher than the average scores fo . comparable group without PLATO lessons. The probability of this difference occurring by chance was less than 1%. The students without PLATO experience missed each problem more often than those with PLATO experience and they skipped three times as many problems. The three problems on quantities from chemical equations were missed respectively by 38%, 46%, and 54% of those with PLATO experience and by 85%, 85%, and 100% of those without PLATO experience.

On the final exam questions dealing with the same material (worth 16 points), those with PLATO experience had an average score of 13.85 while those without PLATO experience had an average score of 11.38. The probability of this difference occurring by chance was between 10% and 20%. On the same exam for questions on material other than that covered in the PLATO lessons, (108 points), the probability that the difference of 1.4 points between the average scores of the two groups, occurred by chance was greater than 98%.

The results of the PLATO administered quiz indicated that those who had both PLATO instruction and PLATO aided practice problems did better than those who had only PLATO instruction. For example, the first problem on quantities from chemical equations was missed by ten of twenty-five or 40% of those without PLATO aided practice problems, but by only one of seven or 14% of those with both experiences. Similar

When the quiz was administered both two weeks and eight weeks after instruction the average score was slightly higher the second time, however, there was little correlation between the students' scores.

Students who had PLATO instruction on balancing oxidation-reduction equations generally did much better on both exams and the PLATO quiz than those without PLATO experience.

Ten of the thirteen students who had PLATO instruction in this area scored maximum credit on the final exam problem worth 10 points. Only three of the rema ing thirty-five students who had the same teaching assistant scored maximum credit.

Each time the PLATO administered quiz was given the average score was above 75%. On the quiz in the Spring 1970, when the procedure for balancing equations for reactions which take place in base was covered only on PLATO, none of the students who had attended PLATO instruction missed the equation for the reaction in base. All four students who were absent the night of instruction were unable to balance this equation correctly.

The analysis of the student data indicated that all three types of lesson materials for each of the three topics had a significant and beneficial effect on student performance and that the students enjoyed PLATO instruction.

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APPENDIX A

INSTRUCTION SHEET PRESENTED TO STUDENTS WHEN THEY ARRIVED AT THE PLATO CLASSROOM

Welcome to PLATO

PLATO is a computer-assisted instruction facility which is now in the experimental stage, but it will be expanded to some 4000 student stations all over campus in the early 1970s. In order to be ready for the expansion, various programs have been written to teach certain skills and subject materials normally covered in first-year chemistry courses. As you work through these programs, try to continually evaluate them for us--what you tell us will in large part determine what students will be required to do in 1972. Whenever anything seems unclear or confusing (or really good, for that matter) and you want to tell us about it, press the -TERM- key and type the word "comment"; then press NEXT and follow the directions that appear on the screen.

You will be interacting with PLATO just as you would with a teacher. PLATO will give you information and ask you questions on it; you will have to answer these questions correctly before you can move on to new material. However, this shouldn't alarm you, for PLATO will often be able to help you solve a problem if you need the assistance.

When you arrive at PLATO Room 257 take a seat at any terminal. When you are told to begin press NEXT, type your last name. For the course name type GCHEM. Do not use any spaces. Then follow directions. If you have any trouble please call an instructor.

Some of the special keys on the typewriter that you will be using are explained below:

NEXT — Use this key whenever you want the computer to recognize the information you have just typed in (for instance, an answer to a problem). If your response was an answer and it is judged wrong, press NEXT to erase it before typing another answer. If your answer is right, pressing NEXT will move you to the next question.

BACK — Will move backwards through a lesson to review earlier material. In a HELP sequence, SHIFT and BACK will return you to the main unit.

ERASE — Use to erase typing errors. Pressing ERASE will remove one character at a time. Pressing SHIFT and ERASE will erase a

ARROW — Will move the arrow from one question to the next so that you can answer questions in a different order than they appear on the screen. NEXT must still be pressed to record the answer.

REPLOT — If you spend a fairly long time on any one segment of a lesson, the picture will begin to fade. Pressing REPLOT will restore the picture.

SHIFT — In most respects, this is similar to the shift on a normal typewriter. In particular, SHIFT must be held down <u>similtaneously</u> with another key to have any effect.

SUP
SUB — Press this key, then release it and type a number to get a subscript. Press SHIFT and this key simultaneously, release, and type a number to get a superscript.

<u>SPECIAL CASES</u>:

1. Using the computer as a calculator:
   You may use the computer as a calculator by pressing TERM, typing Calc and Pressing NEXT.

2. Making comments about the lesson:
   We encourage you to tell us what you think. Press TERM, type comment, and press NEXT.

3. Judging an answer:
   After each answer you must press NEXT. Pressing ARROW or ANS will <u>not</u> record your answer and will not permit you to go on.

4. Conversion factors:
   If you are required to fill in a conversion factor you must judge (press NEXT) after each part. For example.

   $$4g \times \frac{\rightarrow\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}{\rightarrow} = \rightarrow$$

   There are 3 separate answers.

5. Using subscripts and superscripts:

   To write CrO_4^{-2}

   1) Hold SHIFT down and press C

6) Hold SHIFT down, press $\frac{SUP}{SUB}$, release both and press 2.

6. Arrows in equations:
   When writing equations such as $2H_2 + O_2 \rightarrow 2H_2O$,

   press STAR, release, hold SHIFT down and press D.

7. Notice that there are special keys for the numbers 1 and 0 for +, -, x, and ÷.

APPENDIX B

PLATO ADMINISTERED QUIZZES

1. Math Quiz

AREA	QUESTION	ANSWER	NUMBER OF CHANCES
Fractions			
	1. $4 \times \frac{2}{5} =$ ______	1.6	2
	2. $12 \times \frac{3}{4} =$ ______	9.0	2
	3. $24.5 \times \frac{3}{2} =$ ______	36.75	2
Conversion Factors			
	1. The numerator and denominator of a conversion factor are: a) equivalent and in the same units b) equivalent and in different units c) nonequivalent and in the same units d) nonequivalent and in different units	b	2
	2. Which conversion factor would you use to convert inches to yards? a) $\frac{36\ \text{inches}}{1\ \text{yard}}$ b) $\frac{36\ \text{yards}}{1\ \text{inch}}$ c) $\frac{1\ \text{yard}}{36\ \text{inches}}$ d) $\frac{1\ \text{yard}}{1\ \text{inch}}$	c	2
	3. Do the following problem: $4.0\ \text{lb} \times \frac{454\ \text{grams}}{1\ \text{lb}} =$ ______	1814 g	2

AREA	QUESTION	ANSWER	NUMBER OF CHANCES
	4. Use the proper conversion factor to determine how many feet are in 40 inches. NOTE: Judge the numerator and denominator of the conversion factor separately. The long line is the line for the fraction. Make sure you use units on each answer. 40 inches x ____________ = ______	$\frac{1 \text{ foot}}{12 \text{ inches}}$	
		3.33 ft.	3
	(this question counts as 2)		
Percent			
	1. 15% of 100 = ______	15	2
	2. 12.5% of 100 = ______	12.5	2
	3. 20% of 60 = ______	12	2
	4. 73 is what percent of 100? ______%	73	2
	5. If you had 75 test tubes and broke 15, what percentage of the original number would you have left? ______%	80	2
Ratios			
	Express these ratios in the smallest possible whole numbers.		
	a) 0.5:1.5	1:3	2
	b) 14:7	2:1	2
	c) 4:6	2:3	2
	d) 0.33:0.66:1.32	1:2:4	2

2. Formula Quiz

AREA	QUESTION	ANSWER	NUMBER OF CHANCES
Moles			
	1. 1 mole of atoms = ______ atoms	6.02×10^{23} x	1'2
	2. 1 mole = 6.02×10^{23} (?) a) atoms b) molecules c) formula units d) particles (anything you name)	d	1
	3. 1 mole of Zinc atoms = ______ grams	65.4	2
	4,5,6, A sample of hydrogen gas contains 18.06×10^{23} molecules of hydrogen. The molecular formula is H_2.		
	a) How many moles of H_2 molecules are in the sample?	3	2
	b) How many moles of hydrogen atoms are in the sample?	6	2
	c) How much did the sample weigh? _____ grams	6	2
Conversion factors			
	1. The numerator and denominator of a conversion factor are: a) equivalent and in the same units b) equivalent and in different units c) nonequivalent and in the same units d) nonequivalent and in different units	b	1
	2. Which conversion factor would you use to convert liters to milliliters? a) $\frac{1\ \text{liter}}{1000\ \text{ml}}$ b) $\frac{1\ \text{ml}}{1\ \text{liter}}$ c) $\frac{1\ \text{liter}}{1000\ \text{ml}}$ d) $\frac{1000\ \text{ml}}{1\ \text{liter}}$	d	1

5. Use a conversion factor to convert 16.03 g Ca to moles of calcium atoms. | $\frac{1 \text{ mole}}{40 \text{ g}}$,

16.03 g Ca x________ = _____ moles Ca

.4 4

Simplest Formula

1. The subscripts in a formula tell the...

   a) relative weights of the elements in the compound
   b) relative number of atoms of each element in the compound
   c) number of atoms of each element in a mole of the compound
   d) number of atoms of each element in 100 grams of the compound

   b 1

2. A sample of a compound contains 1.0 gram of hydrogen and 35.5 grams of chlorine

   Before you can determine the simplest formula you must convert the weight of each element to ______?

   atoms or moles 2

3. The atom ratio in a compound is found to be 0.14 hydrogen atoms to every 0.07 oxygen atoms. What is the simplest formula?

   H_2O 2

4. If a compound contains 88.8% copper and 11.2% oxygen, what is the simplest formula?

   Cu_2O 2

Formula Weight

1. The formula weight of NH_3 is _____ grams? 17 2

2. 1 mole of NH_3 molecules weighs ______ grams? 17 2

3. The molecular formula for a compound is C_3H_8.
   0.5 moles of C_3H_8 molecules weigh ______ grams?

   22 2

4. A sample of $Zn(NO_3)_2$ weighs 94.7 grams. How many zinc atoms are in the sample?
   ______ zinc atoms

   3.01×10^{23} 2

Molecular Formula

1. The molecular weight of a compound is a whole number multiple of the simplest formula weight.

   a) true b) false a 1

2. Before you can determine the molecular formula of a compound, you must first determine the molecular weight in the laboratory.

   a) true b) false a 1

3. The simplest formula of a compound is BH_3. The weight of a mole of molecules is 27.6 grams.

   What is the molecular formula? B_2H_6 2

3. Concentration of Solutions and Quantities from Chemical Equations Quiz

AREA	QUESTION	ANSWER	NUMBER OF CHANCES
Moles			
	1. 0.12 moles of $Al(OH)_3$ = ______ grams?	9.36	2
	2. 39.0 grams of C_6H_6 = ______ moles C_6H_6	.5	2
	3. How many grams does 0.5 moles of hydrogen molecules weigh? ______ grams	1.0	2
Concentration of Solutions			
	1. The term used to describe the concentration of a solution in moles/liter is called ______ and is abbreviated ________?	molarity M	2
	2. How many grams of HCl are required to make 250 ml of a 0.1 M solution? ______ grams HCl	.91	2
	3. What is the molarity of a solution of 40 g of acetic acid ($HC_2H_3O_2$) in enough water to make 100 ml of solution? _________ M	6.6	2
Balancing Equations			
	1. Write the balanced equation for this reaction: $Fe + O_2 \rightarrow Fe_2O_3$	$4Fe + 3O_2$ $2Fe_2O_3$	2
	2. $4 Fe + 3O_2 \rightarrow 2Fe_2O_3$ What is the mole ratio of Fe to O_2? ______ Moles Fe:______ Moles O_2	4:3	2

Weight-weight problems

1. How many grams of $MgCl_2$ can be produced from 5.83 grams of $Mg(OH)_2$ according to this equation:

   $Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2\ H_2O$

   ______ grams (4 points) 9.53 2

2. How many grams of ethyl alcohol (C_2H_5OH) can be produced from the fermentation of 2000 g of glucose ($C_6H_{12}O_6$) as indicated by this equation:

   $C_6H_{12}O_6 \rightarrow C_2H_5OH + CO_2$

   _______ grams (4 points) 1021 2

3. How many grams of carbon disulfide can be produced from 450 grams of SO_2?

   $5\ C + 2\ SO_2 \rightarrow CS_2 + 4\ CO$

   ______ grams (4 points) 218.9 2

a) balance the atoms
b) balance the charge
c) assign oxidation numbers
d) determine the oxidizing agent — c — 1

9. Picking the oxidation half reaction:

$$H^+ + Cr_2O_7^{-2} + Cl^- \rightarrow Cr^{+3} + Cl_2 + H_2O$$

(acid)

a) Which reactant is oxidized? — Cl^-
b) What is the product of oxidation? — Cl_2 — 3

10. Consider this unbalanced equation and pick out the reduction half reactions.

$$Cu + H^+ + NO_3^- \rightarrow Cu^{2+} + NO_2 + H_2O$$

a) Which reactant is reduced? — NO_3^-
b) What is the product of reduction? — NO_2 — 3

11. Which of the following is the proper sequence of steps when balancing a half reaction?

a) balance oxygen, balance hydrogen, balance charge, balance elements other than hydrogen and oxygen

b) balance charge, balance oxygen, balance hydrogen, balance elements other than hydrogen and oxygen

c) balance elements other than hydrogen and oxygen, balance oxygen, balance hydrogen, balance charge

d) balance hydrogen, balance oxygen, balance elements other than hydrogen and oxygen, balance charge — c — 1

Balancing Half Reactions

12. When balancing a half reaction which takes place in acid, the excess hydrogen is balanced by adding ________ to the opposite side. — H^+ — 2

13. When balancing a half reaction which occurs in acid, the excess oxygen is balanced by adding _______ to the opposite side. — H_2O — 2

14. When balancing a half reaction which occurs in BASE, each excess oxygen is balanced by adding (type the letter)

a) 1 OH^- to the side with excess and 1 H_2O to the opposite side

b) 1 H_2O to the side with excess and 2 OH^- to the opposite side

c) 2 H_2O to the side with excess and 1 OH^- to the opposite side

d) 1 OH^- to the side with excess and 2 H_2O to the opposite side   b   1

15. When balancing a half reaction which occurs in BASE, each excess hydrogen is balanced by adding (type the letter)

a) 1 OH^- to the side with excess and 1 H_2O to the opposite side

b) 1 H_2O to the side with the excess and 2 OH^- to the opposite side

c) 2 H_2O to the side with excess and 1 OH^- to the opposite side

d) 1 OH^- to the side with excess and 2 H_2O to the opposite side   a   1

Equations

The next three questions are equations to be balanced. You will have only 2 tries at each equation so be careful when you type your answer.

If you miss any of these twice, the computer will help you after the exam.

Each equation is worth 3 points.

16. $SO_2 + NO_3^- + H_2O \rightarrow SO_4^{-2} + NO + H^+$ (acid)   2

Ans. $2H_2O + 3\ SO_2 + 2\ NO_3^- \rightarrow 2\ NO + 3\ SO_4^{-2} + 4H^+$

17. $Cr(OH)_3 + ClO^- \rightarrow CrO_4^{-2} + Cl^-$ (base)

Ans. $4\ OH^- + 2\ Cr(OH)_3 + 3\ ClO^- \rightarrow 3\ Cl^- + 2\ CrO_4^{-2} + 5H_2O$ 2

18. $MnO_4^- + S^{-2} \rightarrow Mn^{+2} + 5$ (acid)

Ans. $16H^+ + 2\ MnO_4^- + 5\ S^{-2} \rightarrow 5\ S + 8\ H_2O + 2\ Mn^{+2}$ 2

APPENDIX C

AUTHOR SUPPLIED PRACTICE PROBLEMS

Type 1: Calculating the Simplest Formula of a Compound from the Known Composition by Weight

1. What is the simplest formula of a compound which was found to contain 57.5% sodium, 40.0% oxygen and 2.5% hydrogen?

2. A compound was found to contain 34.5% zinc, 14.8% nitrogen and 50.7% oxygen. What is the simplest formula?

3. Laboratory analysis of a compound shows that by weight it contains 83.72% carbon and 16.28% hydrogen. What is the simplest formula.

4. What is the simplest formula of the compound which contains 21.21% nitrogen, 6.06% hydrogen, 24.24% sulfur and 48.48% oxygen?

5. A compound is composed of 26.52% chromium, 24.52% sulfur and 48.96% oxygen. What is the simplest formula?

6. Laboratory analysis of a compound shows that it contains 47.3% carbon, 10.6% hydrogen and 42.1% oxygen. What is the simplest formula?

Type 2: Determining the Percentage Composition of a Compound Given the Chemical Formula

1. $(NH_4)_2SO_4$
2. CH_2O
3. $Ca_3(PO_4)_2$
4. C_3H_8NBr
5. $Na_2Al_2(SO_4)_4$
6. $KC_{18}H_{35}O_2$
7. CH_3COOH
8. $CH_3CH_2COCH_3$

Type 3: Calculating Quantities from Chemical Equations

1. When strongly heated, calcium oxalate, CaC_2O_4, decomposes according to this equation

$$CaC_2O_4 \rightarrow CaO + CO + CO_2$$

How many grams of calcium oxide, CaO, can be produced by the complete decomposition of 32 grams of calcium oxalate?

2. Nitric acid, HNO_3, can be produced by reacting nitrogen dioxide with water. How many moles of nitrogen dioxide are needed to make 126 grams of nitric acid if the equation is

$$2NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

3. Ethane, C_2H_6, burns completely in oxygen to produce carbon dioxide and water vapor:

$$2\ C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

How many grams of oxygen are needed to completely burn 4 grams of ethane?

4. Aluminum sulfide, Al_2S_3, reacts completely with water to produce aluminum hydroxide and hydrogen sulfide. How many grams of aluminum sulfide are needed to produce 39 grams of aluminum hydroxide:

$$Al_2S_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2S$$

5. Iron(III) oxide is produced by the reaction of $KMnO_4$ with Iron(II) oxide. How many moles of Iron(III) oxide, Fe_2O_3, can be produced from 100 grams of Iron(II) oxide FeO, according to this equation:

$$2KMnO_4 + 10FeO \rightarrow K_2O + 2MnO + 5Fe_2O_3$$

Practice Equations for Balancing Oxidation-Reduction Equations

1. $Cr_2O_7^{-2} + H^+ + I^- \rightarrow Cr^{+3} + I_2 + H_2O$ (acid)
2. $Fe^{+2} + H^+ + NO_3^- \rightarrow Fe^{+3} + NO + H_2O$ (acid)
3. $Sb + H^+ + SO_4^{-2} \rightarrow Sb^{+3} + SO_2 + H_2O$ (acid)
4. $NH_3 + Br_2 \rightarrow NH_4^+ + Br^- + N_2$ (base)
5. $C_2O_6^{-2} + I^- \rightarrow CO_3^{-2} + I_2$ (base)
6. $Br_2 + OH^- \rightarrow Br^- + BrO_3^- + H_2O$ (base)

APPENDIX D

SUMMARY OF STUDENT QUESTIONNAIRE RESULTS FOR SPRING 1970

1. After Instruction on Chemical Formulas, Concentration of Solutions and Quantities

Date 3/16/70

To improve the chemistry lessons it is important to have student opinion. Your answers to the following questions will be greatly appreciated. PLEASE ANSWER EVERY QUESTION.

1. Have you ever used PLATO prior to Chemistry 100?
   If yes, in what courses?

   All answers were NO.

2. "I found it hard to concentrate on the lessons because the machine is difficult to operate." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
0	0	1	4	10

3. "I feel that I really learned the material in the PLATO lessons." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
6	7	2	0	0

4. "When I made an error the computer gave me the help I needed." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
4	9	1	1	0

5. In which way do you feel the PLATO lessons should be used in General Chemistry?

   a) In addition to the regular lecture, quiz and lab 8
   b) As a replacement for lecture 3
   c) As a replacement for quiz 3
   d) As a replacement for lab 0
   e) Other (practice problems as an option)

6. Suppose the same material covered in the PLATO lessons was also available in a textbook, as a lecture, a movie, and on TV. Of these methods which do you feel you would learn from:

	Text	Movie	Lecture	PLATO	TV	Other
Best	1			14		
Most easily	1	1		12		
Least easily	5	3			3	3
Worst		6	[illegible]		6	1
Prefer	2			10		2

Under other: Least easily
movie and TV
lecture & TV
text and TV

Worst
movie & TV

Prefer
text & PLATO
lecture & PLATO

7. Answer these questions on the basis of <u>ALL</u> of your PLATO experience. If possible, give specific examples.

a) Have there been times when you needed hel but no help was available? If yes, give an example.

No 6 Yes 9

There was always a T.A. available, but so etimes I like to figure the problem out for myself and no omputer help was there.

On the first math review session, I neede help on logs but I missed them because I had forgotten certa steps in calculating the answer.

Review

Occasionally when I would like to be able to review something such as conversion factors which aren't i that lesson but which you need to use to do the problems.

b) Have there been times when the help avail ble was very useful? If yes, give an example.

No 0 Yes 15

When you're not quite certain of a formul --Help at what step is next. Sometimes helps figure it out.

Solving equations.

Anytime I am really stuck and have no ide about what to do next PLATO was always very helpful.

When the computer can't explain a problem any further.

Problem solving, review procedure.

When given a review question at third session that I learned in second session, I had forgotten how to work it. I pushed the help button for review.

Many times when I have been "stuck" the "help" has clarified it for me by showing me how.

Help with steps in molarity and solution problems.

When simple procedures (finding no. of moles in a solution) slip my mind for a moment.

While working some problem. They weren't clear.

c) Have there been times when the help available didn't help you? If yes, give an example.

No 12 Yes 3

Help needs more detail.

If there was help it always helped me.

d) Which of the above situations have occurred most often?

1.	No help	1
2.	Useful help	14
3.	Irrelevant help	0

e) The use of the computer as a calculator helps me.

Very Much	Some	Undecided	Not Much	Not At All
11	2	0	0	2

8. What do you like most about PLATO lessons?

The fact that it tells me right then when I've done something wrong and goes over it again to make lesson clear.

It explains the steps clearly and if you miss the answer it gives hints on how to correct the answer.

You're on your own - you don't have to feel like you're holding any-one up - or no one holds you up. You learn as fast as you are capable, on your own! Just enough help. Work at your own speed.

Great. It gets monotonous after a while though.

I just like doing things on my own without a teacher watching over my shoulder. If I make a dumb mistake I don't feel bad since only the computer knows. Also a teacher may be more helpful and end up just telling you the answer but PLATO makes you really think about it, and I learned a lot better from PLATO.

You learn at your own rate of speed.

1. Calculations; 2. Step by step procedure of problems; 3. Help.

If I don't understand something easily, I know I can take my time until I do. In a lecture, if I don't understand it, I have to skip over it and go on to something else without understanding what is happening.

The "work at your own pace" feeling - no pressure - no grading; just learning.

They help me understand the material better.

It gives clear cut and understandable steps in these problems. And you have enough time to work on the problems and really get to understand them. Also, I love the calculation part!!

Active participation in problem solving in a dramatic presentation of the material.

I begin the week having an idea how to do things correctly - a review.

You are forced to do <u>all</u> the problems and you can't move on until you get the problem. Helped considerably with homework.

I can learn the material very well.

9. What do you dislike most about PLATO lessons?

Takes time but then I should spend the time studying anyway.

I'm a slow worker and they seem to be long, but that is not the computer's fault.

If there is anything bad, it is learning the operation of the machines. Sometimes a wrong answer can be because you wrote 1/2 and the machine wants .5.

I would like to see PLATO available at any time and having units in other spots on campus.

There is not enough time to complete them if you are slow.

Nothing.

Much better in class. If I have to learn the stuff, PLATO is the least painful method.

Having to come at 6:00 p.m.!

The time it takes - for a 2 hr. course there is a lot of work involved.

Nothing really.

The computer is not always helpful - sometimes when you'd like help the most, it's not there - also, I find myself extremely tired for some reason. I can't explain very well - possibly, frustration, too much reading, taking too long on problems, etc.

I get very frustrated when I can't reach the correct answers but I understand the "Help" lesson. I have to keep hashing over a problem that I just can't work.

Some problems were unclear.

It is too far to walk to it.

2. Immediately after the Quiz on Concentration of Solutions and Quantities from Chemical Equations

Date 4/6/70

Please answer all the following questions. Your response will be invaluable when making changes in the present programs and when writing new programs.

1. "I can spend less time on my chemistry homework if I've had the material on PLATO." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
1	6	1	0	0

2. "I feel that PLATO helps me prepare for the hour exams." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
3	5	0	0	0

3. "I like PLATO administered quizzes."

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
3	5	0	0	0

4. "I feel that the scores on PLATO quizzes were a fair evaluation of my knowledge." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
2	5	0	1	0

5. "I feel that PLATO quizzes do NOT adequately test the material I learned." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
0	1	0	6	1

6. What do you like most about PLATO administered quizzes?

   They show me what I really don't know.

   In solving the problems, they take you through step by step.

   They let me know what to expect on hourlies, how much I have learned, and how to work the ones I missed.

   The follow-up help if you miss a question helps you learn the material.

Shows what I need to know better.

Instant evaluation--available help while material is fresh.

The help given at the end. Also my score.

Fair, cover material previously presented.

7. What do you dislike the most about PLATO administered quizzes?

Nothing

Nothing

The machine errors which doesn't allow for human errors--(multiplication, etc.)

Nothing

They're tricky.

8. After the quiz has established that you need some help in a given area, which of the following do you prefer?

a) Different problems than the ones on the quiz but covering the same materials with help available.	3
b) Help with the same problems that you missed on the quiz.	3
c) Other--please specify	2

First do the ones on quiz, then others also.

Help with the same problems on the quiz plus additional problems.

9. Summarize your feelings about PLATO lessons:

They help, they show me the material I don't know.

I like them!

Quizzes help me understand what I was supposed to have learned. The first one lesson really helped but the first lesson on molarity confused me. The quiz I took tonight, however, gave me a much better understanding of stoichiometry.

I liked PLATO very much, and I think it helped me very much. I think it helped me very much so far this semester.

They really help a lot in understanding the lesson.

I feel that they have helped me to learn difficult material immensely. I wish we had help, however on the pressure/volume/temp. problems as well.

I enjoyed coming to PLATO. I was able to learn the material quickly and easily. Sometimes, however, I wanted to work the whole problem out by myself and not through the steps with PLATO.

Fine, but most problems stereotypes of presented material. More problems needed requiring more thinking such as combination of problems and from different lessons.

3. Immediately After the Quiz on Balancing Oxidation-reduction Equations

Date 4/27/70

Please answer all the following questions. Your response will be invaluable when making changes in the present programs and when writing new problems.

1. "I can spend less time on my chemistry homework if I've had the material on PLATO." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
5	4	1	1	0

2. "I feel that PLATO helps me prepare for the hour exams." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
6	5	0	0	0

3. "I like PLATO administered quizzes."

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
6	5	0	0	0

4. "I feel that the scores on PLATO quizzes were a fair evaluation of my knowledge." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
1	8	1	1	0

5. "I feel that PLATO quizzes do NOT adequately test the material I learned." How do you feel about this statement?

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
0	0	1	10	0

6. What do you like most about PLATO administered quizzes?

The help at end.

Contingency of reinforcement upon making correct and incorrect answers.

It tests you on just the basic material.

It gives me a chance to practice typing.

They start out gradual and get more difficult.

They are a challenge.

To know that I have plenty of time to answer--also the 2 chances!

I thought the way it was handled was all right--easily understood.

You can get things straightened out immediately.

Going back over and seeing right answer to question missed.

7. What do you dislike the most about PLATO administered quizzes?

If you type something wrong or push NEXT by accident it is frustrating to not find out for sure if you're right.

The answers which are similar or in different terms are sometimes rejected--material at times was hard to figure out just what answer machine wanted.

Nothing.

Often times you get frustrated and just guess.

If you word or misspell it is counted wrong.

The position of the TV screen. It should be lower so that the student wouldn't waste time and lose his train of thought.

No gripes.

Some questions vague--but that happens.

They're hard.

8. After the quiz has established that you need some help in a given area, which of the following do you prefer?

a) Different problems than the ones on the quiz but covering the same materials with help available. 2

b) Help with the same problems that you missed on the quiz. 5

c) Other--please specify 4

Situation b with an additional problem that is similar but different. (1)

Both a and b. (3)

9. Please summarize your feelings about the PLATO lessons.

I feel they have good problems. I guess this is all they can have, but the hourly had experiment questions which I had not reviewed. Is there a way to include explanations of experiments?

I like this--wish there'd be a similar program for 101 if the kind of work involved can be put into a computer.

I like it very much. I feel it has helped me very much! Very beneficial--should be available to all who desire it.

I learned well.

I liked them and found them extremely helpful. However often having the material on Mon. morn lecture and then that night is not enough time to study it and learn it.

I learned a lot faster and more efficiently. The only session that got on my nerves was the 2 hour one.

I love them.

I like them--although the lesson April 13 was long, but it sure helped. It isn't fun getting frustrated after 2 hours because you keep getting the wrong answers. Once you make a correct response it feel great to see the ok.

They help a lot.

VITA

Robert Clifford Grandey was born in Ellwood City, Pennsylvania, on November 29, 1943, and was educated in the public schools there until his graduation from Lincoln High School in 1961. He received a Bachelor of Science degree in education from the Indiana University of Pennsylvania, Indiana, Pennsylvania, in May 1965. After teaching high school chemistry at Altoona High School, Altoona, Pennsylvania, for one year, he enrolled at the University of Illinois and received a Master of Science degree in chemistry in 1968. He was a teaching assistant in the School of Chemical Sciences at the University of Illinois from 1966 to 1970.

He is a member of the American Chemical Society, American Association for the Advancement of Science, Chi Beta Phi, Kappa Delta Pi, Phi Delta Kappa, and Alpha Chi Sigma.

Publications: R. C. Grandey and T. Moeller, "1,10-Phenanthroline Complexes of the Lanthanide Ions prepared under Anhydrous Conditions," J. Inorg. Nucl. Chem., 32, 333-336, 1970.

NAVY

3 Chief of Naval Research
Code 458
Department of the Navy
Washington, D.C. 20360

1 Director
ONR Branch Office
495 Summer Street
Boston, Massachusetts 02210

1 Director
ONR Branch Office
219 South Dearborn Street
Chicago, Illinois 60604

1 Director
ONR Branch Office
1030 East Green Street
Pasadena, California 91101

1 Contract Administrator
Southeastern Area
Office of Naval Research
2110 G Street, N.W.
Washington, D.C. 20037

10 Commanding Officer
Office of Naval Research
Box 39
Fleet Post Office
New York, New York 09510

1 Office of Naval Research
Area Office
207 West Summer Street
New York, New York 10011

1 Office of Naval Research
Area Office
1076 Mission Street
San Francisco, California 94103

6 Director
Naval Research Laboratory
Washington, D.C. 20390
Attn: Technical Information Division

20 Defense Documentation Center
Cameron Station, Building 5
5010 Duke Street
Alexandria, Virginia 22314

1 Superintendent
Naval Postgraduate School
Monterey, California 93940
Attn: Code 2124

1 Head, Psychology Branch
Neuropsychiatric Service
U. S. Naval Hospital
Oakland, California 94627

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Service School Command
U. S. Naval Training Center
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Naval Personnel Research Activity
San Diego, California 92152

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Naval Medical Neuropsychiatric Research Unit
San Diego, California 92152

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Naval Training Device Center
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1 Chief, Aviation Psychology Division
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Naval Aerospace Medical Center
Pensacola, Florida 32512

1 Chief, Naval Air Reserve Training
Naval Air Station
Box 1
Glenview, Illinois 60026

1 Chairman
Leadership/Management Committee
Naval Sciences Department
U. S. Naval Academy
Annapolis, Maryland 21402

1 Technical Services Division
National Library of Medicine
8600 Rockville Pike
Bethesda, Maryland 20014

1 Behavioral Sciences Department
Naval Medical Research Institute
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Bethesda, Maryland 20014
Attn: Dr. W.W. ythorn, Director

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Washington, D.C. 203[illegible]

1 Capt. J.E. Rasmussen, MSC, USN
Chief of Naval Material (MAT 031M)
Room 1323, Main Navy Building
Washington, D.C. 20360

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ARMY

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Division #6, Aviation
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Post Office Box 6021
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300 North Washington Street
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300 North Washington Street
Alexandria, Virginia 22314

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Chief
Training and Development Division
Office of Civilian Personnel
Department of the Army
Washington, D.C. 20310

1 U. S. Army Behavioral Science
Research Laboratory
Washington, D.C. [illegible]

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Walter Reed Army Medical Center
Washington, D.C. 20012

1 Behavioral Sciences Division
Office of Chief of Research and
Development
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Washington, D.C. 20310

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U. S. Army Signal School
CAI Project
Fort Monmouth, New Jersey

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U. S. Air Force Academy
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Ohio 45433
Attn: Dr. G. A. Eckstrand

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Attn: Aeromedical Library
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Aerospace Medical Division
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San Antonio, Texas 78236

1 AFOSR (SRLB)
1400 Wilson Boulevard
Arlington, Virginia 22209

1 Headquarters, U.S. Air Force
Chief, Analysis Division (AFPDPL)
Washington, D.C. 20330

[illegible]

...oulevards
...is, Missouri 63130

1 Dr. Jack W. Dunlap
Dunlap and Associates
Darien, Connecticut 06820

1 Professor W. K. Estes
The Rockefeller University
New York, New York 10021

1 Dr. John C. Flanagan
American Institutes for Research
Post Office Box 1113
Palo Alto, California 94302

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Division of Organizational Sciences
Case Institute of Technology
Cleveland, Ohio 10900

1 Dr. Robert Glaser
Learning Research and Development
Center
Univeristy of Pittsburgh
Pittsburgh, Pennsylvania 15213

...rt Green
...tment of Psychology
...gie-Mellon University
...urgh, Pennsylvania 15213

... P. Guilford
...sity of Southern California
University Avenue
...geles, California 90007

...rold Gulliksen
...ment of Psychology
...ton University
...ton, New Jersey 0540

... D. Havron
...Sciences Research, Inc.
...te Industrial Park
...ld Springhouse Road
..., Virginia 22101

...bert E. Hickey
...k, Incorporated
...sant Street
...yport, Massachusetts 01950

...lliam A. Hunt
...ment of Psychology
University, Chicago
...orth Sheridan Road
...o, Illinois 60626

...ward H. Kendler
...ment of Psychology
...sity of California
... Barbara, California 93106

Robert R. Mackie
...an Factors Research, Inc.
...80 Cortona Drive
...anta Barbara Research Park
Goleta, California 93107

1 Dr. A. B. Nadel
General Learning Corporation
5454 Wisconsin Avenue, N.W.
Washington, D.C. 20015

1 Dr. Slater E. Newman
Department of Psychology
North Carolina State University
Raleigh, North Carolina 27607

1 Dr. C. E. Noble
Department of Psychology
University of Georgia
Athens, Georgia 30601

1 Dr. Henry S. Odbert
National Science Foundation
1800 G Street, N.W.
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1 Dr. Harry J. Older
Software Systems, Inc.
5810 Seminary Road
Falls Church, Virginia 22041

1 Dr. Leo J. Postman
Institute of Human Learning
University of California
2241 College Avenue
Berkeley, California 94720

1 Dr. Joseph W. Rigney
Electronics Personnel Research Group
University of Southern California
University Park
Los Angeles, California 90007

1 Dr. Arthur I. Siegel
Applied Psychological Services
Science Center
404 East Lancaster Avenue
Wayne, Pennsylvania 19087

1 Dr. Arthur W. Staats
Department of Psychology
Unversity of Hawaii
Honolulu, Hawaii 96822

1 Dr. Lawrence M. Stolurow
Harvard Computing Center
6 Appian Way
Cambridge, Massachusetts 02138

1 Dr. Donald W. Taylor
Department of Psychology
Yale University
333 Cedar Street
New Haven, Connecticut 06510

1 Dr. Ledyard R. Tucker
Department of Psychology
University of Illinois
Urbana, Illinois 61801

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Center for Research on Learning and Training
University of Michigan
Ann Arbor, Michigan 48104

1 Dr. James J. Asher
Department of Psychology
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San Jose, California 95114

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Human Factors
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National Institute of Mental Health
5454 Wisconsin Avenue, Room 10A11
Chevy Chase, Maryland 20203

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1 Director
Education and Training Sciences Department
Naval Medical Research Institute
Building 142
National Naval Medical Center
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1 Dr. Mats Bjorkman
University of Umea
Department of Psychology
Umea 6, Sweden

1 LCDR J.C. Meredith, USN (Ret.)
Institute of Library Research
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Berkeley, California 94720

1 Executive Secretariat
Interagency Committee on Manpower Research
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1738 M Street, N.W.
Washington, D.C. 20036
Attn: Mrs. Ruth Relyea)

1 Dr. Marshall J. Farr
Assistant Director, Engineering Psychology Program
Office of Naval Research (Code 455)
Washington, D.C. 20360

1 Mr. Joseph B. Blankenheim
NAVELEX 0474
Munitions Building, Rm. 3721
Washington, D.C. 20360

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1 Headquarters, Air Training Command
Randolph Air Force Base, Texas 78148
Attn: ATXTD (Dr. Meyer)

1 Mr. Michael Macdonald-Ross
International Training and Education Company Limited
ITEC House
29-30 Ely Place
London EC1
ENGLAND

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1 Dr. Don C. Coombs, Assistant Director
ERIC Clearinghouse
Stanford University
Palo Alto, California 94305

1 CDR H. J. Connery, USN
Scientific Advisory Team (Code 71)
Staff, COMASWFORLANT
Norfolk, Virginia 23511

1 ERIC Clearinghouse
Educational Media and Technology
Stanford University
Stanford, California

1 ERIC Clearinghouse
Vocational and Technical Education
Ohio State University
Columbus, Ohio 43212

1 Dr. Benton J. Underwood
Department of Psychology
Northwestern University
Evanston, Illinois 60201

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13. ABSTRACT

The development of computer-aided-instructional lessons on the following three topics is discussed: 1) The mole concept and chemical formulas, 2) Concentration of solutions and quantities from chemical equations, and 3) Balancing equations for oxidation-reduction reactions.

Emphasis was placed on developing computer routines which interpret student answers in their normal chemical form and tell the student what, if anything is wrong with them. Among the forms of answers, chemical formulas and chemical equations.

For each topic lessons were developed in each of the following three styles: 1) Instructional sequences, 2) Practice problems, and 3) Quizzes with forced review of weak areas. The combination of the three lesson styles was successful in providing each individual student with a unique educational experience.

The effectiveness of these lessons was determined by analyzing the data generated by the students while using these lessons and by comparing exam results for students who had experience with these lessons and those who did not.

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