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THE UNIVERSITY OF ALBERTA

COMPUTER ASSISTED INSTRUCTION APPLIED TO THE TEACHING OF LOGARITHMS--AN EVALUATIVE AND DESCRIPTIVE STUDY

by

© JACOB ISAAC

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Computer Assisted Instruction Applied to the Teaching of Logarithms--An Evaluative and Descriptive Study," submitted by Jacob Isaac in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

This study was designed to answer some of the questions related to computer assisted instruction. The investigation focussed particularly on the relative effectiveness of two types of CAI programs in teaching factual, algorithmic, and problem solving materials to students of various ability levels.

The sample consisted of 45 students randomly selected from three classes of grade eleven students in an Edmonton high school. These students were then assigned to three groups, each group studying the same material for the same length of time.

The Immediate Review Group (IRG) studied the subject matter at the computer terminals by means of a branching program. Each student in this group reviewed material not mastered adequately as soon as his responses revealed inadequate learning. The Delayed Review Group (DRG) also studied the materials at the terminals but did so by means of a linear program. This program merely spotted errors and corrected them with or without explanatory comments. All review was delayed until the basic material of the course had been covered. The Spaced Review Group (SRG) received their instruction in a more conventional classroom setting. Review of material preceded the presentation of new material.

Measuring instruments were developed to detect achievement in mathematics as well as attitudes toward mathematics and toward computer assisted instruction. Appropriate statistical procedures were used to determine the significance of differences between groups.

At the termination of the experimental period, no significant differences in attitude toward mathematics existed among the treatment groups and similarly no significant differences in attitude toward computer assisted instruction existed between the two experimental groups.

The investigation revealed the superiority of both IRG and DRG over SRG and also of IRG over DRG. The analysis also indicated that the achievement differential was greatest at the low ability level and for algorithmic items.

Although the Computer Sessions Questionnaire did not disclose any significant differences in attitude to CAI, it did reveal features of this instructional mode which were especially appealing to the students. The most popular features were:

1. ability to proceed at an individual rate,
2. opportunity to work independently,
3. individualization of instruction,
4. immediate checking of responses followed by a review of material not thoroughly mastered, and
5. encouragement obtained through a knowledge of the successful completion of each assignment.

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CHAPTER I

STATEMENT OF THE PROBLEM

1. INTRODUCTION

The computer has invaded a number of phases of man's life in the past decade. Significant among these are business, commerce, and construction. Thus far, the domestic and educative aspects of society have remained relatively untouched by direct computer influence. Numerous indications exist, however, that instruction will not long be able to remain uninfluenced by the computer.

A number of prominent educators imply the inevitability of the computer becoming an integral part of the educational process. Suppes (1966) discusses the computer's dual function in the schools and then refers to "the optimum teacher-machine interaction pattern that would take full advantage of both (p. 303)." Heinrich (1969) becomes somewhat more explicit when he states that

> at least three educational requirements make CAI (computer assisted instruction) inevitable: (1) the trend to individualized instruction, (2) the growth in information to be acquired, and (3) the shortage of qualified teachers. . . . At the moment, CAI is like the Wright brothers' first airplane: it is hardly of practical value, but its development cannot be ignored (p. 337).

The first two requirements are very prominent trends at present, and computer assisted instruction appears specially adapted to meet the demands of these trends.

Buchman feels that the rather limited use of the computer in education today may soon give way to the widespread introduction of this machine because of certain factors operating within the sphere of education today:

> Three additional factors may accelerate the present moderate growth in the number of high schools using computers in mathematics instruction: (1) community pressures due to the increasing use of computers in many fields, (2) the greater availability of textbooks suitable for use in courses in high school computer mathematics, and (3) the continued decrease in the price of small computer systems with which pupils can interact in user oriented language (p. 390).

It is quite reasonable to assume that each one of these factors may become a fairly substantial force directing educators to make better and more extensive use of a device with such apparent potential for education.

2. IMPORTANCE OF COMPUTER ASSISTED INSTRUCTION

The importance of CAI lies partly in the computer's dual role in the educational process: it functions as an instructional device, and it serves as a research tool. That it is a powerful instructional device will be developed more fully later. Suffice it to say at this time that computer assisted instruction may well achieve two very important objectives of education. It may promote the individualization of instruction, and it may free the classroom teacher from many routine chores, thereby enabling him to put forth more concerted efforts toward adjusting his own instruction to the diversity in ability and achievement represented in the group he teaches. That the computer is a powerful tool in the development of educational theory is fairly evident. In the words of Dick (1962), "The versatility of the computer opens a virtually unlimited area of research in learning as well as the potential of programming for individual differences (p. 41)." Its power to provide, to assemble, and to analyze data in research studies has important ramifications for theory development. During the course of lesson-involving CAI, the computer can assemble a detailed and accurate record of all inputs from each student as he proceeds.

A word of caution is in order at this point. Since both of the above-mentioned roles are important for education, neither should be exploited to the detriment of the other; rather, each should complement and supplement the other. Whereas the same two roles were possible for programmed instruction, its role as a research tool and stimulus to educational theory turned out to be much more significant than its role as an effective instructional device. Programmed instruction was used extensively for research purposes. The number of experiments and the literature related thereto attest to its widespread use in the field of research. Its effectiveness as an instructional device has been circumscribed greatly by the infrequent and often inept use which teachers in the classroom have made of it. Two factors account for the limited use of programmed learning in the classroom. Firstly, many teachers were uninformed or even misinformed about this instructional aid. Forbes (1963) has said that "unfortunately, the stormy origin of programming has left its mark--not so much on the materials themselves as on what people believe about programmed materials (p. 224)." Gentile (1969) expressed it rather forcefully when he said, "Is programmed learning, then, just another gimmick being perpetrated on unsuspecting educators as a scientifically sound method of teaching (p. 36)?" Secondly, teachers have not been trained in the most effective use of programmed materials. The improper use of these materials did not produce the promised and anticipated results, and teachers lost interest in their use. Stolurow (1962) maintains that

> the need is for better dissemination of information and preferably at a face-to-face level. In fact, if programmed instruction and teaching machines are to be used extensively outside of the few major cities, then there has to be a systematic effort to teach both new and experienced teachers about teaching machines and programmed instruction (p. 520)."

Since the potential of the computer as a teaching tool is so much greater than that of programmed instruction, this trend ought not to develop with computer assisted instruction.

The importance of CAI is enhanced further by a current interest in cybernetics as a fundamental concept in learning theory. The precise nature of cybernetics and its role in learning theory will be discussed somewhat later. It is sufficient at this time to point out that the computer is certainly capable of checking for the presence of cybernetics in the learning process and, if present, of using it to best advantage in promoting learning.

The foregoing discussion points out the need and the importance of controlled studies of the effects of CAI. If CAI is here to stay as Heinrich (1969) and Zoet (1969) maintain, then it is essential that educators study its strengths and weaknesses in order to use it most effectively. Many questions need to be answered, many aspects need to be examined, many implications need to be investigated. In summary, it is important that the effectiveness of this teaching technique be tested by a large number and variety of well constructed experiments.

This study has been designed to supplement the body of knowledge regarding the optimum use of the computer in the field of education in general and of mathematics in particular. More specifically, the study was intended to provide some specific knowledge of the relationship between two types of computer assisted instruction and:

1. the intelligence of the student,
2. the rate of progress of the student,
3. the acquisition of knowledge, skills, and processes by the student,
4. the difficulty level of the problems solved by the student,
5. the attitude of the student.

3. STATEMENT OF THE PROBLEM

Introduction

The failure to grasp or to master fundamental concepts is a major drawback in the rapid and efficient acquisition of subject matter of all types. This would appear to be true especially in mathematics since the number of such concepts is so great and since their importance and interdependence is such that insufficient mastery not only hampers progress but also precludes advancement altogether.

Various forms of instruction may be used in an attempt to ensure thorough and permanent mastery of fundamental concepts and processes. Not all of these are equally effective. Their relative effectiveness must be established through carefully designed research. Since only three of the many forms are used in the experiment described in this report, these three alone will be identified and described briefly. The forms are immediate review, delayed review, and spaced review. A description of each follows.

Immediate Review. The first method would emphasize the immediate detection of weaknesses and would follow these up with remedial instruction and/or further practice. The presentation of every new concept would lead directly into a diagnostic set of exercises. If the individual indicated satisfactory progress through these problems, he would proceed on to the next concept. If he did not, further instruction would be presented if the answers indicated that a concept had not been understood, or more practice would be given if errors in procedure or application were evident from the answers.

Delayed Review. The second method would emphasize the presentation of a unified topic in its entirety and delay any systematic or directed review until this has been accomplished. Under this procedure, all students would be taken through the basic material and the sets of exercises in sequence. After having done so, important concepts would be reviewed, stressed, or placed in context with each other and with other concepts in an attempt to consolidate understanding and to increase insight into the topic and its various aspects. Further practice with simpler questions as well as with more involved problems would be incorporated into this review.

Spaced Review. The third method would be somewhat of a compromise between the first two. Subject matter would be presented to students in units requiring approximately equal time intervals for presentation. This would permit spaced review of the concepts and procedures considered to be fundamental for satisfactory progress through the material still to be learned.

Each of these three methods (as well as any others which might be used) would appear to have advantages as well as disadvantages. The question immediately presents itself: would these advantages and disadvantages make one method superior or inferior to the others?

The Problem Stated

The problem to be investigated could be characterized best in terms of the two purposes which guided the design of the study.

The main purpose of the experiment was to investigate various aspects and outcomes of learning in a computer assisted instructional setting. The problem was to determine what benefits are realized by eleventh grade students as a result of the teaching mode used in computer assisted instruction.

As a subsidiary to this primary purpose, the study proposed to compare the effectiveness of the three teaching methods outlined above. Consequently, the present study has been designed to investigate the relationship between these teaching methods and the achievement of the students. If the superiority of any one of these methods could be confirmed, then such findings might well have practical implications for CAI and classroom instruction.

In view of the above-outlined primary and secondary purposes, the experiment was designed to answer the following questions.

1. Are there differences in the level of learning of mathematical concepts, skills, techniques, and processes under three teaching modes--two modes involving computer directed instruction and one of teacher directed instruction?

2. Is there any interaction between instructional mode and learning at the factual level, at the algorithmic level, and at the problem solving level?

3. Is there any interaction between the ability level of students and the three instructional modes?

4. Is there any relationship between achievement and the time required to complete the basic instructional program?

5. Within the CAI modes, is there any interaction between the the manner of progress through the material and the resultant learning? How, for instance, does a rapid coverage of the subject matter followed by a period of time devoted to review, consolidation, and enrichment compare with a slower, more thorough, and analytic progression through the material?

In addition to the foregoing questions, the study could produce data relevant to the following:

1. Do students show a preference for CAI over classroom instruction?

2. If so, is this preference related to the type of program used, and does it effect a noticeable difference in attitude toward mathematics?

3. When provision is made for branching in CAI, do the paths taken by students indicate:

a. common patterns or trends?

b. prominent instructional strengths of weaknesses?

c. necessary additions, possible deletions, or other changes in the program?

To place the earlier set of questions into sharper focus, a schematic diagram of three factors, each being subdivided into three types or levels, is presented in Figure 1. Immediately below the tabular diagram is a three-dimensional representation of the aspects to be considered in the investigation.

Experimental Setting

The research study involved the comparison of three basic teaching modes. Two of these were forms of CAI. The third could be considered to be a carefully defined type of conventional classroom instruction. Thus, three experimental groups were formed from three classes of grade eleven students in one of the public high schools of Edmonton.

The modes used in the study were called Delayed Review Program, Immediate Review Program, and Spaced Review Program. The nature of each is described in the following paragraphs.

Delayed Review Program. The first of the CAI modes involved a strictly linear progression through the material to be taught. What time was left thereafter was used for review, for practice at greater depth and breadth, for a concentration on the "gestalt" of the topic, and for enrichment.

A. Tabular Schematic

	Classroom			Linear			Branching		
	Fact[a]	Algor[b]	Prob[c]	Fact	Algor	Prob	Fact	Algor	Prob
High ability									
Medium ability									
Low ability									

[a]Factual

[b]Algorithmic

[c]Problem Solving

B. Three-dimensional Schematic

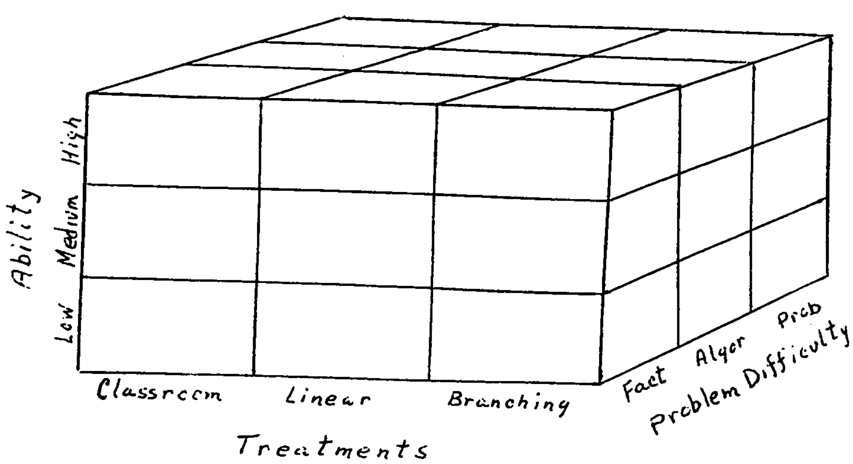


Figure 1

Treatments x Ability x Problem Difficulty Factorial Representation of the Problem under Investigation

Immediate Review Program. The second of the CAI methods was basically a progression through the program according to the ability and achievement of the individual. By using a branching technique, the program enabled the student to progress at a rate commensurate with his ability, to review poorly mastered concepts and procedures, and to study at greater depth as he was proceeding through the subject matter to be learned.

Spaced Review Instruction. The third strategy involved conventional group instruction in a classroom. The presentation of theory was preceded by the review of important questions posed by students and of concepts and procedures deemed important by the researcher. This was followed by seatwork, at which time the investigator circulated around the classroom, giving suggestions and assistance as required or requested.

4. DELIMITATIONS

To obtain answers to the basic question as to how computers can be used effectively within an educational system, two basically different computer programs were devised. These programs sought to develop the same mathematics as that which is prescribed by the Alberta Department of Education. The programs were written in the tutorial mode rather than in a drill-and-practice mode.

Practical considerations dictated certain restrictions in experimental conditions and design. Since a maximum of fifteen terminals were available groups of fifteen students were compared on the basis of the criteria chosen. Transportation and encroachment on school time necessitated restricting the length of the study to ten 55-minute lessons. Finally, the investigator's special interest, training and experience in mathematics led him to choose a chapter in mathematics as the subject matter for this study--the chapter on logarithms as currently being taught in eleventh grade mathematics.

The sample was chosen from the second semester grade eleven mathematics students at the Jasper Place Composite High School.

5. LIMITATIONS

The above-outlined problem deliminations imposed certain limitations on the generalizability of the results. The important ones are listed below.

The limited amount of time, especially in view of the oft-debated "Hawthorne effect," may necessitate a more protracted experiment as soon as such a study becomes practicable.

The results obtained may not generalize to groups of students from a different subject area, from a different age group, or even from a rural setting. Further research would be required to determine whether they can be applied to any or to all of these groups.

A special difficulty may be foreseen in comparing computer assisted instruction with conventional classroom instruction. Such a comparison may involve two widely dissimilar situations, leaving a question as to what the set of variables in the two situations actually is. Thus the classroom instruction mode includes a wide variety of teaching styles, personality factors, interaction incidents, and so forth. In a given experiment, only a sample of each is taken. Is the chosen sample truly representative? A similar situation exists for the computer instruction mode, but the variables may now be branching techniques, reinforcement styles, step size, and so on. Stolurow (1969) has stated the quandary very emphatically and succinctly. He says, in part, that

> this type of study is inappropriate when we know very little about a complex phenomenon; . . . With the comparative study, each of the specific conditions being compared is not *the* condition, but rather a sample of just one condition from a population of essentially infinite variations (p. 520).

The writer admits that a serious limitation regarding generalizability exists; he believes, however, that this aspect of the study has merit and importance in the information gained concerning the relative effectiveness of the teacher and computer in imparting facts, thinking processes, attitudes, et cetera, especially in the light of the fact that the teaching in the classroom and the writing of the CAI programs were done by the same person. The writer's point of view is also expressed by Feldhusen (1963) when he counters Stolurow's objection:

> In response we may echo the classic words, "Life is complicated.' . . . We want very much to know if learning from machines and programs is as effective as learning from a live teacher or other available media. We want to know what things the program can teach well and what must be left to the teacher. Thus the teacher must continue to be involved in comparisons with programmed instruction--but with improved experimental techniques designed to achieve better understanding (p. 267).

The investigator maintains that each experiment, when controlled as well as possible, does add significant information to a very complex problem.

6. DEFINITION OF TERMS

<u>CAI</u>. CAI refers to any and to all forms and modes of computer assisted instruction.

Delayed Review Program. A delayed review program is one in which the sequence of subject matter presentation is more or less identical for all students using the program. The only departure from the usual fixed sequence of "linear programming" is the provision for several trials in a given problem. In this case, the student is given instructions such as "Wrong. Try again." or "Time out. Work a little faster." Incorrect responses--whenever the student is not permitted a second attempt--are dealt with by presenting the correct answer together with a brief explanation.

Immediate Review Program. An immediate review program is one in which the sequence of material presentation depends on a variety of factors related to individual differences. Among these factors are the correctness of response, the type of error, the time required to respond, the cumulative record of the student, and the students' own assessment of the level of his understanding of the concept being presented.

DRG. DRG is the designation used for the group of students who have worked through the delayed review program at the computer.

IRG. IRG is the designation used for the group of students who have worked through the immediate review program at the computer.

SRG. SRG is the designation used for the spaced review group taught by the investigator in a traditional classroom situation.

Error. An error is a response which is not acceptable to the investigator. For the DRG and IRG, errors will include all wrong as well as all unrecognizable responses.

Error Rate. A student's error rate is the percentage of incorrect and unrecognizable responses to an item, a set of items, or a whole program.

Feedback. Feedback is the programming technique which provides the student with immediate knowledge of the acceptability of his response or of his error rate or score on a set of problems.

Pace. A student's pace is the rate at which he is permitted to work through the programmed material.

Step. A step is an increment in the presentation of subject matter as the learner proceeds from item to item.

Ability Groups. The grade eleven mathematics population of Jasper Place Composite High School were ranked on the basis of I.Q. as measured by the Lorge Thorndike test and then divided into three groups of equal size, thereby forming a high ability group, a medium ability group, and a low ability group.

Classroom Instruction. For purposes of this study, classroom instruction is to be understood as follows. Each period begins with a brief review of theory relevant to and significant for the material to be learned in that period. Important questions raised by students are answered as briefly as possible but as explicitly as necessary. New concepts, theory and procedures are developed after these preliminaries have been taken care of. The remaining time is used for seat work, which is closely supervised by the investigator, and for quizzes which parallel those used in the other two groups.

Factual Items. A factual item requires pure recall or repetition of facts, relationships, and/or procedures in the exact form in which they have been presented previously.

Algorithmic Items. An algorithmic item requires the knowledge and application of a previously studied algorithm, sequence of steps, or generalized approach to a problem.

Problem-solving Items. A problem-solving item requires the student to go beyond facts and algorithms, thereby involving him in an analysis or synthesis of the problem in order to discover a new approach or technique or to use some novel combination of facts and algorithms.

The reader is referred to the appendix for further details on these three types of items.

7. OUTLINE OF THE REPORT

Chapter I has outlined the problem and indicated in part its significance in view of the computer's potential and of its importance for the advancement of education. Chapter II presents a survey of the literature relevant to the problem under investigation. This includes a review of the literature on programmed instruction as well as all research which has implications for the present investigation. Chapter III begins with a presentation of the theoretical rationale underlying the investigation, continues with a discussion of some of the implications of this rationale and concludes with the flowchart outlining the nature of the branching program used in the study. Chapter IV includes a full report of the manner in which the data was gathered, of the hypotheses formulated for the study, and of the statistical procedures used in testing them. Chapter V presents the analysis of the data gleaned from the experiment. Chapter VI interprets the findings recorded in the preceding chapter in the light of the rationale developed earlier, extracts the conclusions from the findings, and lists some recommendations for future research.

CHAPTER II

SURVEY OF RELATED LITERATURE

1. OVERVIEW

This chapter begins with a brief indication of the relationship existing between PI (programmed instruction) and CAI (computer assisted instruction) and continues with a discussion of some of the main tenets of theory as found in the literature on these instructional modes. This discussion leads to a statement of important principles and implications with respect to CAI. The chapter concludes with a review of some of the most significant research conducted in the areas of PI and CAI.

2. RELATIONSHIP OF CAI TO PI

Clearly, CAI is related to PI in purpose, method, adaptations, and results. Because of this and because PI can be thought of as a forebearer of CAI, PI literature has an important bearing on this study. Whereas the literature on CAI is rather limited, that on PI is copious. Whereas research studies about CAI are few in number, those about PI are abundant in number and variety. The task at hand is to glean from this abundance those elements relevant to the development and actual testing of the hypotheses of this study.

Gentile (1969) supports the view that PI theory and research cannot be applied indiscriminately to CAI. He says: Even if there were systematic data collected in programmed learning, generalizability to CAI cannot be assumed without replication of studies (p. 37)." The way has been paved, however, for CAI theorists and researchers. The close relationship between the two modes does suggest extensive overlap in theory and does encourage researchers to replicate PI studies in CAI mode.

The writer maintains, therefore, that a survey of CAI literature on theory and research should be supplemented by a survey of the more plentiful PI literature.

3. BASIC TENETS OF LEARNING THEORY

PI and CAI are based on a number of fundamental tenets believed to be significant in the learning process. These are related to:

1. the size of step in presenting material;
2. the activeness of participation on the part of the learner,
3. the rate at which the individual is led through the subject matter,
4. the reinforcement and/or feedback used,
5. the individual differences present in the group.

These aspects will be developed and discussed in the order in which they have been listed.

Size of Step

Considerable disagreement exists on the question as to what constitutes an optimum step size. Skinner maintains that the step differential between frames ought to be small--so small, in fact that a student working through a carefully developed program can do so without making any errors. This almost invariably necessitates a linear program with a heavily prompted sequence of frames, with very easy questions and with a fair amount of redundancy. Skinner's position appears to be based on the assumption that conditioning is of paramount importance in human learning.

Other theorists disagree with this position on several grounds. It is said to defeat one of the most powerful arguments for PI and CAI, viz., the provision for individual differences, since "an ideal sequence of items for one student would be less than maximally effective for some other student (Coulson, 1962, p. 208)." It is almost inevitable that, because of the slow pace, the time of the average and above-average student will be wasted. Secondly, a small-step program may have negative effects on the attitude of many students since the pace is too slow and since redundancy of material and consistent, easily attained success both contribute towards making the course "boring" for many students. This type of program robs such students of one of the "prime drives in studying mathematics . . . the joy that comes from mathematical insight and accomplishment (May, 1966, p. 447)." Thirdly, the making of errors may not be as detrimental as Skinner would lead us to believe. There may be positive effects which more than compensate for any negative effects. Thus Crowder says,

> It is a current shibboleth that "when the student makes an error, the fault is in the program." . . . anyone would prefer programs on which no student made an error *if this could be achieved without other undesirable results* . . . We can produce virtually error-free programs if we are careful never to assume knowledge that the most poorly prepared student does not have, never to give more information per step than the slowest can absorb, and never to require reasoning beyond the capacity of the dullest (1963, p. 253).

Finally, the small-step program results in a fragmentation and a fractionization of learning. Many theorists feel that this is a serious defect since students "will not learn to see the big picture, to read long passages, to analyze complex ideas without guidance or to express themselves in an extensive way (May, 1966, p. 448)." Gestaltists would certainly stress the importance of the "gestalt" as opposed to the detail, while cognitive theorists would maintain that it is a process, not a response, which is to be learned.

Active Participation

The principle of active participation is one of the widely accepted and well-established aspects of learning theory. According to Forbes (1963), "Learning is an active rather than a passive process. Hence, an effective learning situation must provide for an extensive interaction between the learner and the material to be learned (p. 224)." PI and CAI are well adapted to do this. By allowing each student to determine his own pace, each is led to participate actively. Individual responses to each item together with the machine's responsiveness to individual differences in the responses given make individual participation meaningful and rewarding.

Individual Rate of Progress

The lock-step nature of most educational systems has long been recognized as a necessity forced on us by economic, administrative and other practical considerations. Much preferred would be a system whereby every individual progresses as fast as he is able to assimilate and to master the required subject matter. The bright student would not be bored with material mastered long ago. The dull student would not feel undue pressure to proceed and would certainly not be faced with the necessity of proceeding with new material before having mastered its pre-requisite. The child absent from school for any length of time would simply proceed from the point where he was forced to discontinue his studies. Problems would be presented and responded to at a rate commensurate with the ability of each individual. Students would be permitted to skip items and sections as well as to retrace their steps on the basis of their abilities and needs. An interesting experiment on the sources of differences in rates of learning performed by Gagne and Paradis led them to conclude that such differences are

> due not to variations on some underlying general ability to learn fast, but rather to (a) the number and kind of learning sets (competencies, knowledge) the learner brings to the situation, and secondarily to (b) his standing in certain basic abilities relevant to the competencies to be acquired as they are identified in the theoretical hierarchy for the task and (c) his level of general intelligence (Briggs, 1968, p. 162).

Individual Differences

The significance of this concept for the problem under consideration is quite evident. As Gagne has said,

> A general principle emerging from modern learning studies is that learning is an individual matter, in which essential idiosyncratic elements must be supplied by the learner himself. In applying these principles to the choice and use of media, an analysis of the events of instruction is required. These involve gaining and controlling attention, stimulating recall, guiding or cueing the learning, providing feedback, arranging for remembering, and assessing the final outcomes (Heinrich, 1969, p. 351).

The computer is uniquely adapted to handle individual differences in learning rate, aptitude and background.

Reinforcement and/or Feedback

Depending on what point of view is taken or what particular educational philosophy is subscribed to, the act of providing students with immediate knowledge of the acceptability or non-acceptability of their responses is considered to be reinforcement or feedback. Whatever viewpoint is taken, the concept involved is of primary importance in education. This aspect, too, merits separate and extensive discussion at a later stage.

4. INFERRED PRINCIPLES AND IMPLICATIONS

The rather broad tenets discussed above lead to more specific principles which are important in establishing a situation conducive to the acquisition of knowledge and in devising a programming method which increases the probability of optimal learning on the part of all students. These principles (broad and specific) have definite implications for procedure, content, breadth and depth of instruction, whatever presentation mode is chosen. The most important of these will be dealt with in the following pages.

Factors Determining Learning Effectiveness

The foregoing discussion has indicated directly or indirectly that the effectiveness of instruction is dependent on a number of factors in the learning situation. Briefly, the most important of these are as follows.

1. Learning is much more effective if the learner is active rather than passive.

2. Instruction will be much more effective if the learner is informed regarding his progress.

3. Instruction which is maximally adjusted to individual differences will be most effective.

4. Learning will be more efficient if the goals are stated clearly and in behavioral terms.

Difficulty Levels of Tutorial Instruction

The proposed problem does not require an extensive treatment on these levels. Several observations, however, are pertinent and important. The level at which instruction is given is determined in part by the accepted view of the learning process. Two such views are stated by Forbes (1963).

> Premise 1. Learning is linear in nature. It is a "steady growth" process, which proceeds in small steps with complete mastery of each small step preceding progress to the next step. . . .
> Premise 2. Learning is a process of irregular growth in which the less difficult aspects throughout the concept are learned first (p. 225).

The acceptance of Premise 1 would lead naturally in PI as well as in CAI to a Skinnerian program. Premise 2, on the other hand, would more likely result in a Crowder-type program, in which a concept is presented in its entirety with a possibility of branching back to a less difficult but pre-requisite concept. These two types of programs roughly approximate Stolurow's two levels of instruction

> the *lower* level obtains when the system is programmed to teach with a fixed logic and a fixed sequence . . . The *higher* level obtains when the system is programmed to alter either its logic, its content, or both, for subsequent parts of the instructional program depending upon the students' performance on the earlier parts (Stolurow, 1968, p. 106).

The latter level implies a branching program. The types of, and the theory relevant to, branching will be discussed more fully in subsequent pages.

Individual Differences

Meaning of Individualization. A precise definition of this term will not be attempted here. It is hoped that the ensuing discussion will make clear the meaning which will be attached to it as well as the extent of individualization which can and should be realized. That the problem is more involved than it might at first appear to be is indicated by Oettinger's comments on the meaning of the term.

> It turns out, as one might have expected, that the meaning of "individualized instruction" is in fact exceedingly fuzzy and of little value as anything but a flag. . . . A case may be made for defining it as something like personalizing or customizing . . . A loftier interpretation postulates that individualizing means giving full scope to idiosyncrasy, to the freedom to pursue whatever subject suits one's fancy in a manner entirely of one's own choosing (Oettinger, 1968, p. 698).

In a reaction paper to Oettinger's presentation, Suppes comments:

> A discussion of individualizing instruction is like a discussion about predicting the weather. For the main purposes at hand we don't need a precise definition of what we mean by "weather." We can simply resort to our intuitions, and we all recognize when these intuitions are violated by an example or a statement (Oettinger, 1968, p. 731).

Significance for Instruction. A number of educators stress the need to consider individual differences. Briggs (1968) mentions that educators have been searching for many decades already for ways to adapt group instruction to the individual pace and progress of the members in the group. Bennis, in reply to Oettinger's criticism of individualized instruction, says that

> adapting instruction to individual characteristics and background [is] the most pressing need in education today and in the foreseeable tomorrow cannot only maximize individual

> competence, but provide every individual with a sense of pride and uniqueness, and a feeling of capability to assist as a full-fledged member of society (Oettinger, 1968, p. 740).

Suppes (1968) refers to it as "the single most powerful argument for computer-assisted instruction (p. 208)." He continues as follows:

> It is widely agreed that the more an educational curriculum can adapt in a unique fashion to individual learners . . . the better the chance is of providing the student with a successful learning experience (p. 208).

Literature generally agrees that PI has greater potential in catering to and capitalizing on individual differences than classroom instruction. This is especially true of CAI. Coulson (1962) speaks of "machine responsiveness" to individual differences, resulting in "differential instructional procedures for different students (p. 208)." Bushnell (1962) comments on the computer's potential for handling differences in learning rate, background, and aptitude. Jensen (1962) maintains that "the teaching machine, far more effectively than the human teacher, can capitalize on individual differences if they are properly taken into account (Smith, p. 220)." As a last of many possible references, Trow (1963) speaks of the "computer's almost unlimited potential for satisfying all the above requirements except preparing the programs (p. 105)."

Difficulties and Realistic Considerations. Whereas the possibilities in PI and CAI of considering individual differences are great, the actual realization of these noble objectives is not without its difficulties. Possibly the greatest of these is the anticipation or identification of the precise nature of these differences. In this respect, the teacher has an advantage since he can respond to unanticipated incidents. According to Briggs (1968), we are still uncertain as to what the needs of the learner are.

> If somehow, attention could be focussed first on the learner variables--why the person does or does not meet the criteria of progress--then insights might be gained into what the individual learner needs by way of instructional materials and media (p. 160).

The problem is stated at a somewhat deeper level by Jensen (1967) when he says:

> The presence of individual differences in school performance are so obviously great as to have become traditionally one of the primary concerns of educational psychology. But nearly all of the efforts to measure individual differences have been what might be called "static." Rather than studying individual differences in the dynamics of behavioral change, we have studied only the end products of learning by means of our intelligence tests, aptitude tests, and achievement tests. How people differ in the processes by means of which behavioural change takes place is truly an unknown and unexplored territory in psychology (Smith, p. 219).

Thus, while experimentation for the present will be based more on the aforementioned end-products of learning, future theory and research must strive for tests of the dynamics of behavioral change and seek to implement the findings from these tests to the individualization of instruction. In the meantime, useful results can be achieved by studying the endproducts of instruction. It is quite conceivable, furthermore, that such results may in turn lead to knowledge of the dynamic process which produces these endproducts. PI and CAI, it is believed, can be especially useful in this experimentation because they are particularly adapted to individualizing instruction and to observing and recording the steps that individuals go through in learning.

The difficulty outlined above is one of Gentile's "realistic considerations" which should temper our enthusiastic and wide adoption of CAI as a solution to the problem of individual differences. He urges a consideration of three other aspects:

> There are many varieties of individual differences. . . . It is unrealistic to expect any teaching method to eliminate individual differences. The subtle influences of directions and mental set virtually assure us that students will attend to different stimuli in the learning situation . . . Finally, and most crucial, although it is sanctioned by the Zeitgeist to "adapt to individual differences," such adaptation must be demonstrated to be superior to teaching aimed at the mean of the group (Gentile, 1967, pp. 38-39).

It should be noted that, while it may be true that no teaching method will eliminate all individual differences, one should not conclude that the elimination of all individual differences is desirable. What is desired is the optimum adjustment to and capitalizing on the existing differences.

Aspects. A number of different aspects in which individuals differ have already been mentioned. These include differences in rates of learning, in initial ability, and in mental sets. What research in these areas has already been done will be discussed later.

One further aspect occurring frequently in literature is the existing differences in cognitive styles. Especially relevant here are two problems raised by Suppes (1966):

> It is not at all clear how evidence for the existence of different cognitive styles can be used to guide the design and organization of individualized curriculum materials adapted to these different styles . . . To what extent does society want to commit itself to accentuating differences in cognitive style by individualized techniques that cater to these differences (p. 220)?

Bundy feels that there is a relationship between cognitive style and ability and that a student's cognitive style will affect the way he approaches and uses the computer system.

<u>Attainment</u>. Before leaving the topic, a comment on how individualized instruction can be achieved should be made. Braunfeld (1964) refers to the computer's ability to change its course of action on the basis of the student's response to a question. He maintains that these are nontrivial decisions on how to tailor the course to individual needs. Suppes (Oettinger, 1968) lists three distinct ways in which the computer individualizes instruction:

1. the pace of presenting problems and responding to the student's answer,

2. the organization of problems according to difficulty, and

3. the selection of review on the basis of the student's past performance.

Reinforcement

The importance of reinforcement as an underlying concept of programmed instruction is stated by many PI protagonists and is expressed by Creswell (1968) as follows:

> Many advocates of programmed instruction are supporters of the reinforcement theory of learning. Indeed, the basic concept involved in programmed instruction is that of reinforcement (p. 366).

<u>Meaning and Implications</u>. It should be noted, first of all, that there is considerable disagreement about a number of aspects of this concept. Not the least of these is concerned with the meaning of the term itself. Maehr (1968) focusses on this problem when he says,

> It is, of course, relatively simple to define reinforcement in a *post hoc* fashion. But how does one predict what will be reinforcing across a wide variety of situations . . . There is only limited information provided within the confines

> of Skinner's theory which would help us to define reinforcement generally, and, therewith, predict choices under widely divergent situations (p. 109).

Maehr also points out that the subject's perceptions may transform reinforcement and ameliorate its effects. Consensus of opinion would probably center somewhere on defining reinforcement operationally as a matter of obtaining the correct answer or of being made aware that one's answer is correct.

According to Skinner, such knowledge given to the student has two beneficial effects. It "reinforces" the answer given, thereby preventing its extinction and prolonging the student's retention. He goes so far as to maintain that a single reinforcement can accomplish a significant change in behavior. It also "motivates" the student by capturing his attention and inducing a positive attitude toward the task being undertaken. Maehr (1968) does not concede the latter. He says:

> According to the press releases, students persisted at these programmed tasks in spite of hunger, thirst, or foul weather. Apparently, however, not all subjects read the press releases, for it seems that programmed materials can be just as boring as an ineffective teacher. They also can be just as exciting as a good teacher (p. 109).

These two viewpoints, in varying degrees, are expressed repeatedly in reinforcement literature. Most theorists would accept the principle of reinforcement: Feldhusen (1963) actually speaks of the well-established principle of reinforcement. Explanation of the result, however, ranges all the way from Skinner's reward to Guthrie's contiguity and Estes' law of context.

Frequency and Type. This divergence in explanation is reflected in a corresponding divergence in view with respect to the frequency and mode of providing for reinforcement. Thus Skinner would emphasize the need for a *positive* reinforcement of every response, Guthrie would stress that *desired* responses occur in contiguity with relevant stimuli, believing that no other reinforcement would be necessary, and Estes would argue that a *confirming* response be placed in appropriate context rather than in isolation. With respect to frequency of reinforcement, Creswell (1968) states that "learning takes place best when a complex task is broken into many small steps each of which is constantly reinforced many times (p. 366)." Not all theorists believe that every response should be reinforced. Maehr (1968) indicates that partial reinforcement, under certain circumstances, is more effective in prolonging memory. He refers to an unfortunate side-effect of repeatedly being right, viz., boredom on the part of the student. He says, "Regular, consistent positive reinforcement may be reassuring, but it certainly is not challenging . . . The reality of failure simply makes success meaningful and a successfully performed task interesting (p. 110)."

Writers are more agreed on the type of reinforcement which ought to be used. Thus, positive feedback is better than negative. With CAI a much richer type of feedback is possible than with PI, and it is expected that research will show that feedback appropriate to the individual's response has a significant bearing on instructional effectiveness.

In summary, theorists generally agree that reinforcement plays an important role in the learning process. It remains for research to determine more precisely what form it should take, at what intervals it should be given, and what results can be expected from it.

Branching

A survey of PI and CAI literature would not be complete without some reference to branching--the need and criteria for branching, the types of branching, and the amount of branching available in instruction.

Need. Basic to all branching within auto-instructional programs is the desire to provide for individual differences. The programmer seeks to vary the sequence, difficulty, and content of the presented material as well as the answer analysis and relevant comments thereto according to the needs detected within the individual through prior testing or interspersed quizzes. Thus Coulson (1968) maintains that the rationale and theory of CAI is based on a recognition "that no two students are completely alike and that each can learn most effectively when the sequence of instructional material, pace and mode of presentation and even the style of instruction are tailored to his individual needs and capabilities (p. 140)." To which Crowder (1963) adds:

> To me the essential problem is that of controlling a communication procedure by the use of feedback. The student's response serves primarily as a means of determining whether the communication process has been effective and at the same time allows appropriate corrective action to be taken when the communication has been ineffective (Galanter, p. 114).

Suppes' "organization of problems in terms of their difficulty" is accomplished in part by the branching on the basis of the individual's experiences as he proceeds through the sequence. His "selection of individualized review" is determined from the student's errors and difficulties.

Criteria. As already intimated above, the criteria for the built-in branching reside in the individual and in his responses. Ideally, these criteria would include relevant personal data such as I.Q., aptitudes, personality characteristics, and motivation. Stolurow (1968) proposes the following:

> The outcome of the pre-tutorial processing is a tutorial program for each student based upon data about his aptitudes, abilities and personality . . . The content depends upon the student's pretest performance on a test covering the behavioral objectives of the instruction and his performance while learning . . . Whenever the student's performance does not meet the specified standards, adjustments are made in some part of his projected program. Also the data contribute to the adjustments made in the decision rules themselves for future applications to other students (pp. 104-6).

Thus, the student's past performance would affect information presentation, sequences of displays, and the temporal pace of the program.

More realistic criteria in view of the present stage of CAI development are listed by Braunfeld (1964). He includes the specific answers given by the individual to diagnostic questions, the student's cumulative record, and the student's own assessment of his mastery of the theory presented. To these, Bushnell (1962) would add the characteristics of the response; that is, its promptness and definitiveness; its nature, including the specific errors made; the history of the individual's learning; and the nature of the subject matter being taught. He, too, would consider a student's own assessment of his progress by honoring his request for re-routing (p. 528).

Types. Creswell (1968) describes three basic types of branching programs currently in use.

1. Washback branching is a branching backward to review a concept which the student, as indicated by response errors, has not mastered.

2. Sub-sequence branching is *remediation* which appears necessary on the basis of a series of incorrect responses.

3. Wash-ahead branching is a skipping of already mastered materials in order to accommodate the more capable student.

In addition to backward and forward branching, Bushnell (1962) mentions lateral branching for further practice or for more varied application.

Amount available. The branching capability of today's computer is truly impressive. Already man envisions an almost unlimited capability in this respect.

> The electronic computer has the capability of presenting a rich branching program that would be too unwieldy in book form . . . The computer behaves like a slightly deaf teacher with an enormous memory and little imagination, who has been coached by someone with quite a bit of knowledge and experience. It can take into account all past performance of the student and all information about him that has been fed in, *provided* someone has written a program sufficiently complex to involve all these factors (May, 1966, p. 450).

At present it appears as though further sophistication in branching techniques are circumscribed only by the present state of theory and instrumentation. The upper limit eventually may exist only in Hickey's "exponentially growing tree of stimulus frames that quickly exhausts the author (Heinrich, 1969, p. 336)." Unless, of course, the system truly "learns how to teach more effectively."

5. PI-RELATED RESEARCH

It is impossible, in a brief survey, to cover the full range of research literature available on PI. However, a selection of studies which are significant for the problem at hand will be reported on. In addition, a few generalized statements regarding findings will be made.

Reinforcement

A number of experiments bearing on the reinforcement theory as outlined previously merit comment. Skinner (1954) reports that

> one of the most striking principles to emerge from recent research is that the *net* amount of reinforcement is of little significance. A very slight reinforcement may be tremendously effective in controlling behavior if it is wisely used (p. 90).

The contention of PI proponents that immediate confirmation has a positive effect on learning is not borne out by the work of Evans (1962) who concluded that total learning errors are not affected significantly by providing immediate confirmation. Krumboltz (1962) reports a similar result on that portion of his criterion test which measured knowledge of terminology, but indicates that a significant difference favoring the "context" group appeared on those items which measure application of principles.

Feldhusen (1963), after examining some of the research, concludes that

> a linear program written to assure correct response 90 or 95 per cent of the time is inherently so easy for most learners that they know they are giving right answers without having to check with a feedback system . . . instead of reinforcement, some researchers found disturbing signs of boredom . . . sufficiently great to indicate that the program would not be a uniformly reinforcing experience for all youngsters (p. 266).

He concedes, however, that those who expressed a negative attitude toward programmed learning did not achieve significantly less than the others.

Time

Many of the reported studies point to a saving of time through the use of PI. Hough (1962) reports studies by McNemar and Hughes and by Porter to the effect that instructional time favoured the machine-taught group. Stolurow (1968) agrees that one of the findings of research is that students often learn in less time. One such experiment was conducted by Hough (1962) in teaching elementary statistics. In a multidimensional study, Coulson (1962) concluded that training time favored:

1. "branching" students as compared with "fixed sequence" students,
2. a large-step program as compared with a small-step program, and
3. "multiple choice" responses as compared with "constructed answer" responses.

Melaragno (1962) also found a significant saving of time in the branching program when compared to the linear program.

There is some evidence to the contrary as well. Roe (1962) concluded that freshman engineering students took less time to complete the course when taught by the lecture method. Zoll (1969), after reviewing research in PI in mathematics, maintains that "in those studies that considered time spent studying the program as a criterion very few, if any, indicated significant differences in this measure (p. 108)."

Learning Effectiveness

General Effectiveness. Evans (1962) lists a number of research studies which indicate that programmed instruction has produced better achievement, as measured by devised tests, than other instructional measures. He suggests that future refinements resulting from research are likely to accentuate this difference. Stolurow (1966) reports that "the most consistent finding is that students learn at least equally well compared with other methods of instruction (p. 520)."

Zoll (1969) reports a somewhat different conclusion after reviewing some of the most recent research in PI as applied to mathematics:

> Of the studies reviewed in this paper in which programmed instruction was compared to the traditional methods, three reported significant learning gains in mathematics in favor of programmed instruction, three reported significant learning gains in mathematics in favor of the traditional courses, and seven found no statistically significant differences (p. 103).

Effectiveness in Teaching Mathematics Concepts. Whereas it is generally accepted that programmed instruction can be used quite effectively in teaching factual material, there is considerable doubt about its usefulness in teaching concepts, principles, or logic. In this respect, Zoll's conclusion is rather encouraging. He states that "these four studies indicate some success in developing programmed units to teach concepts, although more research seems to be needed in the area of mathematical proof (p. 106)."

Program Characteristics

Some studies which involved different types of programs have already been reviewed. The following should be noted as well.

Findings on the size of step to be used do not agree. Feldhusen (1963) reports that Coulson's experiment favored the large step but that Sharp's study favored the small step. Evans (1962) cites two studies in which the use of a large number of small steps was found to be more effective than a smaller number of large steps. Coulson (1962) reports a similar result but indicates that this advantage is offset somewhat by the fact that the "small step" group required significantly more time.

Whereas Skinner emphasizes the need for overt responses to questions, Feldhusen (1963) reports that the work of Evans, Holland, McDonald, and Stolurow indicate that this is not necessarily so. Evans (1962) sets forth similar findings.

Research does not agree on which response mode is superior. When comparing the constructed response with the multiple choice response, Evans, Coulson, Roe, and Hough (1962) found no significant difference, whereas Fry concluded that the constructed response was superior.

Personality-related Factors

Attitude. Reference has already been made to attitude. Smith's study (1962) led him to conclude that

> The students being taught by programmed instruction did, on the whole, respond favorably to this method of instruction, did consider it more efficient, and did feel that they had more opportunity to receive individual assistance from the teacher than under more conventional methods (p. 419).

The opposite result comes from a more descriptive study conducted by Roth (1963). Though learning was satisfactory, a very negative attitude of boredom and constraint was quite evident.

Neidt (1968) investigated the novelty effect of instruction based on various instructional media. The hypothesis that novelty was the variable underlying a positive attitude was supported by the lower rates of decline of attitude among the groups using PI and TV and by a levelling off of attitude in the same groups at a higher level. The latter was interpreted to mean that a simple relationship between attitude and novelty was not enough to explain the results which were obtained.

Zoll's review of PI research in mathematics (1969) included ten studies which used attitude questionnaires designed to detect student reaction to programmed instruction. He states:

> Generally, this response was favorable, although three studies (1, 18, and 20) indicated that interest decreased as the time spent studying the program increased. No study reported unfavorable student attitudes toward programmed instruction (p. 105).

Anxiety. MacPherson's investigation (1968) led him to conclude that the only significant relationship between anxiety score, I. Q., learning scores, and the time required to complete a mathematics program was a high negative correlation between anxiety scores and the time required to complete the program.

Ability. Zoll's review (1969) indicates that "for students of determined ability level in mathematics, programmed instruction seems to be as effective as conventional teaching (p. 105)."

6. SUMMARY OF PI RESEARCH FINDINGS

Feldhusen (1963) answers the question as to whether children can learn as well by the conventional method by saying, "Lo and behold, students can still learn well from narrative instructional materials (p. 267." May (1966) agrees with Stolurow and Davis (1967) who maintain that the typical finding is that there is no difference in the effectiveness of a machine and a book (Gilman, 1967, p. 424)." Within PI, however, a number of significant differences have been found. Most of these have already been reported on.

7. CAI-RELATED RESEARCH

Research on CAI is much less abundant than that on PI. As Suppes (1966) has said, "While some creditable work has been done in the areas of branching and feedback variables, few studies using computer-based teaching devices are available (p. 303)." Most of the work thus far has been of an exploratory nature in order to determine whether this mode of instruction can be used effectively and what gross effects various programming techniques may have. Relatively few elaborate and highly controlled experiments are available. It should be noted, however, that many universities are presently engaged in long-term studies in CAI and are doing so in a more normal classroom situation. Among these are Pennsylvania State University, Stanford University, Florida State University, and the Universities of Texas and Illinois.

Time

The evidence for a saving in time which is available in PI is also beginning to show itself in CAI. Hansen (1966) declares that "One of the most consistent findings associated with CAI tutorial application is the marked saving in instructional time with no loss in post-instructional achievement test performance (p. 601)." In support of this contention, he cites the work of Grubb and Selfridge, of Shurdak, and of Goodman. Dick (1965) arrives at the same conclusion; in doing so, he refers to three IBM research studies on stenotyping, statistics, and German. According to Bundy (1968), learning time is related to four factors:

> The major determinant of time to complete the computer program is the number of student responses required to meet internal course criteria established by the author teacher.
>
> Employment of optional delays in the learning program, plus the opportunity for review and remedial work, would provide help for some students.
>
> There is great variability in how long children will work at the computer instructional terminal when free to decide.
>
> Deterioration in learning performance has been noted in grade school children when sessions ran longer than 20 - 30 minutes (p. 425).

Other investigations add to the evidence of the economy in time effected by CAI. Ford (1970) found that CAI produced faster learning than lecture-based instruction in electronics, indicating that time savings of 33 - 44 per cent were being realized in the various ability tracks. The study conducted by Grubb and Selfridge (1964) showed that students are able to absorb large amounts of instruction in a short time and that the mean time spent at the computer (5.5 hours) was somewhat less than half the time used by the programmed instruction group and less than one quarter of the time taken by the lecture group.

Two studies comparing two or more modes within CAI are also of interest. Gilman and Harvilchuck (1967) report that the verbal content can be reduced in order to achieve a significant reduction in instructional time without significantly decreasing the resultant learning. They believe that this saving is due largely to the time required to read and comprehend the lengthier material and to the slower type-out rate of the typewriter terminal device. This may also be the explanation for the results obtained from a second study by Gilman (1967) in which he compared feedback modes. He concluded that those students who received long feedback messages required significantly more time than those who received shorter messages and that those students who received feedback as to what the correct answer should have been required the least time.

Learning Effectiveness

Bundy (1968) lists a number of factors affecting the effectiveness of instruction. These include cognitive style, branching criteria and methods, student determination of sequence, number of "help" sequences, and type of response form permitted. He lists the following studies as evidence that CAI students appear to achieve and to retain better than classroom students: Bitzer in clinical nursing, Martin in early reading and Grubb and Selfridge in statistics. He further states that Coulson's research indicates that the level of performance of low ability students can be raised to that of higher ability students. In the light of these results, the conclusions of Gilman (1967) are interesting.

> No difference in learning or retention were obtained for a CAI program which incorporated response contingent feedback, prompting, and overt correction procedures when compared to a CAI program which simply typed the correct response following a student response. No differences in learning or retention were obtained for a condition in which an instructional program was administered by a teletypewriter as compared to a condition in which the material was presented by means of programmed texts. Both conditions in which instruction was presented by a CAI communication device took significantly more instructional time than the programmed text condition (p. 423).

Morrison's pilot study (1968) of a CAI lab in German suggests that CAI students are comparable in language achievement, acquiring the skills of speaking and listening about as well and the skills of reading and writing as well or better.

Most of the studies which compare CAI with the more conventional classroom instruction indicate that CAI produces as good or better achievement. Kieren (1969) states:

> Thus the hypotheses of no mean difference was rejected in favor of a hypothesis that favored the computer class . . . The statistics show that the computer is an effective learning aid and that the effect of the computer used in this way seems to be stronger for the previously average achiever than for the previously high achiever (p. 309).

Other studies finding CAI superior to conventional instruction are those of Suppes (1969) in arithmetic, Morrison and Adams (1967) in German, Ford and Slough (1970) in electronics, and Sutter (1967) in problem solving. Two studies reporting no significant difference between the two methods are those of Fiedler (1969) in mathematical concepts and of Frasier (1968) in sociological constructs.

Programming Variables

Feedback Methods. Gilman (1969) compares five different modes of feedback, namely,

A. no feedback

B. feedback of "correct" or "wrong,"

C. feedback of correct response choice,

D. feedback appropriate to the student's response, and

E. a combination of the feedback modes B, C, and D.

According to his results, the combination of feedback methods is superior in terms of the number of correct responses. Gilman states, in part,

> Also, this study indicates that the appearance of a correct answer is not wasted when the student's response is incorrect. Data from the present study, however, indicate that providing a student with a statement of which response is correct, may be of much more value than merely telling him "correct" or "wrong." The poor results demonstrated by the knowledge-of-results feedback group (Group B) raise questions as to whether this mode of feedback is of much value for the correction of errors.

This agrees with the findings of Bryan and Rigney (1965) who compared response contingent feedback with knowledge-of-results feedback and found the former superior. Swets (1962), on the other hand, interpreted his study to show that "fairly extensive feedback may be detrimental to learning (Gilman, 1969, p. 504)."

Repetition. Knutson (1967) compared three experimental treatments which differed only in the number and the spacing of repetition trials on incorrect responses. These were termed no repetition, immediate repetition, and spaced repetition. Significant differences were found and Knutson concluded that "immediate repetition of error items produced greater learning (p. 61)."

Number of Examples. Lorraine (1969) studied the effect of varying the number of examples per concept each student received. The treatments included one group who received a fixed number of examples/concept, a second group who received a varied number of examples/concept, and a third group who were allowed to choose the number of examples/concept. Lorraine found that females in the varied examples group were found to be superior whereas males in the choice group performed significantly better than males in the other treatment groups.

Instructional Methods. Ford, Gallienne, and Linthicum (1968) investigated the effect of varying the CAI method by using dialog, tutorial, and dialog/tutorial as instructional methods. Their results indicated that "within CAI . . . the method of instruction did not significantly affect either the M. G. S. (mean gain score) or the time to complete the training (p. 313)."

Personality-related Factors

Ability. Kieren's conclusions have already been referred to (*supra*, p. 42). Similar results were obtained by Morrison and Adams (1967) who found that poorer students obtained larger gains through CAI. This is contrary to the findings of Dick and Latta (1970) who speak of the "startlingly poor performance on the part of low ability students utilizing CAI." and conclude that

> there is a clear indication that the low ability students not only take longer to learn, but they also make significantly

> more errors and have significantly poorer test performance . . . The conjecture may be made that the low ability students are unable to cope with the continuous flow of information as presented by the CRT without the ability to return to information previously provided to them (p. 43-44).

The last observation may explain the discrepancies in the findings recorded above: the material covered and the program devised may militate against the low ability student in some instances.

Attitude. All studies which report on attitudes shown by subjects agree that CAI has a favorable effect on attitude. Morrison's study (1967) indicated a somewhat better attitude toward the CAI lab than the conventional language lab. Students involved in the Farr and Hagan study (1967) felt that they could learn spelling effectively through CAI. Hall's work (1969) with elementary school teachers showed that there was no reason to fear that teachers' interaction with computers might awaken negative feelings toward subject matter. The Washington Schools Project conducted by Stanford University showed that many pupils seemed to develop a more mature attitude toward learning and that all gave evidence of extremely high motivation. Similar enthusiasm is reported by Hughes (1970) who says,

> Motivation continued high long after novelty must have ceased to operate as a factor. Our students in the second year of the program still use the noon hour, their activity period, and after school hours until 5:30 or later each night to test their algorithms, arguing the merits of their solutions with other students as they wait for their chance to use the teletype (p. 88).

The only study expressing any reservation is that of Mathis, Smith, and Hansen (1970) who warn that "the results of this study allow for the possibility of creating a negative attitude to CAI by poor programming (p. 51)." Their study indicates that, while the majority of college students experienced an increased positiveness in their attitude to CAI, the magnitude of this change did depend upon the kind of experiences they had had with it.

Social Conditions. Two studies involved a comparison of achievement of students working alone with students working in pairs. Sutter's problem solving experiment (1967) showed no significant difference between the paired and the alone groups. Love's study (1969) involving Boolean algebra revealed no significant difference in achievement, in error rates, in number of practice problems solved or in daily quiz scores.

Drill Effectiveness

In a project "intended only to give a sense of the methods and procedures that may be used for extensive pedagogical and psychological investigation of arithmetic skills (1966, p. 309)," Suppes found a serious confounding between time and lesson type when using CAI strictly for drill. The results pointed to a relationship between lesson difficulty and predominant problem type. Further experimentation on controlling lesson type and on providing for branching to either more or less difficult material based on performance seems to be suggested. Hansen (1966) reports significantly improved spelling through CAI drill. A similar experiment in spelling, reported by Fishman (1968), indicates that distributed practice is superior to massed practice.

Other Factors

Patterson's work with culturally deprived and underachieving students (1969) shows that CAI can be successful as a device for getting attention, eliciting responses, and establishing concepts through drills. Two preliminary studies by Wodtke point to CAI facility in holding high levels of attention for long periods of time. Whether this is due to the novelty of the method or to CAI itself could not be determined from the experiment.

Two studies on student sequencing of materials in computer assisted instruction brought conflicting results. Grubb (1969) found that students who were given this freedom scored significantly higher, whereas Proctor did not find any significant difference.

8. SUMMARY OF RESEARCH

The studies which have been cited indicate that CAI can be just as effective as classroom instruction and may be able to effect a significant saving in time. They suggest that great care must be taken in writing programs in order to obtain the desired results.

What has been done indicates what remains to be done. Carefully planned and well-controlled studies on a variety of pupil factors and program characteristics are urgently required. In view of the computer's ability to make logical decisions regarding sequence, depth, rate, and mode of instruction, as well as to "record and manipulate a wide variety of learning data about the student during instruction [and to] integrate and control a wide variety of audiovisual aids in the learning program for enrichment and motivation (Bundy, 1968, p. 425)," research must disclose how to use this device to best advantage.

CHAPTER III

UNDERLYING THEORETICAL FRAMEWORK

The review of literature in the preceding chapter was concerned with theory and research specifically related to programmed and computer assisted instruction. Learning theory was introduced only where relevant to or necessary for adequate discussion of these instructional modes. It is the purpose of this chapter to develop the learning theory which is to serve as the theoretical rationale of this study. It is not intended that a complete presentation of learning theory be made, rather that those facets of such a theory which bear significantly on the problem under investigation be given complete discussion. There is also no intention of presenting and analyzing or evaluating various learning theories; instead, the writer will present what, in his opinion, is an adequate and acceptable approach to learning. In order to do so, four aspects of learning will be discussed briefly and will be related to the experiment at hand. These four aspects are:

1. variations in learning backgrounds and rates,
2. gestalt of important mathematical concepts,
3. cognitions and cognitive styles, and
4. cybernetics.

1. VARIATIONS IN LEARNING RATES AND BACKGROUND

Learning Rates

Experience, theory, and research agree that individuals differ in the rate at which they can and will proceed through subject matter.

Whether this is due to a natural propensity for learning, to the teaching style used, to the nature of the subject, or to some other factor or combination of factors, the fact remains that learning rates do differ.

This difference in rates is complicated by a number of factors. Two of these are especially important to this study. The lock-step method of promoting students from one grade to the next can have devastating effects for the slow student who is thrown into more difficult material before he has satisfactorily mastered its prerequisites as well as for the fast student who has either been marking time or been progressing well beyond that level into which he is now being promoted. In the words of Taba (1962),

> It is easy to submit to the tyranny of fixed age-level norms and forget that there are large individual variations in the time at which certain tasks become feasible as well as in the speed with which individuals can master these tasks. . . . It is much more difficult to assess what an individual can do in the light of his previous experience and to fit the information about achievement into a historical or psychological perspective which takes into account his developmental sequence (p. 94).

The skill and ability of a teacher is taxed to the utmost in attempting to cope with such wide divergence of ability and achievement in a conventional classroom situation. Under CAI, on the other hand, it becomes relatively simple to locate the deficiencies in the learning of the slow student and to detect the advanced stage in the educational progress of the fast student. After having done so, the branching facility of the computer readily accommodates itself to the needs of both groups and simultaneously permits students of all groups to continue at a pace suited to their ability.

Not only do rates of learning vary from individual to individual, it also happens frequently that an individual student's rate may change. Taba (1962) speaks of a development which is "cyclic in nature [and which] manifests itself in periodic accelerations, plateaus, and retardations (p. 89)." Starch (1941) refers to another type of irregularity in learning progress when he says, "We should better understand the transference of these temporary gains in learning together with the recurrent forgettings and losses, into the larger and more seasoned processes of growth (p. 178)." Whatever the causal factors for these irregularities in learning, the instructional mode must adapt itself to compensate for these changes. Classroom instruction is again at a disadvantage as compared to CAI.

Background Knowledge

Great variations in learning styles, educational content, and actual achievement are represented in the students of an average classroom in an urban high school or university. All three factors have a significant bearing on the future progress of the students collectively and individually. How satisfactory the progress of the group will be is directly proportional to the degree to which the instructional method can adapt itself to the individual differences present in the group. Since what has been said previously applies here also, no further comment need be made.

2. GESTALT OF IMPORTANT MATHEMATICAL CONCEPTS

Theory

For mathematics, as well as for some other subject areas, the "gestalt" of a particular concept or topic is often of paramount importance if the student is to see all the implications and applications thereof and if he is to solve successfully and efficiently certain related problems. Special stress must be laid on this aspect of learning where mathematics is involved since the complexities of human symbolic learning and insightful problem solving require more than rote memorization, more than acquired but often meaningless skills, and more than blindly repetitive habits. In order to elicit an appropriate new response, thought processes, using insight as a method, arrange the situation so that the desired response forms part of a previously accepted "gestalt." According to Taba (1962),

> this understanding of relationships steers man's actions . . . Man learns only through his own responses: in part by reacting to selectively organized stimuli (Gestalten), and in part by creating new organized wholes (pp. 80-81).

Whereas it is frequently necessary to break up a concept, a principle, or a unit into its parts and often advisable to present these parts piecemeal before portraying the whole, understanding is not complete until these parts become fused into a meaningful whole. This points to the fact that the question, "What has the individual learned to do?" is quite frequently not nearly as important as the question, "How has he learned to perceive the situation?" Far too easy and far too prevalent is the practice of placing too much emphasis on rote memorization, development of skills and habits and solution of problems by formulas and patterns. Hill (1963) has expressed it very aptly thus:

> Even when a solution is correct, it is important to distinguish whether or not real understanding is involved. . . . A student may fumble around algebraically until he finds a valid proof that a certain equation is correct, but he may still not understand the equation in the sense that Wertheimer means. Understanding implies not merely logical correctness but a perception

> of the problem as an integrated whole, of the ways in which the means lead to the end. In going through an algebraic proof, for example, one should ask at each step not only "How does this lead toward the solution I am looking for?" but also "How does this logically follow from the previous step?" In Wertheimer's opinion, education should make such understanding, or perception of whole gestalten, its primary goal (pp. 101-103).

Implications for the Study

It is readily admitted that teaching for insight and for "gestalt" is most difficult. Even partial success requires the patient and painstaking planning of the presentation of subject matter and necessitates constant revision of lesson plans in the light of students' responses to questions and exercises. Whereas it is relatively easy to analyze the topic under consideration into its component parts and subsequently to present these parts to the students, it is much more difficult to lead students to assimilate these parts into a unified and meaningful whole--one which can serve adequately as a basis for further investigation, problem solving, and insightful learning.

It appears especially difficult to do so through programmed or computer assisted instruction since little, if any, interaction (at least at this stage in computer development) is feasible. Thus the onus rests on the programmer. The success of the program in teaching meaningful wholes is thus dependent on his ability to foresee what problems, difficulties, pitfalls, and shortcomings students may encounter in their pursuit of the "gestalt" of the topic and, by doing so, to devise a program which will avoid all difficulties and which will lead students in spite of individual variations to the desired understanding. Whereas the teacher in a classroom can make on-the-spot adaptations in the light of discerned deficiencies, the programmer must delay any changes in programming until the group leaves the terminal. These changes may come too late for the departing group of students.

3. COGNITIONS AND COGNITIVE STYLES

Theory

While this aspect of learning overlaps with the previously discussed aspect, there are major differences that need consideration and emphasis. Cognitions may lead to a perception of and appreciation for "gestalt;" it does not need to. Cognitions are operative at all levels of learning, in all phases of a topic, and in all activities related to it. Cognitions may accompany the acquisition of skills in drill, the learning of algorithms in exercises, and the development of approaches and methods in problem solving.

However, while cognitions may occur at various levels of learning, emphasis (especially in mathematics) should be placed on the cognitive processes involved in the highest levels. While it is important that students acquire specific content, such content is important primarily to the extent that it becomes part of a meaningful context, serves a definite purpose, or is incorporated into a given frame of reference. In each of the foregoing functions, higher cognitive meanings or processes are likely to be involved. In the words of Taba (1962),

> Learning specific facts is important to the extent that they feed the formation of ideas. The process of arriving at ideas and the ways of using them to create new knowledge are more important than the specific facts which "serve" these processes.

> Those who follow this concept stress integrated learning and relationships rather than the mastering of specific content (p. 82).

Implied in the above assertions are three important principles discussed briefly below. First, in order to ensure maximum transfer of cognitions to new situations, a thorough grasp of the essential principles of the situation is necessary if these are to be seen as applicable to a different situation. Thus, a student who understands the principle underlying the properties of logarithms will experience no difficulty applying them to the solution of various types of logarithmic equations. On the other hand, the student who practices these basic properties without understanding will be receiving limited educational value. Second, cognitive learning at all levels is possible for most, if not all, students. The need for cognitions at a high level is nowhere so apparent as in the abstract thinking involved in modern mathematics. The possibility of imparting such high level cognitions is attested by the success with which algebra and arithmetic have been taught inductively in elementary grades. This success seems to be due to careful attention to a cumulative progression in the material taught. Third, cognitive styles, "a term that refers to stable individual references in mode of perceptual organization and conceptual categorization of the external environment (Kagan, 1963, p. 74)," differ from person to person. In this respect, Kagan has said:

> Among children of adequate intelligence there are those who characteristically analyze and differentiate the stimulus field, applying labels to subelements of the whole. Others tend to categorize a relatively undifferentiated stimulus. Some children are splitters, others are lumpers. We have called the former response an analytic attitude and believe it is related, in some degree, to Witkin's notion of field independence versus field dependence (p. 74).

Importance for the Study

All of the foregoing remarks are extremely pertinent to the study at hand. Having asserted the importance of forming cognitions at the higher as well as the lower levels, the writer maintains that teaching mode must be selected in view of the possibility of success in achieving these important objectives. It thus becomes necessary to determine which mode, if any, is best suited to do so. At first sight, the teacher in a classroom situation may have the advantage in the sense that there is the continual possibility of a dynamic teacher-class interaction which can serve as a source of information leading to teaching program adjustments which are better designed to achieve the desired results. Part of this advantage may be offset in CAI through careful planning of the initial program and through successive testings of this program followed by revisions based on the observed results of such experimentation. Moreover, the problem of accommodating teaching method to individual differences (in this case, the set of available cognitions as well as the set of cognitive styles) is more readily tackled through CAI than through classroom instruction. There is the distinct possibility, therefore, that a comparison of the two on the basis of achievement in higher level thinking would favor the former.

4. CYBERNETICS

It was indicated earlier that cybernetics is regarded by many theorists as a fundamental aspect of learning. The concept, according to these theorists, is involved at all levels of learning: it contributes to the acquisition of the simplest learned skill, and it guides the development of the profoundest concept and the most intricate logical process or structure.

Meaning

The term, originally coined by Norbert Wiener from the Greek word for "steersman," was designed to refer to the study of control mechanicsms. Using the image of the steering of a ship as an analogy, Wiener argued that to enable an organism to change its strategic planning of further action intelligently, the organism needs to receive certain information regarding the effects of related actions in the past. This feedback of information would enable it to adjust its actions in a manner designed to keep it in a steady state by compensating for any deviation from the desired state.

Cybernetics is defined more generally today as "the science of message transmission, processing, and the regulation and control of complex systems such as automatic devices and organisms (Silberman, 1968, p. 272)." A further description and characterization of a feedback system is given by Wilson and Wilson:

> In any feedback system, (1) a wanted output performance reference is supplied; (2) some function of the controlled variable is examined to see how closely the output performance agrees with the reference; (3) the difference between the wanted and the actual performance generates an error signal; (4) power is applied under the control of the error signal to reduce the difference so that it approaches zero. . . . (Silberman, 1968, p. 270).

Thus the basic concept in cybernetics is the feeding back into a system (as an input) the effects of an output in order to regulate the action and the direction of the system.

Importance for Learning

Cybernetic theory adds a valuable dimension to a number of aspects of learning theory. Learning itself may be regarded as "the process of reorganizing feedback-regulated activity patterns in relation to new environmental patterns (Smith, 1966, p. 381)." As such, feedback, hence cybernetics also, plays a prominent role in learning.

Cybernetics has added an important dimension to the stimulus-response theory of learning. Whereas the simple S-R paradigm, as an attempt to explain learning, leaves many questions especially where complex skills and theory are involved, cybernetics affords an interpretation of complex behavior far more complete and satisfactory. Predicated on the feedback loop as the fundamental building block of the nervous system, cybernetics offers a more satisfying explanation of learning as it ranges from a skilled act to complex and purposive behavior. A skilled act is learned and performed through the continual feedback of sensations from muscles, eyes, and other senses. In a similar fashion, complex purposive activity, whether physical or mental, is learned through a lengthy process of adjustment and refinement of actions on the basis of information of results fed back from various sources within the organism. In this respect, Wiener explains human behavior as follows:

> It is my thesis that the physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feedback. Both of them have sensory receptors as one stage of their cycle of operation: that is, in both of them there exists a special apparatus for collecting information from the outer world at low energy levels and for making it available in the operation of the individual or of the machine. In both cases these external messages are not

> taken in *neat*, but through the internal transforming powers of the apparatus, whether it be alive or dead. The information is then turned into a new form available for new stages of performance. In both the animal and the machine this performance is made to be effective on the outer world. In both of them, their *performed* action on the outer world and not merely their *intended* action, is reported back to the central regulatory apparatus (Wiener, 1954, pp. 26-27).

Thus the importance of feedback lies in the fact that an individual's adjustment of his environment depends upon the information provided by his senses. In order to make "correct" decisions we need certain information, the amount actually required depending on the complexity of the choice to be made.

The question as to what may constitute feedback is answered by Rosenblith thus:

> *Feedback* can refer to the success or failure of a simple act or it may occur at a higher level when information of a whole policy of conduct or pattern of behavior is fed back, enabling the organism to change its strategic planning of further action. It is fairly easy to see how this concept of feedback can be further extended to the realm of social groups such as families, firms, and indeed whole societies (Wiener, 1954, p. 276).

Viewing learning, then, in the light of cybernetics as a process of change on the basis of positive and negative feedback has several distinct advantages. Chief of these is the fact that this approach emphasizes the continuous control of sequences of human behavior. As such, it can and should make important contributions to education.

Implications for the Study

If we accept the basic premises of the cybernetic model of learning, then we must concede the great potential of the computer in research and in computer assisted instruction. With respect to the former, Johnson (1964) says:

> A computer model should include a number of parameters whose values can be changed to approximate a variety of situations. For instance, the proportion of times that a correct response is rewarded, the strength of reward, the number of trials over which learning may take place, and the difficulty of the task could be built into a model as variable parameters. The suggestions obviously do not begin to exhaust the factors lurking in the background of the majority of learning situations (p. 66).

The foregoing also provides a glimpse into the feedback potential and variety which is available to the CAI programmer. Using a hackneyed phrase, "the sky is the limit." Furthermore, this potential and variety can serve two distinct and extremely important purposes. Feedback, as the student progresses through the material, is very valuable as a motivational device and as a basis of adjustment, where necessary, of skills, procedures, and concepts. Feedback is also the basis upon which the computer "makes decisions"--decisions which will affect the depth, the direction, the rate, and the repetition of instruction to be given to each individual student.

Cybernetics has implications for a number of aspects of the learning situation, notably the following: individualization through CAI, the recognition of and accommodation to individual differences, the active participation of students in a learning situation, and the attitude toward subject matter and instructional mode. Cybernetics has special implications for the tutorial mode, as opposed to strictly drill teaching, since success in the former case is especially dependent on extensive and immediate feedback. And the computer can provide both extensive feedback as well as immediate feedback. The importance of the latter is indicated by Smith (1966) when he says,

> Feedback delayed by small fractions of a second is seriously detrimental to performance. . . . No effective learning occurs under conditions of delayed feedback (p. 381).

In concluding this section, it should be noted that the TOTE model (Test-Operate-Test-Exit) which is basic to cybernetics was used as a basis for all branching in the CAI programs. A simple diagrammatic representation of a TOTE loop is seen in Figure 2.

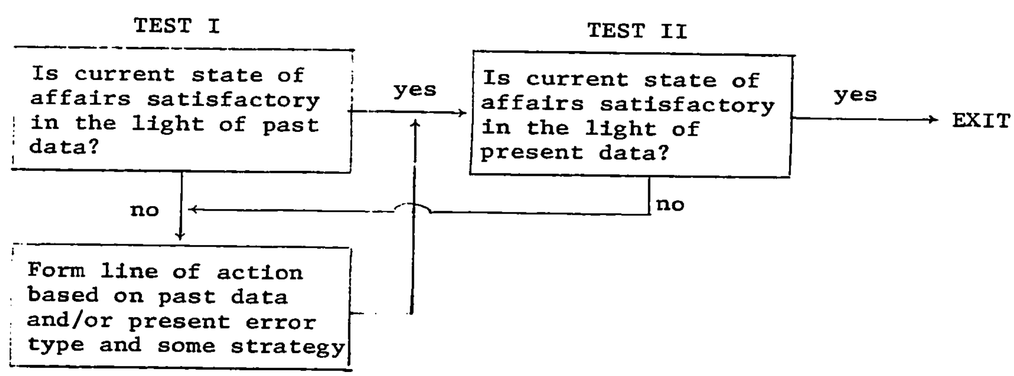


Figure 2

Schematic Representation of a TOTE Unit

Summary

To conclude this section, it might be well to summarize and to synthesize what has been said. Inevitable individual differences in group instruction are important considerations in any learning situation. Such differences are readily amenable to treatment in CAI mode. Feedback is an important adjunct in any attempt to meet the needs of the individual. Gestalt is an important objective for best results in learning. Here again the computer, because of its cybernetic capability, may be useful in achieving this level of instruction. Cognitions and cognitive styles are basic to satisfactory progress in learning. They merit serious consideration in the selection of mode and in the process of teaching itself. Feedback is essential in order to assess the degree of success in imparting cognitions and to adjust further teaching accordingly. Feedback is also vital in any attempt to detect cognitive style and, having done so, to provide the necessary path for each style.

5. PRACTICAL IMPLICATIONS

Programming

Mager (1961) has designed a rather comprehensive outline of the procedure which should be followed in preparing an auto-instructional program. While his method is highly commendable in most respects, practical considerations dictated a number of significant adjustments in the method suggested. What follows is a resumè of methods used, principles applied, and decisions made in the process of drafting and finalizing two acceptable programs.

Objectives. A specific list of the objectives of the course stated in behavioral terms were drawn up. Three major benefits accrued from doing so at the outset. The list, it was felt, contributed significantly toward the validity of the achievement tests devised by the investigator. More important, however, in terms of programming was the fact that these objectives served as a logical starting point for determining the content to be used in the programs as well as the sequence to be followed in program construction. Most important of all, they were used as guide and control in making decisions regarding the inclusion of problems and quizzes.

The set of objectives is included in Appendix A.

<u>Content</u>. As indicated above, the objectives were used as a guide in determining the actual content of the program. Content and objectives together constituted the basis for decisions regarding a sequence of topics which would comply with Gagne's "hierarchical structure of certain special information domains (Heinrich, 1969, p. 336)." The first draft of the content outline formed in this way was made as specific as possible in order to establish the sequence and, to some extent, the nature of the program which was to be used in developing each concept or procedure. Part of the teaching strategy was thus incorporated into the outline of contents. This had the effect of helping to avert two of the programming pitfalls mentioned by Briggs (1968):

> Reasons for failure to learn to perform a task after taking a learning program could be as follows: (a) some subordinate knowledge may have been left out of the learning program: . . . (c) the program may have been defective in guiding thinking required to induce the necessary integration of subordinate competencies (p. 162)

Minor revisions in the outline of contents were made in the course of programming. Some of these affected the sequencing of some of the topics. The final version is included in Appendix A.

<u>Program Development</u>. In order to facilitate the production of two programs which would be truly comparable in sequence, content, and emphasis, the investigator began by developing a program of basic information, theory, problems, and so forth. While it was intended initially that this program serve as a basis for the construction of the two programs required by the study, it soon became apparent that the unfolding program was, in fact, turning out to be the envisioned

delayed review program. Basically a linear program, it was formed by making provisions for feedback, error correction, hints, and opportunities to try again and by including supplementary material to augment, to reinforce, and to enrich the basic program for the exceptional students who would complete the rest of the course in less than the allotted time.

Using the delayed review program as a basis, the immediate review program was constructed quite readily. The contents of the former remained intact. All changes took the form of insertions. Response analysis was made somewhat more sophisticated in order to accomplish necessary, meaningful, and acceptable branching from one point of the program to another. On the basis of a number of criteria which will be discussed later, extensive branching--including backward, lateral, and forward branching--was incorporated into the previously constructed and presently duplicated program. This new program, for instance, permitted the student to skip certain rather elementary parts of the linear program if he had been making satisfactory progress.

More information about this program will be provided later. Suffice it to say at this point that the investigator was satisfied that the sequence, the content and the emphasis of the two programs was comparable but that the teaching strategies of the programs were basically and materially different.

Program Revision. After the first draft of both programs had been completed to the satisfaction of both computer and investigator, a trial run of each program was conducted using adult volunteers.

The adults who were willing to work through a program were members of a Mathematics 20 evening class taught by the investigator. They were very interested and most cooperative in giving information, advice, and constructive criticism. The number of students was restricted to three per program in order to enable the investigator to follow the progress of each student, to detect any difficulties experienced by the group, and to find any errors in programming. On the basis of this try-out, a number of modifications in the programs, including additions and deletions, were made. The main changes concerned the timing on responses and the eliminating of closed loops.

Guiding Principles for Programming. It is impossible in the space of a short report to give a complete account of how the learning principles have been applied in two relatively lengthy and complete programs. This would involve extensive detail and tiresome illustrations. One must be satisfied with a fairly broad delineation of the attempts made to incorporate the concepts listed and described under the section on rationale.

A concerted attempt was made to individualize instruction. This attempt resulted in the insertion of quizzes, reviews, and graded assignments and necessitated the extensive provision for technical requirements such as time-outs and cumulative information about responses, errors and times.

Variations in individual learning rates present no great problem in CAI. Messages may be left on the screen or erased from it at the will of the student. The timing on problems can be adjusted readily to the progress and the needs of the student.

In this respect, both programs were more or less identical. Variations in individual background are more easily dealt with through a branching program. Thus the immediate review program was designed, on the one hand, to detect important weaknesses in knowledge or procedures and to provide the necessary review or instruction before allowing the student concerned to proceed and, on the other hand, to discern the superior progress of other students and to take action accordingly.

The desire to provide feedback--whether regarded as reinforcement or otherwise--required that fairly continuous information on progress be built into the program. Students were aware of the fact that the absence of feedback after a registered response implied the acceptability of that response. The type of reinforcing information supplied depended on the response given and was varied intentionally in nature, content, and frequency in line with the previously expounded learning theory. Learning as an active rather than as a passive process is inherently characteristic of CAI; however, a special effort to ensure active participation was made through the programming of short presentation of theory followed by learner activity in the application of that theory or in the discovery of new theory. Since the efficiency of learning depends on the establishment of well-defined, behaviorally-stated goals, the objectives for each section were specified clearly and forcefully before any theory was presented, and students were advised to copy these objectives and to keep them in mind as they progressed through the theory and its application.

An effort was made to ensure the adequacy of all cognitions shaped by the instructional material, the programmer hoping to produce thorough understanding as quickly and as efficiently as possible. Numerous exercises and quizzes were inserted to consolidate insight as well as to detect any misconceptions which might have arisen. For those which could be anticipated, the program presented directed hints, completed solutions, or more detailed instruction in an effort to reshape cognitions. The immediate review program, understandably, through its manifold branching facility, was particularly suited for a concerted effort at reconstructing the student's thinking.

The overall "gestalt" of the topic received attention in so far as efforts were made to relate subtopics, procedures, or problems back to the basic concept being studied. Graphs, properties, and procedures were used to elucidate the idea of logarithms. Furthermore, a concerted effort was made to investigate the interrelationships of all aspects which had been studied after the basic material of the course had been covered.

Programs

Tutorial Nature of the Study. It is abundantly clear, at this point, that the study was concerned mainly with the facility of the computer for providing instruction of material completely new to all students. In order to bias this new-material instruction as little as possible, the investigator sought a topic which required minimal algebraic background. It was believed that logarithms was such a topic. It was felt, moreover, that the difficulty and the sophistication of this topic would provide a thorough test of the computer's ability to teach.

Description of Programs. While various aspects of both programs have been referred to frequently, it may be advisable at this point to recapitulate what has been mentioned and to append what has not been said.

The delayed review program is an attempt to duplicate in CAI mode what normally occurs in a classroom. The program basically presents some unit of information as completely and as thoroughly as deemed necessary. The student is called upon to answer questions, to solve a set of problems, or to do a set of drill questions. The program checks all answers. If the answer is correct, some feedback message is usually forthcoming. If, however, the answer is incorrect, any one of the following procedures may be followed: (1) A message such as "Incorrect. Try again." is displayed in the lower part of the screen; (2) A hint is given with a request to try again; (3) The complete solution with or without additional comments is displayed. Following the student's completion of the activities requested, the procedure is repeated with another unit of information. After all the material of the course has been covered, an extensive review is undertaken, the purpose being to consolidate understanding, to develop interrelationships between topics, and to emphasize special implications or applications of some of the algorithms or concepts.

The immediate review program includes all of the delayed review program. Parallel exercises consisting of an easier or a more difficult set of questions, alternative explanatory information, and enrichment material are examples of sections which have been inserted. Their inclusion presented the possibility of providing further practice, more instruction, deeper penetration, and so forth. A further modification of the program enables the computer to keep detailed cumulative records of the types, the errors, and the timing of a given student's responses. On the basis of this available information, a few simple instructions sufficed to introduce a fairly sophisticated branching system into the second program. The types of branching as well as the criteria for doing so will be described shortly. Before doing so, it should be noted that, with the above-mentioned changes, a new program with a materially different instructional mode has emerged. The main advantage gained is the greatly increased attention to individual differences, needs, and interests.

Types of Branches. Three basic types were used. The backward branch, designed for those students whose error types and time-out frequencies indicate a lack of knowledge or comprehension, takes these students backward in the program either to a simpler set of questions or to a review of basic material through more explanation and/or further practice. The lateral branch may introduce a more difficult concept, application or question set if performance reveals the individual's readiness for such work, or it may shunt the student off to a set of less difficult exercises if progress is not satisfactory. In either case, the material branched to will not be part of the basic program. The forward branch makes it possible for the bright student whose performance has been excellent to skip the explanatory and illustrative material of the next section and to proceed with the applications or the problem set therein.

A flow chart in the following pages indicates some of the main branches used for each type.

Criteria for Branching. Some of the contingencies used for branching decisions have already been mentioned. In addition to these, the reader should be aware of the ones to follow. The type of error made is often significant. Those which the programmer could foresee and detect were used to effect a lateral or backward branch. The cumulative record stored in the system at times revealed patterns of responses (both in time and error type) which strongly suggested a different instructional sequence. Finally, at some points in the branching program, provision was made for a student-requested or a student-determined branch. Thus a student whose achievement was borderline was permitted to decide whether he should continue in the sequence or whether he ought to branch back to remedial work. Similarly, a student whose progress almost reached the standard set for excellence was permitted to decide whether he was to branch forward or to stay in sequence.

Classroom Instruction

Purpose. One of the questions plaguing the investigator was the effectiveness of CAI relative to classroom instruction. The difficulties in making such comparisons and the justification for doing so have been discussed earlier. It was hoped that some kind of meaningful comparison yielding important information could be made.

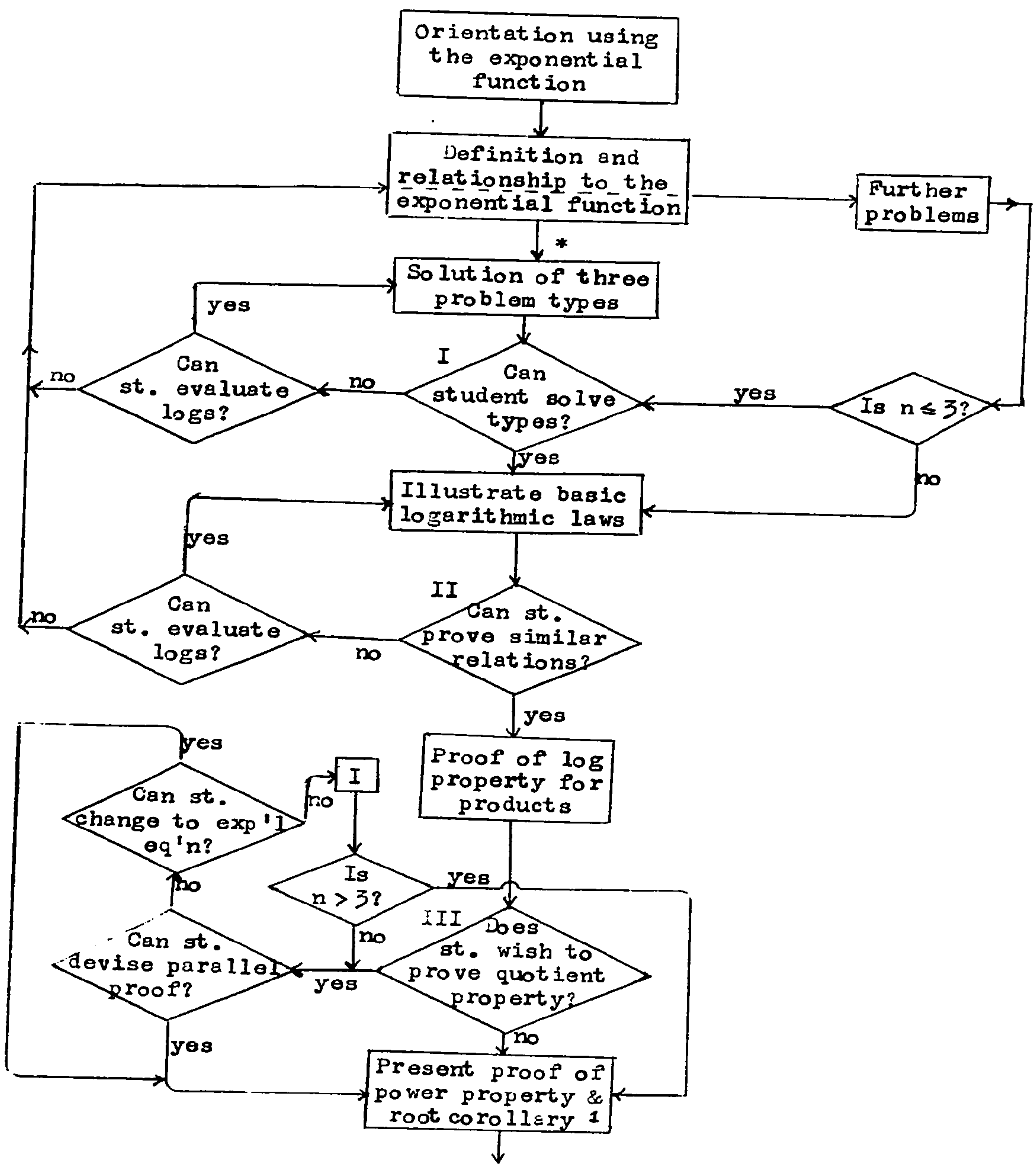
Description. A group of thirty-one students, from which fifteen were chosen as a sample, were instructed in their regular classroom. In order to control as many variables as possible, the class was taught by the investigator. In doing so, he attempted to keep the classroom instruction closely parallel to that of the two CAI programs by using the same sequence of topics, the same illustrations, and the same sets of exercises. The basic differences (other than in setting) lay in the manner of feedback and review. The former was minimal since feedback was restricted to comments related to a limited number of responses in class and to the return of marked assignments. Since the latter was greatly delayed feedback, its efficacy is very doubtful. The type of review might be called spaced review in the sense that each period began with review either in the form of a resumè of important processes and ideas or of class directed questions designed to provoke recall of that which had been learned.

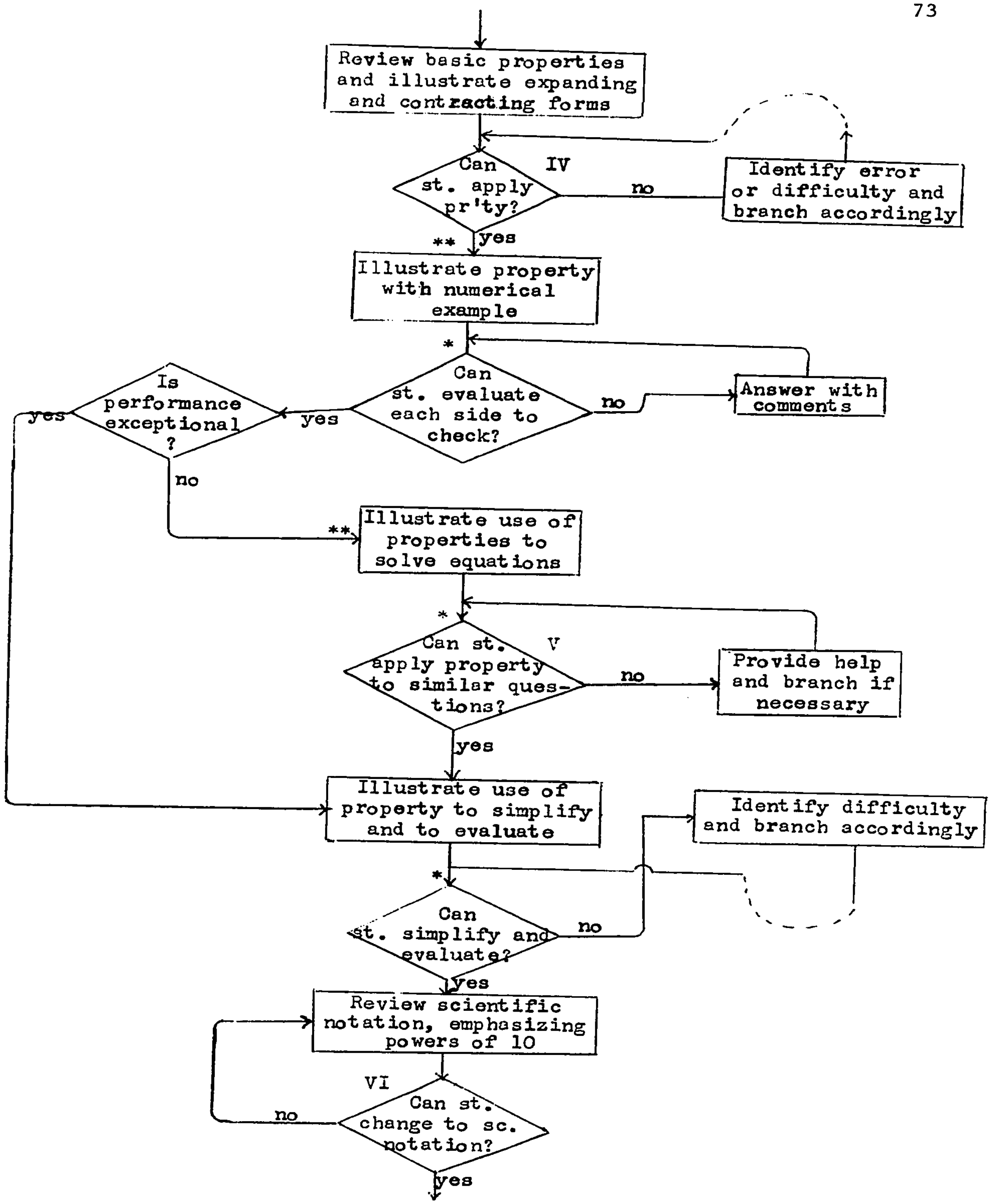
Flowcharts Illustrating Programming Sequence and Techniques

Explanatory Comments. Figure 3 indicates the basic portions of the branching program. Only the barest outline of content has been included. Such aspects as decisions relative to the number of errors permitted per branch or course to be followed when too many time-outs occur are not shown. For further detail, the reader is referred to the "Basic Program" outlined in Appendix B. A single asterisk appearing in the flowchart shows that lateral branching is possible at that point, while the appearance of two asterisks indicates the possibility of branching forward. Other instances of

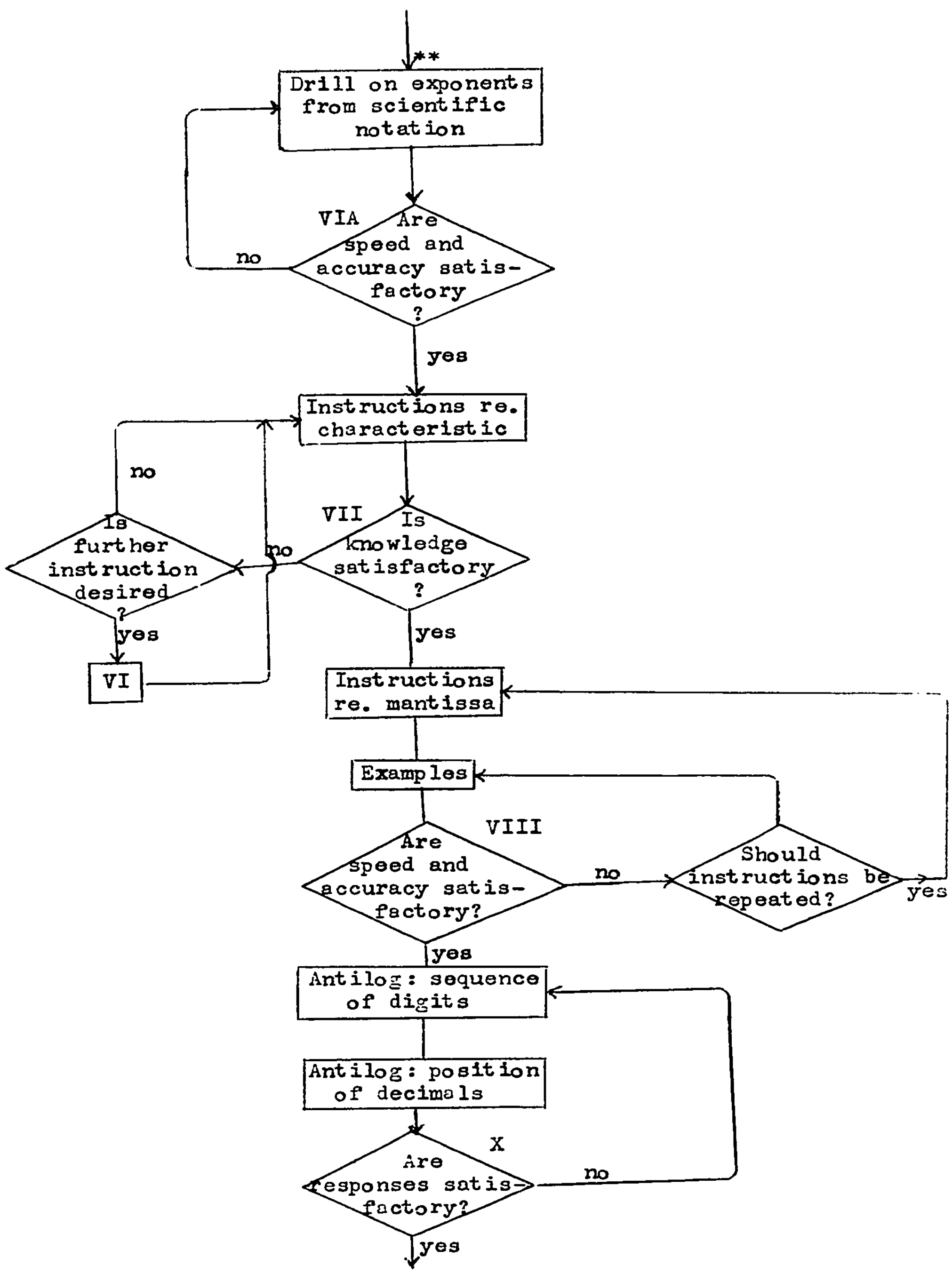
Figure 3

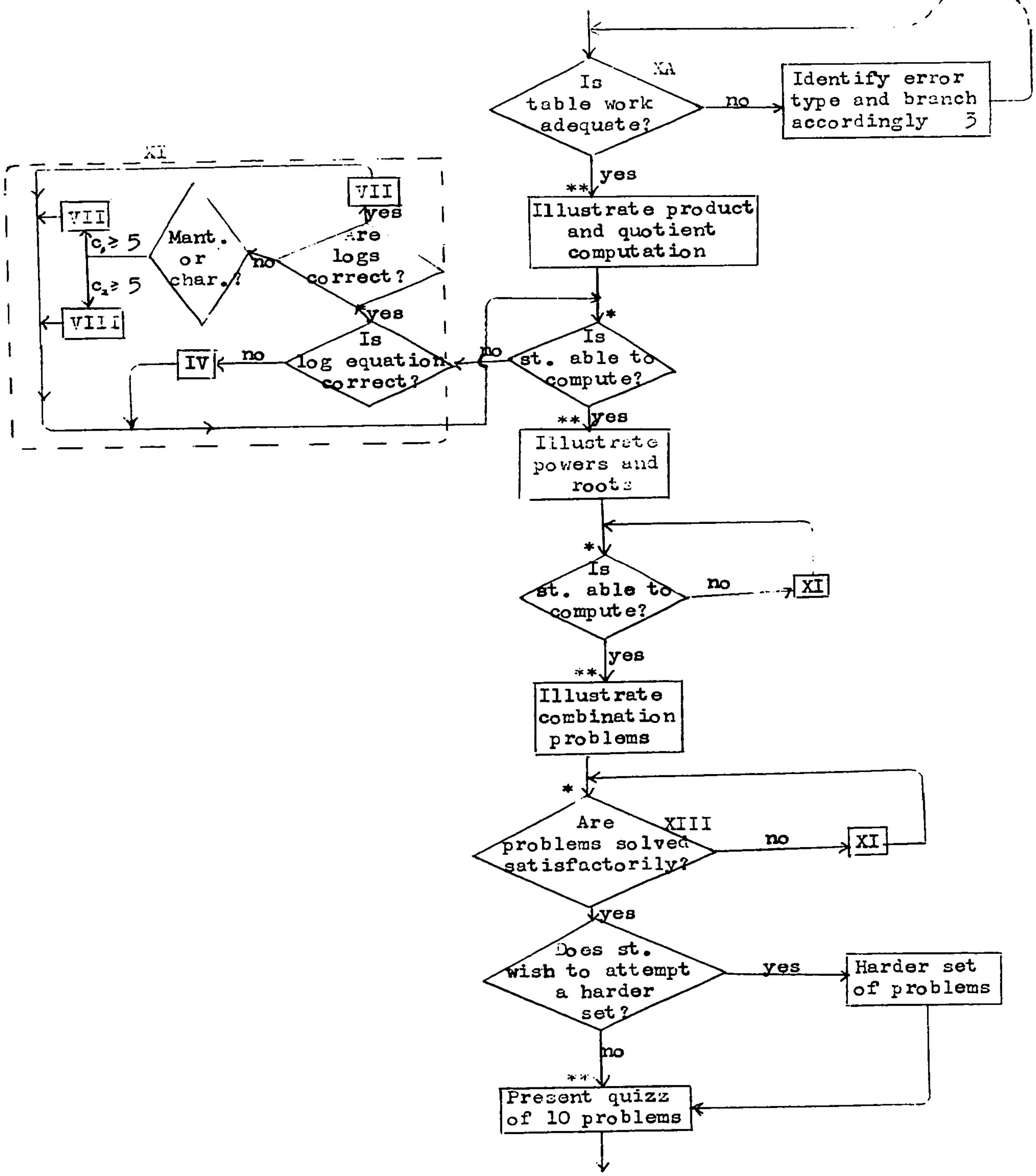
Flowchart of the Branching Program

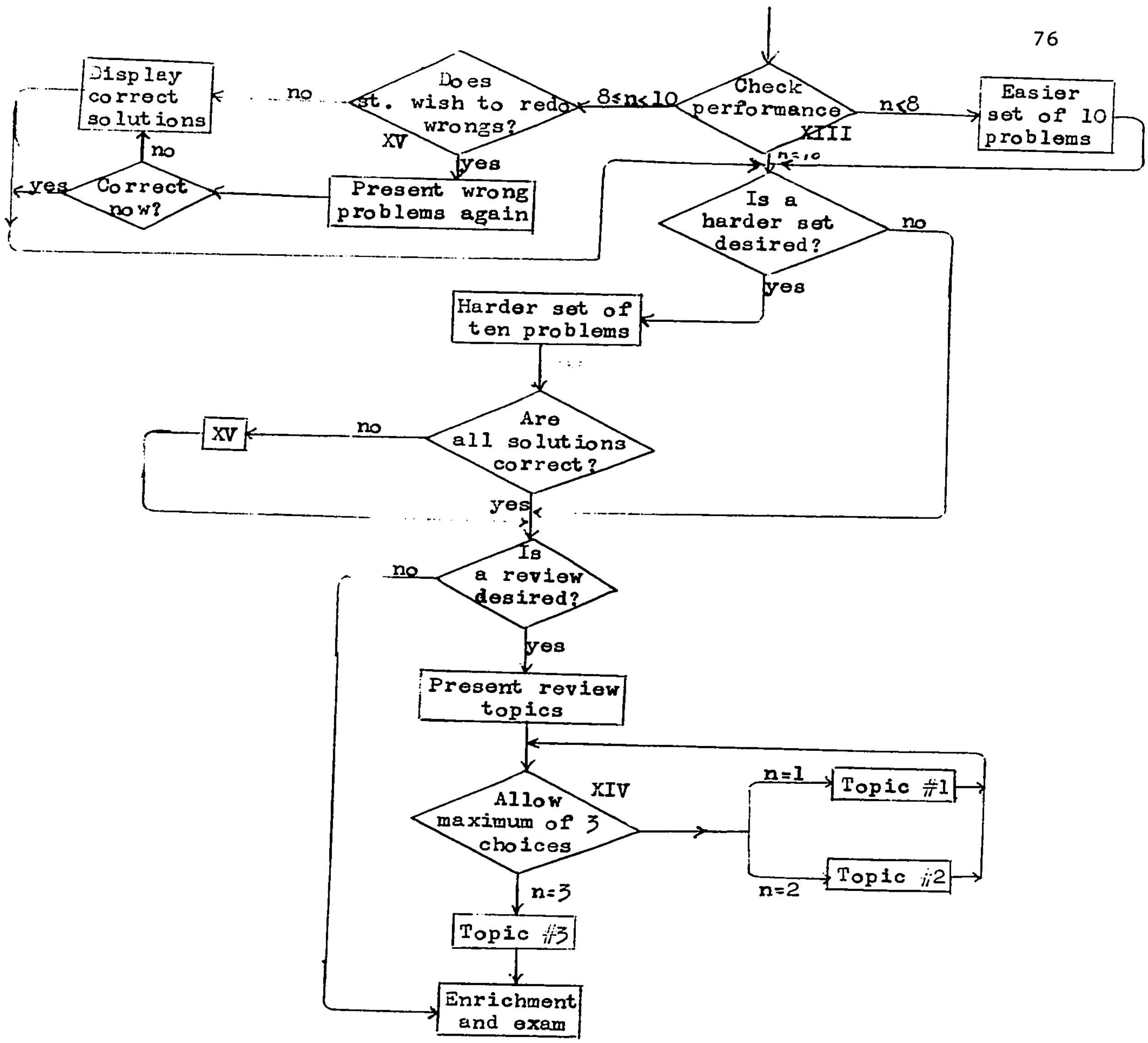




Review basic properties and illustrate expanding and contracting forms
Can st. apply pr'ty?
IV
no
Identify error or difficulty and branch accordingly
yes
**
Illustrate property with numerical example
*
Can st. evaluate each side to check?
no
Answer with comments
yes
Is performance exceptional ?
yes
no
**
Illustrate use of properties to solve equations
*
Can st. apply property to similar questions?
V
no
Provide help and branch if necessary
yes
Illustrate use of property to simplify and to evaluate
Identify difficulty and branch accordingly
*
Can st. simplify and evaluate?
no
yes
Review scientific notation, emphasizing powers of 10
VI
Can st. change to sc. notation?
no
yes


**
Drill on exponents from scientific notation
VIA
Are speed and accuracy satis-factory ?
no
yes
Instructions re. characteristic
no
VII
Is knowledge satisfactory ?
no
Is further instruction desired ?
yes
VI
yes
Instructions re. mantissa
Examples
VIII
Are speed and accuracy satis-factory?
no
Should instructions be repeated?
yes
yes
Antilog: sequence of digits
Antilog: position of decimals
X
Are responses satis-factory?
no
yes


XA
Is table work adequate?
no
Identify error type and branch accordingly 3
yes
Illustrate product and quotient computation
XI
VII
yes
Are logs correct?
no
Mant. or char.?
$c_1 \geq 5$
$c_2 \geq 5$
VII
VIII
yes
Is log equation correct?
no
IV
Is st. able to compute?
no
yes
Illustrate powers and roots
Is st. able to compute?
no
XI
yes
Illustrate combination problems
Are problems solved satisfactorily?
XIII
no
XI
yes
Does st. wish to attempt a harder set?
yes
Harder set of problems
no
Present quizz of 10 problems



Footnotes. 1. Students were asked to fill in the steps. If their responses were not given in the time allowed, the corret answers were displayed.

2. Students showing exceptional progress were given an opportunity to supply alternate forms.

3. This step involved student identification through light pen response or computer identification through questioning. Branching took place according to detected weaknesses.

branching, such as those within problem sets, have not been shown. Arabic numerals in the chart refer to footnotes while Roman numerals designate loops used in the program at the points indicated on the chart. A completely documented flowchart has been prepared by the computer using the Flatham program. Since this chart covered several hundred pages of output, it was too extensive to include as part of the report. The chart is available through the Division of Educational Research Services.

Figure 4 depicts a flowchart illustrating the type of computer decisions affecting learning sequence which have been incorporated into the branching program. Again, provisions for exits from loops are not shown in the diagram.

Figure 5 is a flowchart which illustrates the type of logic which was used in response analysis. Here, too, many variations and sophistications are possible. As many as were feasible have been devised and inserted into the branching program.

6. SUMMARY

This chapter has explained the four aspects of learning which are relevant to the study. These four aspects are:

1. variations in learning background and rates,
2. gestalt of important mathematical concepts,
3. cognitions and cognitive styles, and
4. cybernetics.

This chapter also discussed in some detail how these aspects relate to CAI and how CAI can be used effectively to obtain the maximum

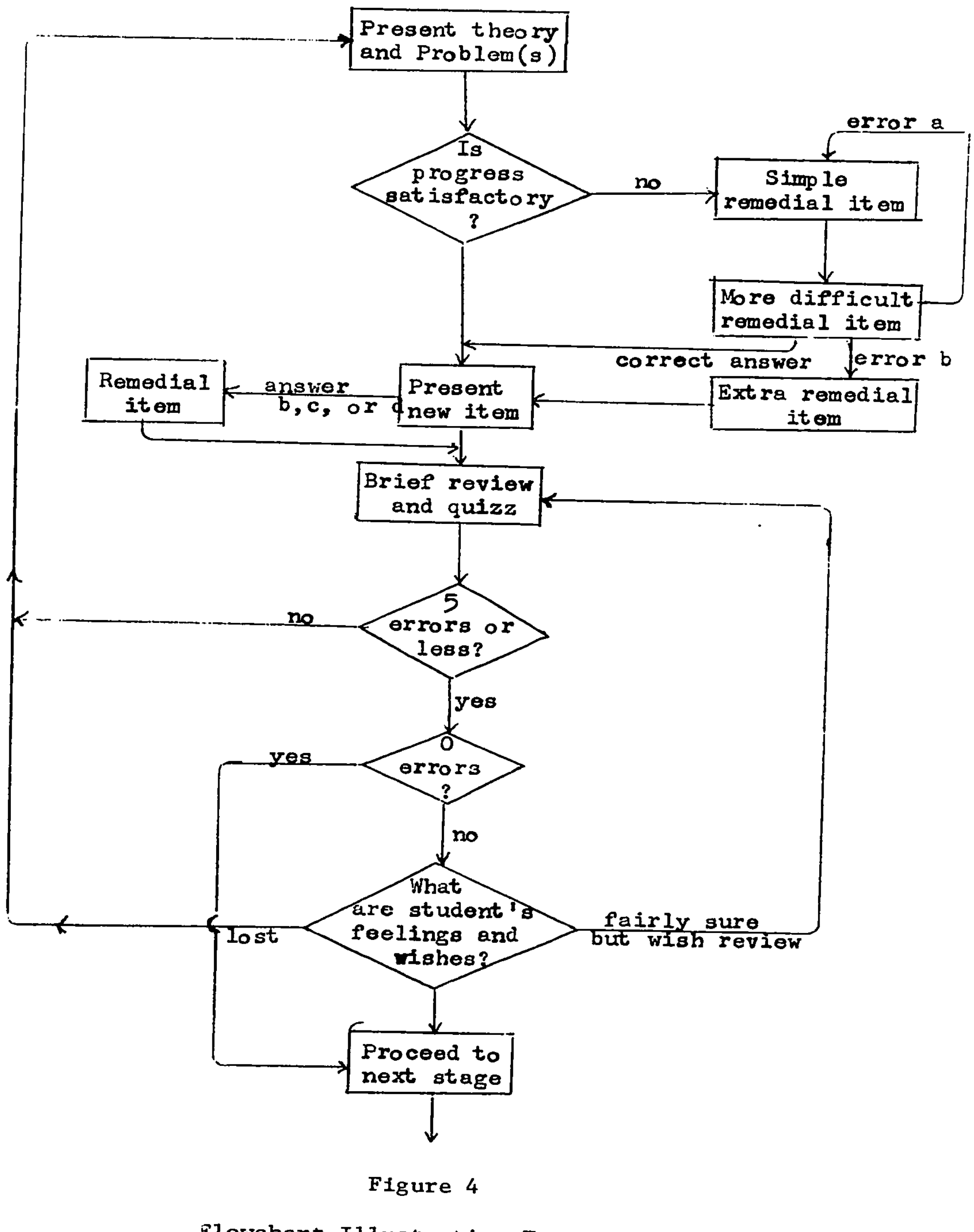


Figure 4

Flowchart Illustrating Types of Computer Decisions

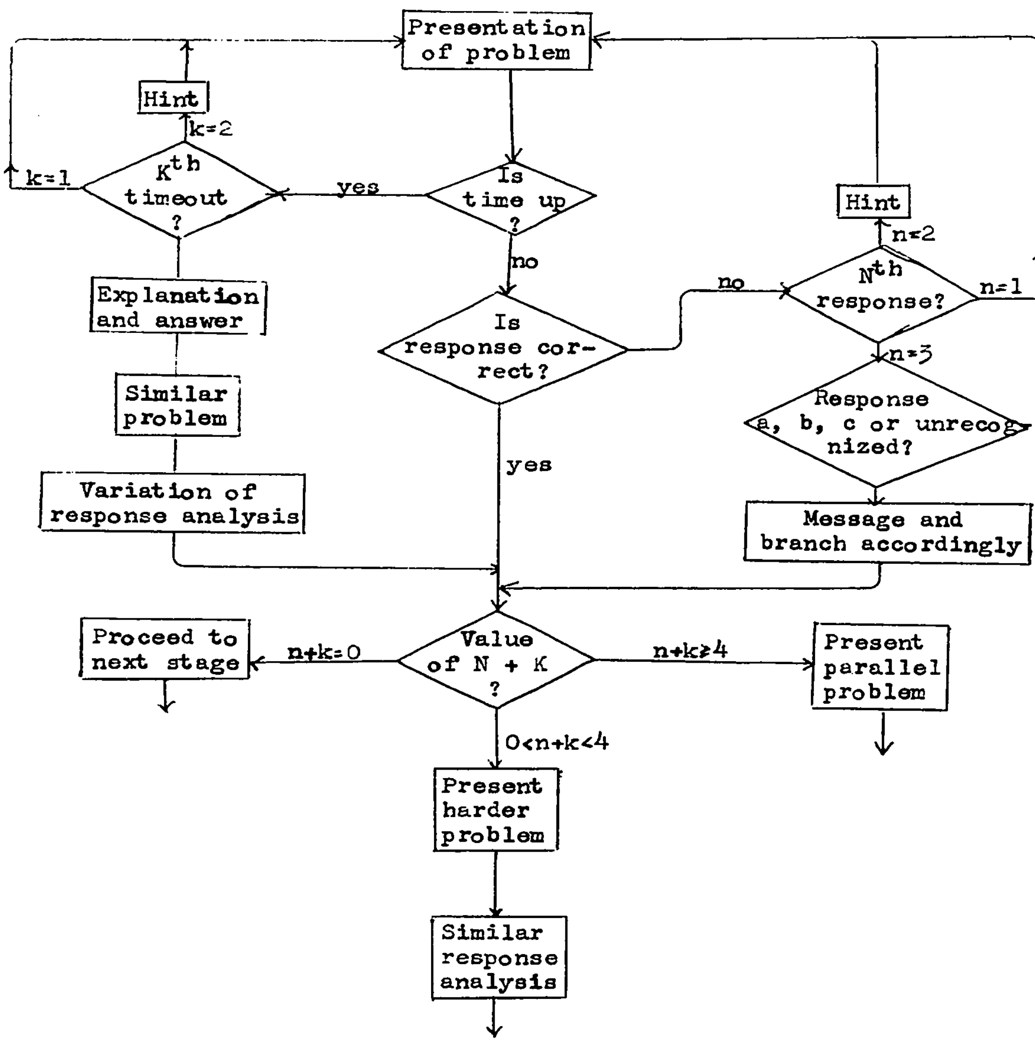


Figure 5

Flowchart Illustrating Types of Logic used in Response Analysis learning results through the proper application of each of these factors. It concluded with an account of the attempts which have been made to incorporate these ideas into the two CAI programs.

CHAPTER IV

EXPERIMENTAL DESIGN AND RESEARCH PROCEDURES

The study investigated the possibility of using CAI effectively in the field of mathematics instruction, concentrating on a comparison of two different types of CAI programs. Two groups of fifteen students were given instruction in mathematics through these programs while one group, also of fifteen students, was instructed in a more conventional classroom setting. The effectiveness of the instructional modes was tested by administering an achievement test at the conclusion of the learning sessions.

This chapter reports on a number of topics relative to experimental design and research procedures. It begins with a brief treatment of the pilot study as it relates to the present project. Thereupon follows a discussion of important research aspects of the testing program and an outline of the actual procedures used in forming the treatment groups and in collecting the data. The chapter concludes with a statement of the hypotheses to be tested by the experiment and of the statistics used to check them.

I. PILOT STUDY

A few remarks relative to a pilot study conducted in the spring of 1969 are pertinent at this stage. A brief description of that study will lead to a discussion of how it affected the present study.

Fifteen vocational education students enrolled in Mathematics 12 were given five hours of instruction on binomial products through a program written in APL by the investigator. While some emphasis was placed on underlying theory, the main thrust of the lessons was on the acquisition of skill and speed of expansion. Thus drill through numerous sets of practice exercises constituted the bulk of student participation at the terminals. Since students had had some previous contact with binomial products, the effect of the program was measured through gain scores based on comparable pretest and posttest scores. To obtain some indication as to the effectiveness of this instruction, the gain scores of this computer-taught group were compared with the gain scores of a group of students taught in a more conventional classroom situation. This comparison indicated that the gain scores of the CAI group were slightly, though not significantly, higher than those of the control group.

As indicated above, this initial experimentation with CAI made important contributions to the present investigation. It indicated that lack of motivation, fear of the machine, and technical introduction to computer learning would not present any insurmountable difficulties. Students showed interest in the hardware in front of them, adjusted readily to the use of the keyboard, and gave evidence of sustained motivation. The wide range in ability suggested that a fruitful investigation could take the form of a test of the efficiency of CAI for students at different ability levels. The satisfactory achievement produced by CAI as applied to drill-and-practice raised the question as to whether equally satisfactory achievement could be produced in a predominantly tutorial mode.

Difficulties experienced by students at certain points in the program suggested that it might be to their advantage if the branching facility of the computer were utilized and raised the question as to the relative effectiveness of branching versus linear programming. This possibility, together with other factors, led to a consideration of Coursewriter instead of APL 1500 as the computer language to be used for the major study. The pilot study seemed to indicate that the former would be the more suitable language in view of the characteristics of the CAI system and the purposes of the study.

The pilot study also instigated the devising of a questionnaire on student attitude toward CAI and provided an opportunity to test its suitability as an instrument for future research.

2. TESTING PROGRAM

Three types of testing instruments, based on purpose, were used in arriving at the measures required by the study. These three can be characterized as intelligence scales, achievement tests, and attitude measures. The subsequent sections will describe briefly each of the test used and, where necessary, report on details of construction and of validity and reliability.

Intelligence Scale

The investigator used the IQ scores available from school guidance records. These scores were based on the Lorge-Thorndike Tests administered to students upon entering high school.

The tests were considered particularly suited to the experiment at hand since they included both verbal and nonverbal batteries and since tests were available at all grade school achievement levels.

Achievement Test

Construction. As indicated earlier, the test of student achievement produced by the two-week instructional program was constructed by the investigator. In the process of forming the first draft, several factors were kept in mind: the behavioral objectives referred to earlier; the comprehensiveness of the problem set; the equal coverage of factual, algorithmic, and problem solving items; the estimated time required to write the test; as well as aspects of item construction such as clarity, specificity, and correctness.

It should be mentioned that a special effort was made to ensure that each of the three categories of items mentioned above was adequately represented and that each item was in fact the type which it was claimed to be. Advice was sought on a number of questions, and on the basis of such advice, the question concerned was either changed and included or rejected altogether. The final set of questions was examined thoroughly by a team of professors and graduate students as to purpose, phrasing, and categorization.

The final draft of the test consisted of twenty multiple choice questions and twenty open-ended questions. It was designed in such a way as to enable most students to complete it in the eighty-minute period being used in the experimental school.

Reliability. One of the purposes served by a pilot run of the achievement test just described was a check on its reliability. The application of the Kuder-Richardson Formula 20 to the results obtained thereby produced a reliability coefficient of .87. This coefficient was deemed sufficiently high to warrant considerable confidence in the test's internal consistency. Further, in the words of Guilford (1965),

> It is probably not true, however, that there can be high internal consistency and at the same time low retest reliability, except after very long time intervals. High internal-consistency reliability is in itself assurance that we are dealing with a homogeneous test, at least within the broad meaning of the term stated above (p. 450).

Validity. The investigator was particularly interested in Cronbach's content validity, where "Adequacy of content is attained by defining the universe appropriately and representing the universe fairly in the test (Cronbach, 1970, p. 145)." Thus the test was constructed only after the objectives of the course had been stated explicitly and in behavioral terms and was designed so as to cover these stated objectives equitably. Here, too, the assistance of a team of professors and graduate students was enlisted to determine whether the devised test actually had this type of validity.

Attitude Measures

Importance for the Study. There is universal agreement that attitudes toward a course are important in the learning and retention of its content, that attitudes are likely to stimulate or to stifle further study, and that attitudes will inevitably be formed in the superior as well as the inferior student. This being so, one must conclude that the development of favorable attitudes is an important objective in teaching a subject. Johnson (1957) stresses the importance of teaching good attitudes toward mathematics: "It is the attitudes which we teach that are the most important factors in the activities in which our youth participate--now and later (p. 113)."

There is some disagreement, however, as to how attitudes are developed, how quickly they are formed, and how readily they are changed. Is it reasonable, for instance, to postulate that measurable changes in attitude toward mathematics can be brought about through ten hours of instruction and to assume, further, that such changes are stable and relatively permanent? Skinner's assumption that a single response made by an organism produces significant changes within it would appear to make measurable changes in attitude within a ten-hour instructional period possible. Johnson (1957) maintains that "Every hour spent in the classroom results in developing attitudes, desirable or undesirable (p. 113)," but he cautions that

> The pupil who dislikes arithmetic because he is not successful in it will likely avoid any further contact with it. You may be able to change his attitude but it usually requires an intense or long experience to do so (p. 114).

The investigator feels, therefore, that detectable changes may take place in the designated time interval if the instructional circumstances are changed radically and if the instruction itself is carefully structured in the light of the desired attitudinal changes which are to be effected and in the light of the forces producing those changes, such as those mentioned by Johnson (p. 115).

Measures of Attitude. Interest in this research focussed on two aspects involving attitude, viz., attitude to mathematics as described above, and attitude to computer assisted instruction in mathematics. These two aspects involved the use of two different instruments.

The former raised the question: what would be the effect of ten hours of instruction at the computer on the attitudes of the students working through the two CAI programs? The answer was sought from data gathered by using an attitude scale developed by Remai (1965). This scale was found to have a satisfactory test-retest reliability and internal consistency coefficient. The scale was administered six weeks prior to the experiment as well as immediately after its completion in an attempt to detect any attitudinal change which had taken place as a result of the treatments. Students given this test could not be assured of anonymity since a comparison of pretest and posttest responses for each individual was required. However, they were given the pledge that their answers would not be divulged to school personnel and would, therefore, in no way affect future scholastic achievement.

In order to gain some insight into the attitude of the participating students toward CAI, a special Computer Sessions Questionnaire was prepared for the study. This instrument led students through a series of questions in which they were asked to compare the effectiveness of CAI to classroom instruction by responding to each of twenty-four comparative statements with an A (Agree), a D (Disagree), or a U (Undecided). The designer also included a few open-ended questions, hoping thereby to glean some information which would give direction to the interpretation of some of the results of the statistical analysis. The set of questions was presented to the Mathematics 12 students involved in the pilot study. Minor revisions were made as a result. The resulting Computer Sessions Questionnaire was administered to all CAI students involved in the major study upon completion of the project.

It should be noted that both attitude instruments were administered to all CAI students during the last twenty-five minutes of the project by means of computer programs. It was felt that this would have two advantages. First, any changes induced by the experiment would be less likely to disappear through the influence of external stimuli and forces. While this possibility implies an unstable change, it must be recognized that the time interval is very short, and that any change, even if unstable, would tend to deepen and strengthen over a longer period of time. Second, administering the questionnaire immediately following a session would facilitate quickness of response where recall was necessary, as it would certainly be in the case of the Computer Sessions Questionnaire. Whereas one might argue that this procedure would bias the responses significantly either for or against computer assisted instruction, one could counter that the administration of the test in the classroom at a later date would involve the risk of an equivalent but adverse bias. In any case, a bias does indicate an influence upon attitude, and this is precisely what the instruments were intended to determine.

Both instruments--Remai's A Mathematics Study and the Computer Sessions Questionnaire--are included in Appendix C.

3. RESEARCH PROCEDURES

The CAI Groups

The investigation was undertaken by using Mathematics 20 students in one of the semester high schools of the Edmonton Public School Board. The students attending this school in the second semester had been randomly assigned to six mathematics classes through computer scheduling. These students were now divided into three subgroups of equal size, each on the basis of intelligence. The I. Q. scores from the Lorge-Thorndike Intelligence Test were used to rank the Mathematics 20 population, the thirty-third and sixty-seventh percentiles marking the divisions into high, average, and low ability groups.

Fifteen students from each of two classes were selected at random, five from within each of the above-mentioned ability groups. Each student, then, was assigned at random to one of the two CAI programs in order to form the two fifteen-member groups previously referred to as IRG (Immediate Review Group) and DRG (Delayed Review Group).

The Classroom Group

In order to avoid biasing the instruction as much as possible, the fifteen students to be used for the third group were not selected until after the instructional and testing period was completed. Thus the whole class was instructed and tested by the investigator. After all instruction and testing was completed, fifteen of the thirty-one students were chosen, again by using the stratified random sampling technique. This group of students formed the SRG (Spaced Review Group).

Data Collection

Actual instruction and data collection took place during the first two weeks of June. Prior to this period, all participating students were given a briefing on the nature of the experiment, the meaning and importance of CAI, the basics of computer operation, and the significance of their part in the study. The investigator sought at this time to allay any fears which they may have had relative to the computer or CAI as well as to impress them with the importance of their role in the experiment.

CAI Procedure. All 30 students in the two CAI groups were transported daily for two weeks to the Computing Center of the Division of Educational Research Services, fifteen at 10:00 a.m., the remaining fifteen at 2:00 p.m. Each student worked at his own terminal which consisted of a film strip projector, an audio unit, and a cathode ray tube equipped with a typewriter used by the student to enter his responses.

The first part of each of the two programs described previously consisted of an orientation session designed to introduce the student to the computer, to acquaint him with a few basic procedures to be used in the course to follow, and to imbue confidence through successful practice. After each student had completed this portion of the program, he was shifted automatically into the program randomly assigned to him. At the beginning of each subsequent period, the computer transferred each individual to the precise point in the program where he had left off the day before. The latter part of the last period, as mentioned earlier, was used for the administration of the two attitude questionnaires.

It should be emphasized, before passing on to a consideration of the classroom instruction procedure, that at no time was any student in either program kept waiting for any appreciable time for further theory presentation, problem display, or answer analysis. In fact, the only noticeable delay occurred at the beginning of each session when all fifteen students attempted to sign on simultaneously.

Classroom Procedure. The researcher, who also served as the instructor, sought to keep motivation in the classroom group at a high level by initially explaining and frequently recalling the importance of their part in the research, by keeping them posted on the progress shown and the difficulties experienced in the computer group, and by expressing confidence in their ability to outscore the other two groups. Interest and enthusiasm, generally speaking, appeared to be very satisfactory.

Comments have been made previously regarding the attempt to keep instruction, assignments, and quizzes parallel in all treatments. In order to assist the instructor in doing so, a careful plan of each lesson was made, and this plan was then followed as closely as the interests of the students would permit. A careful record was kept of what actually took place in class and of what time was used in each type of activity. This record indicated that, content-wise at least, the classroom instruction was clearly comparable to that of either of the two CAI programs. A resumè of this record is included in Appendix B. It should prove of interest to the reader that the investigator experienced considerable difficulty in keeping pace with even the slower members of the CAI groups, that he found himself forced to "push ahead" at a pace faster than he normally would have used, and that he was constantly frustrated by the knowledge that the pace appeared to be too fast for the low achievers and too slow for the superior students.

As in the CAI groups, the latter part of the last period was used to administer Remai's "A Mathematics Study". Naturally there was no point in asking the students of this treatment group to complete the computer-oriented "Computer Sessions Questionnaire."

Achievement Test. The researcher gave the achievement test on logarithms to all three experimental groups on the first school day following the completion of the instructional sequence. Initial instructions informed the students that this test was a vital part of the whole project and also that the results therefrom would be used to assess their year-end achievement.

Limitations

Some limitations of the study have been noted in Chapter I. Further limitations are given below. Some of these are inherent in the measuring instruments; others are due to externally imposed constraints.

Data Reliability. The use of the questionnaire to obtain self-reports from students resulted in data of questionable accuracy. Problems of faulty perception, lack of awareness of unconscious motives, and of deliberate or accidental errors may have contributed to a reduction in over-all reliability and validity (Oppenheim, 1966). The writer would emphasize, therefore, that the use of the two attitude measures is based on the following assumptions: (1) Students, having gained full assurance that their responses would have no negative repercussions for them, responded to the statements without fear. (2) Students were not influenced to give "expected" answers, having been informed that there were no wrong answers. (3) Students, being convinced of the need and the importance of the project, made a special effort to choose the best alternative and to avoid mechanical errors.

Class Size. The limited number of computer terminals available together with transportation costs and the need to encroach upon school time necessitated a limit in class size. The small size of each sub-class may have made it more difficult to achieve significant differences between the groups and sub-groups being compared.

Teacher Influence. Since the research was conducted late in the school semester, the students had been exposed to the influence of the current mathematics teacher for several months already. This influence may have produced strong attitudes to mathematics, may have formed definite study and thinking habits, and may have produced well-established methods and approaches. All of these may have affected one or more of the results of the study in the sense that settled attitudes and habits may have made it difficult to achieve significant differences within a span of two weeks.

Program Construction. The effectiveness of CAI is determined largely by the quality of the program used. Thus Coulson (1968) cautions: "Research indicates that CAI can be effective only if extreme care has been taken in preparing the content materials and the computer program that controls the lesson sequence (p. 147)." After illustrating the pitfall in programming remedial instruction for detected deficiencies in performance, he advises that "Every remedial sequence must be tested and revised several times to insure, insofar as possible, that it actually rectifies the student's understandings (p. 147)." The writer recognizes the advisability of several revisions on the basis of actual trials. Since practical factors precluded more than one trial, attempts to improve the quality of the program were limited to a concerted "effort to sequence instruction in accordance with explicit analyses of the learning objectives into subordinate components, as in the research by Gagne (Briggs, 1968, p. 173)" and to revisions based on a single testing and on the expert advice of qualified teaching and programming personnel.

Computer Setting. Two aspects of the experimental situation which might be considered to be limitations in the proposed study deserve brief discussion. The more significant of the two is the Hawthorne Effect. Roth (1963) refers to

> an important area which has not yet been considered in detail: student feelings and reactions to these new instructional materials. No one can doubt the important role that non-intellective factors play in the learning process, yet most of the reports on programmed learning have dealt with achievement scores to the almost complete exclusion of attention to student emotional reactions to this new kind of learning situation (p. 278).

Gentile states the situation more explicitly:

> Motivational concerns are a continuing problem in learning theory and remain so in CAI. It has been suggested that the Hawthorne Effect may be operating in the highly atypical CAI laboratories, which may help to account for the generally favorable attitudes of students found by Wodtke and others. . . . In what may be the only study on this question, Wodtke found that "attitude toward CAI did not appear to affect performance when the effects of aptitudes were partialled out." (1967, p. 30).

The Hawthorne Effect--to the extent that it contributed significantly toward the learning of the CAI students--may have been offset wholly or partly by the second of the two situational factors. There was the distinct possibility of one or more students reacting with fear and reluctance toward the mechanical device before them. Suppes (1966) maintained that children have no difficulty in adjusting to the machine, and Coulson (1968) saw no evidence of fear or reluctance when subjects in his research used the machine. This was certainly the case also in the investigator's observations of students involved in his pilot study. Bundy (1968), however, reports findings contrary to those just outlined. It may well be, therefore, that some students do get flustered when confronted by machinery. Furthermore, serious interference with student learning may result from entering responses in "wrong" form when only one form of an answer is permitted. To counteract any fear or reluctance and to acquaint students with the entering of responses at a keyboard, a twenty-minute orientation was inserted into the instructional program. An attempt to minimize interference because of unaccepted but correct answers took the form of a provision for alternative and unrecognized answers, in which case the student was simply informed of the correct answer or given an opportunity to try again.

Since the two factors discussed above would tend to have opposite effects on learning, one might assume that the net group result would be a negligible effect on learning. One might conclude, therefore, that the computer setting, when group effect is considered would not be a limitation under the conditions of the experiment.

This effect receives some corroboration from the results of the attitude tests. These will be reported on later.

4. ANALYSIS OF DATA

Most of the questions which motivated the investigator to attempt this research have already been stated either explicitly or implicitly. In order to bring them into sharper focus, they are now restated as research hypotheses in operational form. They are all stated as null hypotheses rather than as directed hypotheses since they were all of an exploratory nature. There was nothing in the literature which was examined that offered conclusive evidence as to which of the treatments would produce superior results. Thus the researcher concluded that there existed a possibility of a significant difference in either direction and, therefore, that a two-tailed test was required. Hence operational hypotheses of the form, $H_o:\mu_1=\mu_2$ and $H_1:\mu_1\neq\mu_2$ were deemed appropriate. It was considered advisable to apply the .05 level of significance to all tests. However, wherever possible, the calculated probability has also been given, thereby enabling the reader to draw his own conclusions.

Achievement in Mathematics

Hypothesis 1. There is no significant interaction between treatments and achievement at the different levels of ability.

Hypothesis 2. There are no significant differences among the treatment groups on the achievement test when:

a) each group is considered as a whole, and

b) corresponding ability levels are compared.

Levels of Thinking

Hypothesis 3. There is no significant interaction between treatments and achievement on problems involving different levels of thinking.

Hypothesis 4. There are no significant differences among the treatment groups as (i) the knowledge level, (ii) the algorithmic level, and (iii) the problem solving level when considering:

a) each group as a whole, and

b) corresponding ability levels.

Program Progress

Hypothesis 5. There are no significant differences in achievement between the fifteen CAI students progressing farthest in the program and the remaining CAI students.

Attitude

Hypothesis 6. There are no significant differences in post-experimental attitude exhibited by the treatment groups when attitude is measured by:

a) Remai's attitude scale, and

b) the Student Questionnaire.

Descriptive Response Analysis

At the outset of the research project, the writer projected an examination of the computer-stored information regarding the students' responses. It was conjectured that some significant trends by way of response types, error characteristics, time-out frequencies, and paths taken through the program would prove quite revealing as to learning styles and as to ranges of individual differences. The hope was expressed that such an analysis would give some indication as to what direction future CAI research might profitably follow.

Statistical Treatment of Data

Three-way Analysis of Variance. Hypotheses 1 through 4 were tested using a treatment by problem difficulty level by ability level factorial design. Since all factors were fixed factors, Winer's Model I (pp. 172, 248) for a p x q x r factorial analysis was found to be appropriate for the analysis at hand. The steps followed in using this statistical procedure are described below.

First, the three-way interaction and all possible two-way interactions between factors were investigated. If an interaction was found to be significant at the .05 level, the treatment effects at each level were examined by considering these levels as single factor experiments (Winer, p. 210). Where treatment effects for any given level were found to be significant, Scheffe's procedure (Winer, p. 88) was used to test for significance of differences between pairs of means. If the interaction between factors was found to be not significant, an investigation of the main effects due to treatments was made. This was followed once more by an application of Scheffe's method for tests of significance of differences between pairs of means in those cases where the main effects were found to be significant.

Underlying the analysis of variance procedure is the assumption that the error variance is homogeneous. Hartley's F_{max} test (Winer, p. 239) was used to check whether the error variances were indeed homogeneous. Cell variances and the results of the application of this test are reported in the appendix. It should be noted that most statisticians regard the F test as robust with respect to normalcy and homogeneity of variance (Winer, p. 239). Hayes (1963) even maintains that "Modern opinion holds that the analysis of variance can and should be carried on without a preliminary test of homogeneity of variances (p. 381)."

Analysis of Covariance. Hypothesis 6a was investigated on the basis of an analysis of covariance. The assumptions underlying the analysis of covariance, namely, "that treatment effects and regression effects are additive . . . and that the proper form of regression equation has been fitted (Winer, p. 586)," were checked. Winer's test for between-class regression (Winer, p. 587) was also applied to the data before the actual analysis of covariance was carried out.

The covariate used was the set of scores on the first administration of Remai's attitude scale. A multivariate analysis was projected where treatment effects were found to be significantly different in order to determine which pairs of adjusted group means accounted for the significant difference.

Kolmogorov-Smirnov Two-sample Test. Hypothesis 6b was tested by applying the Kolmogorov-Smirnov Two-sample Test (Guilford, 1965, p. 262). This test had the advantage of applicability to small samples. In addition, the assumption of continuity of distribution underlying the test was considered tenable for the data used. Further, according to Siegel, "The two-tailed test is sensitive to any kind of difference in the distributions from which the two samples were drawn --differences in location (central tendency), in dispersion, in skewness, etc. (Siegel, p. 127)."

One-way Analysis of Variance. This type of analysis was used to test Hypothesis 5. Using the information available from the computer output, the fifteen students who had proceeded farthest in either of the two programs were identified. The performance of this group was compared with that of the remaining CAI students by using a simple one-way analysis of variance.

5. SUMMARY

Three groups of fifteen students were selected from the Mathematics 20 population of an Edmonton high school. Stratified random sampling was used to ensure that an equal number of high ability, medium ability, and low ability were present in each group. One group received instruction through a computer program which delayed all review until the student completed the theory which was to be covered. A second group was taught by a computer program which presented immediate review on the basis of needs detected through incorrect answers or student requests. A third group was instructed in a classroom with an approach which stressed periodical review of the material covered most recently.

All students were given an achievement test to determine the effectiveness of the mode of instruction and an attitude test to detect any attitudinal changes effected by the experiment. The CAI students were given a further questionnaire attempting to reveal their personal reactions to CAI as a method of instruction.

Two types of analysis were used on the data obtained from the study. The descriptive analysis of the responses of the students in the CAI groups sought to reveal trends in the responses made by these students. The statistical analysis sought to determine significant differences between various treatment groups and subgroups.

CHAPTER V

DESCRIPTIVE AND STATISTICAL ANALYSIS

1. OUTLINE OF THE ANALYSIS REPORT

The chapter begins with a descriptive analysis of the responses given by the CAI students since such an analysis may or may not justify a more formal treatment of the data. This part of the analysis examines such aspects as actual branches used by the students, the frequency with which they were used by individual students as well as by students grouped according to ability level, types of responses, and some characteristics of the errors which have been made.

The analysis continues with an examination of the five achievement hypotheses. This involves a three-way factorial analysis, including tests of the assumptions and tests for interactions, main effects, and simple effects.

The chapter concludes with a consideration of the students' attitudes. The results from the tests on attitudes to mathematics were subjected to an analysis of covariance using the scores on the first test as a covariate. The attitudes to CAI were checked by means of the Kolmogorov-Smirnov Two-sample Test.

2. DESCRIPTIVE RESPONSE ANALYSIS

Since the effect as well as the effectiveness of the branching sequences involved in the IRG (Immediate Review Group) program is of primary interest in this section, the greater portion of the analysis to follow will be devoted exclusively to the responses of the IRG students. Such aspects as branches taken, response types represented, error characteristics revealed, and learning styles detected will be presented in the sections to follow. The analysis here will be of a descriptive nature.

Branches Used by IRG Students

Table I summarizes some aspects of the effectiveness of the branching in the IRG. The table lists the number and nature of the major loops in this program and indicates the number of students within each ability level as well as the total number entering each of these loops.

Before entering upon a discussion of the results summarized in this table, a few relevant comments should be made. First, not all students finished the program in the allotted time; as a result, not all students reached the latter part of the looping sequence. Thus, two students did not go beyond loop 9, four did not proceed past loop 10; and only one reached loop 14. Secondly, loops 3, 12, and 14 offered students a choice with respect to branching. Loop 3 enabled the student to choose whether he wished to attempt the proof of the quotient property of logarithms. It is interesting to note that all of the low ability students chose to attempt the proof and that all but one in each of the other groups did likewise. Loop 12 offered the student a set of more difficult logarithmic computations. Loop 14 presented a choice of review topics before allowing students to proceed with an examination based on all the theory covered in the CAI program.

TABLE I

SUMMARY OF NUMBERS OF STUDENTS ENTERING THE BRANCHES OF THE IRG PROGRAM

Loop	Description of Loop	High	Med.	Low	Total
1	Changing the form of logarithmic equations	2	1	3	6
2	Forming equivalent exponential equations	3	1	3	7
3	Proving theorem 2 (quotient property)	4	4	5	13
4	Applying the basic properties of logarithms	3	3	3	9
5	Solving logarithmic equations	4	4	5	13
6	Writing numbers in scientific notations	0	1	4	5
7	Determining the characteristic of a logarithm	0	1	1	2
8	Determining the mantissa of a logarithm	4	2	2	8
9	Determining the complete logarithm	3	2	3	8
10	Determining the antilogarithm	1	0	1	2
11	Computing products and quotients by logarithms	2	3	1	6
12	Computing more difficult problems	0	1	0	1
13	Computing an easier set of problems	1	1	0	2
14	Reviewing topics	0	1	0	1
	Totals	27	25	31	83

<u>Frequency</u>. From the entries in the last column of Table I, the most frequently entered loops in order of use are seen to be loops 3, 5, 4, 8, and 9. The comment given earlier with respect to loop 3 explains the frequency with which it was entered. The very high

frequency for loop 5 (used by all but two of the fifteen students) is explained in part by the relative difficulty inherent in the solution of logarithmic equations for students somewhat unfamiliar with the nature and properties of the logarithmic function. It also suggests that the treatment of this topic needs further revision. It is also possible that the frequency of the use of loop 4 could be reduced by revisions in the presentation of the topic involved, especially in the form of further illustrative examples. The fairly high frequencies associated with loops 8 and 9 are due mainly to the high requirements set for the procedures involved and to the low time limit given for each response. Thus, a few time-outs per student would be sufficient to force him into the loop providing further practice on the procedure concerned.

The least used loops, other than those not reached by the majority of students, are seen to be loops 7 and 10. The former is explained by the fact that the procedural technique had been covered in Mathematics 10 and reviewed in Mathematics 20. The latter involves a procedure closely related to procedures which have been covered at earlier stages in the program and whose mastery presumably had been assured by the provision of the required loops. That is, students who thoroughly understand the significance and the determination of characteristics and mantissas should not experience undue difficulty in determining antilogarithms.

Comparisons by Ability Groups. A glance at the numbers in the ability group columns suggests that there are no striking differences between the high ability group and the medium ability group, but that both looped less frequently than did the low ability group. This trend within the individual loops is evident also as an overall trend. This can be seen by examining the totals for the groups. The difference in totals becomes even more significant in the light of the fact that only one individual in the low ability group progressed beyond loop 10.

An examination of individual performances in relation to branching extent reveals some expected as well as some unexpected results. The performance of students with computer numbers sk 6, sk 7, sk 8, and sk 5 deserve special attention. Sk 6 was forced through every possible branch in the material covered. In sharp contrast, sk 5 with the same course coverage used only three of the seven possible loops. Sk 7 and sk 8 missed the use of but one loop and two loops respectively. The reader is referred to Table XIX in Appendix D for a listing of the loops used by each of the fifteen IRG students.

It is worthy of note that the ability groups represented by individuals using the loops most infrequently would be listed as follows: medium ability student (two loops), low ability student (three loops), high ability student (four loops), medium ability student (four loops), medium ability student (five loops). More will be said later about the relationship between the extent of looping and achievement.

Response Types and Error Characteristics

Table XXVII in Appendix E summarizes the response performance of the IRG students in the ten major sets of questions in the basic program used to form the IRG. A summary of this table with results reported by ability groups is presented in Table II.

TABLE II

SUMMARY OF RESPONSE PERFORMANCE ON MAJOR ASSIGNMENTS
ARRANGED BY ABILITY GROUPS

	Qu 1			Sec 10			Show 6			Expa 2			Char		
	H*	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Correct	40	32	39	31	38	29	40	37	38	30	24	28	46	46	38
Wrong	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unrecognized	10	17	11	19	12	19	10	13	11	17	24	19	3	4	10
Time-out	0	1	0	0	0	2	0	0	1	3	2	3	1	0	2

	Mant			Mant 5			Log 2			Anti 2			Comp		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
Correct	45	40	40	43	29	24	85	51	52	55	40	39	11	5	0
Wrong	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0
Unrecognized	5	6	9	3	6	3	9	6	6	22	13	17	8	7	0
Time-out	0	4	1	4	5	3	5	3	2	3	7	4	0	0	0

* H - high ability, M - medium ability, L - low ability

A few observations merit mention. The high ability group performed somewhat better as a group than either of the other two, whereas the number of correct answers given by the low ability students was appreciably lower on most question sets than that of each of the other groups. On the other hand, the number of time-outs per question set does not seem to differ between groups. The differences are accounted for largely by the number of incorrect answers.

The very low number of identified wrong answers (W) as opposed to the very high number of unidentified wrongs answers (U) simply indicates the programmer's inability to foresee the wrong answers which students would give for each question. The quality of the IRG program might be improved appreciably with the identification of more representative wrong answer types followed by suitable instructions for each.

Significance of Tables and Discussion

The discussion and data presented above indicate clearly that the branching feature of the IRG program has been used extensively by students of all three ability levels. One must conclude, therefore, that this feature has introduced a significant change in the basic program, that the two programs differ from each other in an educationally important manner, and that a more formal analysis of the achievements of the IRG and DRG is meaningful and warranted. Thus, the report continues with a statistical analysis of the data provided by the experiment.

3. ACHIEVEMENT HYPOTHESES

Statistical Analysis and Assumptions

The major and subsidiary questions to be examined statistically at this point are:

1. Are there any significant differences between treatments?
2. Is there any significant interaction between treatments and ability?

3. If so, are there any significant differences between treatments at each of the ability levels?

4. Is there any significant interaction between treatments and problem types?

5. If so, are there any significant differences between treatments at each of the difficulty levels?

A 3 x 3 x 3 factorial design was the basis for the statistical analysis of the data collected. The reader is referred to Figure 1, page 10, for a complete outline of the three factors and of the three levels of each factor. At this point, the writer wishes to present a summary of the mean squares and F ratios obtained from the data relating to the achievement hypotheses. This summary is presented in Table III. Immediately following it is a table of all means and standard deviations.

As mentioned earlier, the analysis of variance assumes that the error variance is homogeneous. The validity of this assumption for the research under study was checked by applying Harley's F_{max} test. The variances for each cell in the 3 x 3 x 3 factorial design are given in Table XX of Appendix D. From this table, we find that $F_{max} = F_{largest} \div F_{smallest} = 292.8 \div 8.8 = 33.3$ The probability of obtaining an F as large as 33.3 is greater than .05. Thus the homogeneity of error variance should not be rejected.

Hypotheses Relating Treatment and Ability

Interaction hypothesis. The hypothesis is restated at this point. There is no significant interaction between treatments and ability on the basis of achievement. The data of Table III with

TABLE III

SUMMARY OF TREATMENTS x ABILITY x PROBLEM DIFFICULTY ANALYSIS OF VARIANCE

Source of Variance	SS	df	MS	F	P
Ability levels, SS_a	461.44	2	230.72	7.4	<.01
Problem difficulty level, SS_d	3843.08	2	1921.54	61.8	<.01
Treatments, SS_t	272.28	2	136.14	4.3	<.01
Interaction, SS_{ad}	39.05	4	9.76	0.3	
Interaction, SS_{at}	365.72	4	91.43	2.9	<.05
Interaction, SS_{dt}	61.01	4	15.25	0.5	
Interaction, SS_{adt}	144.39	8	18.05	0.6	
Within cell, $SS_{w.cell}$	3355.40	108	31.07		
Total, SS_{total}	8542.37	134			

respect to the interaction between treatment and ability (SS_{at}) indicates that this hypothesis should be rejected.

Table IV shows the means and standard deviations of various groups and sub-groups.

The profile of cell means depicted in Figure 6 indicates quite graphically the extent and the nature of the interaction between these two factors.

<u>Total Group Hypothesis</u>. The hypothesis restated: there are no significant differences among the treatment groups on the achievement test when each group is considered as a whole.

TABLE IV

MEANS AND STANDARD DEVIATIONS OF VARIOUS GROUPS AND SUB-GROUPS

		SRG		DRG		IRG	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Treatments		13.76*	8.07	13.87	7.86	16.82	7.81
High		16.87	8.66	16.60	8.29	17.40	8.40
Medium		16.00	6.44	12.46	7.73	16.67	8.66
Low		8.40	6.45	12.55	7.33	16.40	6.76
Factual		13.73	9.35	13.07	7.12	17.20	5.44
Algorithmic		19.33	5.31	21.07	5.61	23.87	5.01
Problem Solving		8.20	4.77	7.47	3.42	9.40	4.98
Factual	Low	6.00	4.90	11.20	6.72	18.80	4.15
	Medium	16.00	3.74	11.60	8.41	15.20	7.29
	High	19.20	12.21	16.40	6.39	17.60	4.98
Algorithmic	Low	15.20	4.97	19.60	5.22	21.60	4.10
	Medium	22.00	3.39	19.00	6.44	25.00	5.24
	High	20.80	5.45	24.60	4.22	25.00	5.83
Problem Solving	Low	4.00	2.74	6.80	3.11	8.80	3.56
	Medium	10.00	5.48	6.80	1.48	9.80	5.76
	High	10.60	2.97	8.80	5.07	9.60	6.35
		Low		Medium		High	
Ability (all treatments)		12.44	7.47	15.04	7.72	16.96	8.27

* All entries in all categories are based on a maximum possible score of 34.

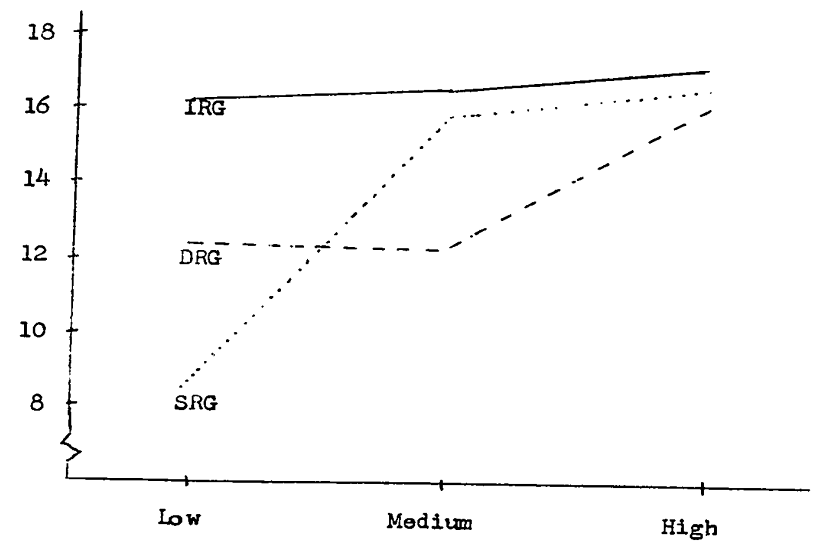


Figure 6

Profile of Cell Means in the Treatment x Ability Grouping

Because of the significant interaction noted in the preceding section, the main effects of the treatments must be viewed with some caution. An interpretation of the results obtained will be attempted in a later chapter.

The results for treatments as a source of variance listed in Table III indicate an F value significant at the .01 level. Thus the hypothesis, viewed apart from the significant treatments x ability interaction would have to be rejected.

Because of the significant interaction, significant differences between pairs of treatment means were not investigated.

Ability Levels Hypothesis. The hypothesis restated: there are no significant differences among the treatment groups on the achievement test when corresponding ability levels are compared.

Table V summarizes the data required for the F-tests on significant differences between means. The computations follow the method of Winer in obtaining sums of squares and mean squares for a factor at each of the levels of a second factor (Winer, p. 256). The calculated F values indicate that the hypothesis would not be rejected for the high and the medium groups, but that it would be rejected for the low group.

Since the analysis showed that significant differences between treatment means existed at the low ability level, the researcher sought next to determine which pairs of means were significantly different. Considering the data relevant to the low ability group as data of a single factor experiment, Scheffe's procedure was used to detect differences between pairs of means. The critical value, given by the value $(p - 1)F_{1-x}[(p - 1), pq(n - 1)]$ (Winer, p. 210), was found to be 6.46 at the .05 level. The calculated F values are listed in Table VI.

The results of the calculations displayed in Table VI indicate that each mean differs significantly from each other mean and further that the means would be ranked as follows for low ability students: SRG < DRG < IRG.

TABLE V

SUMMARY OF ANALYSIS OF VARIANCE OF TREATMENTS AT EACH ABILITY LEVEL

Source of variance	SS	df	MS	F	P
Low ability level, $SS_{t\ at\ a_3}$	480.18	2	240.09	7.73	<.01
Medium ability level, $SS_{t\ at\ a_2}$	152.84	2	76.42	2.46	>.10
High ability level, $SS_{t\ at\ a_1}$	4.98	2	2.49	0.08	>>.20
Within cell, $SS_{w.cell}$	3355.40	108	31.07		

TABLE VI

F VALUES FOR THE COMPARISON OF MEANS FOR TREATMENTS (LOW ABILITY STUDENTS)

	SRG	DRG	IRG
SRG		12.37**	46.34**
DRG			10.82**

** significant at the .01 level

Hypotheses Relating Treatments and Problem Difficulty

Interaction Hypothesis. Hypothesis restated: there is no significant interaction between treatments and achievement on problems involving different levels of thinking.

The summary shown in Table III relevant to this interaction indicates that the hypothesis should not be rejected. The fact that there does not appear to be any significant interaction is also borne out by the profile of cell means graphed in Figure 7.

Problem Difficulty Level, Total Group. Hypothesis restated: When considering each treatment group as a whole, there are no significant differences between the means of the treatment groups at: (i) the factual level, (ii) the algorithmic level, (iii) the problem solving level.

The analysis involved the computing of simple main effects of treatments for the three levels of problem difficulty (Winer, p. 252). The required data pertaining to the analysis of variance is presented in Table VII.

From the results, it is apparent that the hypothesis should not be rejected for any one of the problem difficulty levels. It might seem unnecessary, therefore, to investigate further the possibility of significant differences between pairs of treatment means. Winer, however, maintains that

> specific comparisons which are built into the design or suggested by the theoretical basis for the experiment can and should be made individually, regardless of the outcome of the corresponding over-all F-test (Winer, p. 208).

Hence, all pairs of means at the above levels were compared using Scheffe's procedure. Since the degrees of freedom for estimating error were considered large enough by Winer's standards (Winer, p. 210), the factorial experiment was considered as a single factor experiment, and the method of Chapter 3 was applied directly to this part of the study. The critical F values at the .05 and .01 levels were 6.46 and 10.36 respectively.

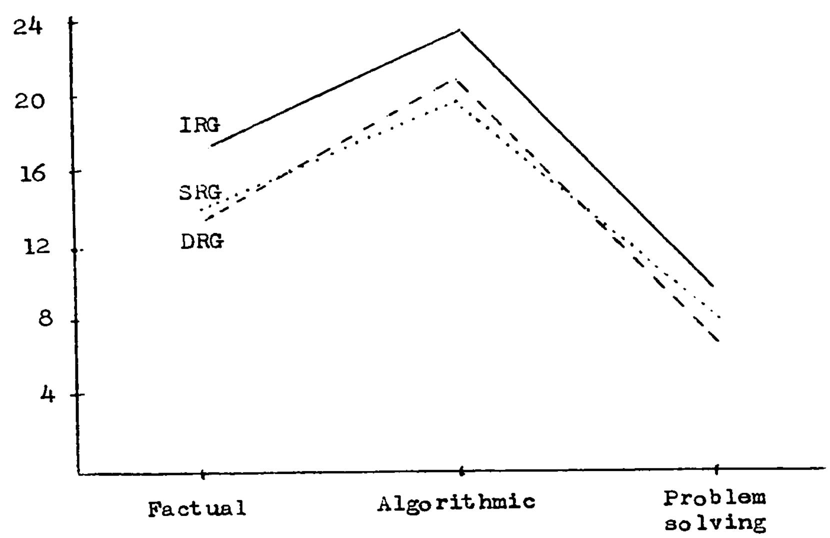


Figure 7

Profile of Cell Means in the Treatment x Problem Difficulty Level Grouping

The F values of the differences between pairs of means are tabulated in Table VIII. The results indicated that IRG is superior to both SRG and DRG at the factual level and to SRG at the algorithmic level.

Problem Difficulty Level x Ability Level Hypothesis. Hypothesis restated: when considering corresponding ability levels, there are no significant differences among treatment means at: (1) the

TABLE VII

SUMMARY OF ANALYSIS OF VARIANCE OF DATA RELATING TO TREATMENTS AT EACH PROBLEM DIFFICULTY LEVEL

Source of variance	SS	df	MS	F	P
Factual	147.73	2	73.67	2.34	>.05
Algorithmic	156.98	2	78.89	2.50	>.05
Problem solving	28.58	2	14.29	0.46	>>.05
Within cell	3355.40	108	31.07		

TABLE VIII

F VALUES FOR PAIRS OF MEANS RELATING TREATMENTS AND PROBLEM DIFFICULTY LEVEL

		DRG	IRG
Factual	SRG	0.32	9.70 *
	DRG		12.37**
Algorithmic	SRG	2.18	14.88**
	DRG		5.68
Problem Solving	SRG	0.39	1.04
	DRG		2.70

* significant at .05
** significant at .01

factual level, (ii) the algorithmic level, (iii) the problem solving level.

Data pertaining to an analysis of variance to test this hypothesis are given in Table IX, the computations in this case involving Winer's simple main effects (Winer, p. 252). Profiles are portrayed in the graphs of Figure 7.

The results recorded in the table indicate that the hypothesis under consideration should be rejected only for the factual-low ability grouping. Scheffe's test was applied to the means of the treatments in these cells to determine which means accounted for the significant F. The results of this application, summarized in Table X, showed that the IRG was significantly superior to the SRG.

Program Progress Hypothesis

Hypothesis restated: there is no significant difference in achievement between the fifteen CAI students progressing farthest in the basic CAI program and the remaining CAI students.

The hypothesis was tested by using the one-way analysis of variance approach. Table XI displays the results of the analysis. The obtained F value indicates that the hypothesis should be rejected and that one should conclude that the group progressing farthest in the program will score significantly higher than the other group.

4. ATTITUDE HYPOTHESES

Attitude to Mathematics

Assumptions. The test on the homogeneity of within-class regression revealed an F value well above the critical value at

TABLE IX

SUMMARY OF ANALYSIS OF VARIANCE FOR TREATMENTS BY PROBLEM DIFFICULTY AT DIFFERENT ABILITY LEVELS

		SS	df	MS	F	P
	Low	414.40	2	207.2	6.67	.01
Factual	Medium	54.95	2	27.47	0.88	
	High	19.75	2	9.87	0.32	
	Low	107.20	2	53.60	1.73	
Algorithmic	Medium	90.00	2	45.00	1.45	
	High	55.73	2	26.87	0.86	
	Low	58.13	2	29.07	0.94	
Problem Solving	Medium	32.13	2	16.07	0.52	
	High	8.13	2	4.06	0.13	
Within cell		3355.40	108	31.07		

TABLE X

F VALUES FOR THE COMPARISON OF MEANS FOR TREATMENTS AT THE LOW ABILITY-FACTUAL PROBLEMS LEVEL

	DRG	IRG
SRG	2.16	12.90*
DRG		4.56

TABLE XI

SUMMARY OF ANALYSIS OF VARIANCE RELATED TO PROGRAM PROGRESS

Source of Variance	SS	df	MS	F	P
Treatments	997.30	1	997.30	6.69	.05
Error	4177.67	28	149.13		

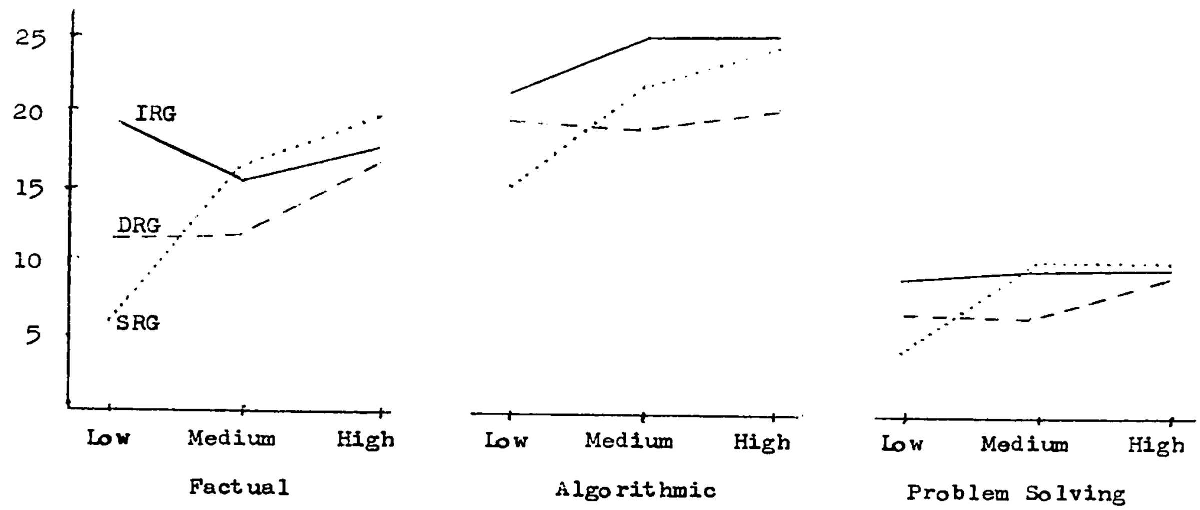


Figure 8

Profiles of Treatment x Ability Cell Means
for the Problem Difficulty Levels

the .05 level of significance. Such homogeneity, therefore, is highly suspect. Winer states that "the effect of nonhomogeneity of within class regression, which is analogous to lack of additivity, has not been studied (Winer, p. 586)." The results of the analysis of covariance should, therefore, be viewed with some caution.

The test of the hypothesis that the between class regression is linear as well as the test of the hypothesis that the between class and within class regression coefficients are equal produced F values well below the listed critical values. Table XII lists the results of all tests on the assumptions underlying an analysis of covariance.

TABLE XII

SUMMARY OF TESTS ON ASSUMPTIONS BASIC TO AN ANALYSIS OF COVARIANCE

	Computed F value	Critical F value
Homogeneity of regression	15.86	3.23
Linearity of regression	0.78	4.08
Equality of regression coefficients	2.76	4.08

Attitude to Mathematics Hypothesis. Hypothesis restated: there are no significant differences in post experimental attitude exhibited by the treatment groups when attitude is measured by Remai's attitude scale.

Table XIII lists the means and standard deviations of the scores on both tests for each of the three treatment groups. Table XIV summarizes the results of the analysis of covariance. Table XV is included to show the comparison of results obtained from an analysis of covariance and those obtained from an analysis of variance on the criterion variable alone.

The results, subject to the effect of non-homogeneity of within class regression, indicate that the hypothesis is tenable. This is in accordance with the results of the analysis of variance applied to the posttest scores alone.

TABLE XIII

MEANS AND STANDARD DEVIATIONS OF SCORES ON THE PRETEST AND POSTTEST ATTITUDE SCALES

		Pretest	Posttest
SRG	$\bar{x}$	62.60	61.53
	s	14.61	13.10
DRG	$\bar{x}$	65.07	67.33
	s	11.38	7.80
IRG	$\bar{x}$	66.67	67.53
	s	9.23	3.62

TABLE XIV

SUMMARY OF ANALYSIS OF COVARIANCE OF ATTITUDE SCORES

Source of variation	SS	df	MS	F	P
Treatments	200.77	2	100.38	1.77	.25
Error	2329.87	41	56.80		
Total	2530.64	43			

TABLE XV

SUMMARY OF ANALYSIS OF VARIANCE OF POSTTEST SCORES ON THE ATTITUDE SCALE

Source of variation	SS	df	MS	F	P
Treatments	348.4	2	174.2	2.12	.10
Error	3436.8	42	81.82		
Total	3785.2	44			

Attitude to CAI

Hypothesis restated: there are no significant differences in post-experimental attitude exhibited by the treatment groups when attitude is measured by the Computer Sessions Questionnaire.

As indicated in a preceding chapter, the assumptions underlying the Kolmogorov-Smirnov Two-sample Test were considered tenable for the data relevant to this hypothesis. Table XVI depicts the cumulative totals for the two computer treatment groups as well as the absolute value of the difference of these totals.

The maximum difference is well below the critical value ($K_D = 8$) listed for the .05 level of significance and a sample size as small as that in this experiment. There is, therefore, no reason why the hypothesis should be rejected.

5. SUMMARY

The most important of the findings recorded in this chapter are summarized below.

The descriptive analysis of student responses showed that students differed with respect to the branches which they chose to take, the branches which they were forced to take, and the number and type of errors which they made. The analysis of the results from the branching program indicated that this program was significantly different from the linear program with respect to instructional method.

The statistical analysis revealed a significant interaction between treatments and ability. Subsequent analysis showed that significant differences between treatment means existed at the low ability level, Scheffe's test indicating that IRG was superior to

TABLE XVI

CUMULATIVE FREQUENCIES OF THE GROUPED SCORES OF THE CAI TREATMENTS ON THE COMPUTER SESSIONS QUESTIONNAIRE

	53–55	56–58	59–61	62–64	65–67	68–70	71–73
Cumulative DRG frequencies	1	2	4	5	12	14	15
Cumulative IRG frequencies		1	3	6	9	13	15
Absolute value of the difference	1	1	1	1	3	1	0

DRG and DRG was superior to SRG. Statistical analysis also identified the significant differences which existed between treatments for problem types. Thus, IRG was shown to be superior to both SRG and DRG for factual problems and to SRG for algorithmic problems. A one-way analysis pointed to the conclusion that the student who proceeded farthest in the program achieved significantly better than the remaining students.

No significant differences between groups in attitude to mathematics or to CAI were detected. The Computer Sessions Questionnaire did, however, reveal some interesting responses on the part of the CAI students.

CHAPTER VI

INTERPRETATIONS, CONCLUSIONS, AND RECOMMENDATIONS

1. GENERAL OVERVIEW OF THE STUDY

Purpose

Current technological advances coupled with expressed educational needs for individualized instruction have aroused increased interest in the promised potential of computer assisted instruction. To use CAI most effectively, many questions must be answered. Expressed rather broadly, two of these questions are: What form should this instruction take? What types of students would benefit most from CAI, and how great would this benefit be?

In response to these questions, this study centered on two different types of CAI programs: the linear program and the branching program. The two particular programs used here have been detailed in Chapter III. The relative effectiveness of these two programs for students of varying ability was evaluated on the basis of a trial of parallel CAI units with two groups of students. At the same time, a third group was taught the same material by the researcher in a conventional classroom setting.

The particular questions to be answered by this study were the following. Which, if any, of these methods of instruction produces the best achievement? Is any one of these methods superior to either of the other two for students having the same I.Q.? Which method would produce the best achievement with respect to a particular type of objective? Do positive attitudes toward mathematics result from any one of these methods? How do students react to CAI as a method of instruction, and is this reaction differentiated between the two CAI settings?

Design

The study involved three groups of fifteen randomly assigned students, each group studying the topic of logarithms by one of three randomly assigned instructional methods mentioned above. For all three groups, instruction was provided for 550 minutes in ten 55-minute periods. Testing involved subject matter achievement, attitude to mathematics, and attitude to CAI.

2. SIGNIFICANT RESULTS AND THEIR INTERPRETATION

Hypotheses Reviewed

The hypotheses basic to the study are relisted below, the first constituting the main thrust of this investigation.

1. There is no significant interaction between treatments and ability levels.

2. There are no significant differences among the treatment groups on the achievement test when:

   a. each group is considered as a whole.

   b. corresponding ability levels are compared.

3. There is no significant interaction between treatments and achievement on problems involving different levels of thinking.

4. There are no significant differences among the treatment groups at: (i) the knowledge level, (ii) the algorithmic level, (iii) the problem solving level when:

a. each group is considered as a whole.

b. corresponding ability levels in each group are compared.

5. There are no significant differences in achievement between the fifteen CAI students progressing farthest in the program and the remaining CAI students.

6. There are no significant differences in post-experimental attitude exhibited by the treatment groups when attitude is measured by:

a. Remai's "A Mathematics Study"

b. the Student's Questionnaire.

Summary of Results

The major statistical procedure used in testing the above hypotheses was the three-way analysis of variance. In addition, the researcher used a one-way analysis of variance to test Hypothesis 5 and the analysis of covariance as well as the Kolmogorov-Smirnov Two-Sample Test to check Hypotheses 6a and 6b.

The three treatments are reviewed briefly for the reader's benefit. One group of CAI students (designated IRG) was given immediate review contingent only upon insufficient mastery of content as revealed by response patterns. For a second group of CAI students (DRG), all review was delayed until the basic material of the chapter had been covered. A third group of students (SRG), taught in a classroom, received spaced review in the form of questions and comments at the beginning of each class period.

The analysis of the data produced by the investigation revealed the following statistically significant interactions and differences between treatments.

1. The data indicated that there was a significant interaction between treatments and ability levels.

2. The analysis revealed significant differences in achievement within the low ability group due to treatments, subsequent analysis showing that each treatment produced significantly different results from each other treatment and that IRG was superior to DRG which in turn was superior to SRG.

3. The analysis also showed that the differences in achievement at the knowledge level due to treatments were significant, IRG being superior to both DRG and SRG.

4. Achievements at the algorithmic level due to treatments were found to be significantly different, IRG being superior to SRG.

5. Differences in achievement due to treatments for the low ability group at the factual level were found to be significant, Scheffe's test showing that IRG was superior to SRG.

6. The one-way analysis of variance disclosed significant differences in achievement between the fifteen CAI students progressing farthest in the basic program and the remaining fifteen CAI students.

The main findings of the study, therefore, point to the differential effectiveness of the treatments over ability levels, the greatest differences existing at the low ability level. At this level, an immediate review instructional mode using CAI is superior to a delayed review instructional mode also using CAI, and the latter in turn is superior to a spaced review instructional mode in a classroom setting.

All other comparisons produced results which were not statistically significant. It is especially important to note that no significant differences in attitude were noted from the application of either of the two attitude tests. This lack of significant difference has special implications for the interpretation of some of the significant differences listed above. These implications are discussed below.

That the Student's Questionnaire would reveal no significant differences is perhaps not surprising. Both groups were having the new experience of learning essentially the same material at the hands of a novel device, the only difference in the treatments of the two groups lying in the sequence of instruction. Hence, the great similarity in their experiences would not likely have a marked effect on their attitude to the computer as a mode of instruction.

More surprising is the lack of differences of attitude to mathematics between the computer-taught groups and the classroom-taught group. It would appear that influences which might awaken new attitudes, including the Hawthorne effect, operating within the CAI groups were not sufficiently strong to affect materially the group attitudes to mathematics.

Conclusions Drawn from the Analysis of the Data

Treatment x Ability Interaction. The fact that this interaction is significant indicates that the relative effectiveness of the three treatments is not the same for the three ability levels. The profiles of cell means depicted in Figure 6 (page 112) indicate not only the presence of interaction but also the change in the relative effectiveness of each treatment as the ability level rises. The discovery of such an interaction is quite important. One explanation for it is given below.

Learning rates and background knowledge are critical as a student progresses through a topic such as logarithms. In this respect, the classroom teacher is at a decided disadvantage. If he is able to detect such differences, he is unable to adjust satisfactorily to such variations in rates and background; as a consequence, he usually teaches for the mean of the group. It is almost inevitable, therefore, that neither the below average student nor the above average student achieves to the capacity of his ability. A well-written program, on the other hand, would enable all levels to perform according to their respective abilities. The profiles of Figure 6 (page 112) indicate that such anticipated results have been approximated by the investigation.

Secondly, cybernetics, the constant feedback of information regarding the individual's performance and progress, plays an important role in learning. Here, too, the classroom situation is not suitable for maximum use of this learning aid. The keener the student, moreover, the more likely he is to become aware of, to understand, and to take advantage of the feedback which the teacher is forced to give to the group as a whole. The situation is reversed in the case of a good program, be it linear or branching. Feedback is given immediately and individually in accordance with the needs of the student at the terminal. That such feedback was effective in the two programs concerned is evidenced by the comments made by students in response to items on the Student's Questionnaire. The reader is referred to Appendix D for examples of such comments.

Thirdly, the investigator hypothesizes that the differences in cognitive styles and the degree of provision for such differences may account for some of the differences in achievement by treatments. The instructor in a conventional classroom tends to use his own cognitive style predominantly or even exclusively in seeking to instruct, to explain, or to elucidate the subject matter at hand. A well-planned and carefully constructed program, on the other hand, can make allowances for various cognitive styles. This is especially true of a branching program. The manner in which the CAI programs sought to incorporate the various cognitive styles has already been described in detail in Chapter IV.

Since learning styles are very closely related to cognitive styles, the report will shift briefly into a discussion of some of the aspects of learning styles incorporated into the program which were actually used by students. These styles appear from an examination of the looping, the responses, and the progress of each individual.

It appears that some students, as indicated by progress and extent of looping, prefer to work more slowly but more methodically and thoroughly. Student sk 4 (medium ability), with only one forced loop, did not even cover antilogarithms, yet this student scored 42 points on the achievement test. Student sk 5 (low ability), with but two forced loops and covering the same course content as Student sk 4, obtained a score of 54. Student sk 0 (high ability), with three forced loops but covering appreciably more content, achieved 72 points. Other students, on the other hand, prefer to work more quickly even at the expense of more branching, to cover more material, and to learn from their errors. Student sk 12 (medium ability) serves as an example: the number of loops taken was six; the course content included the complete course, the examination, and the initial stages of review; the score obtained was 73, the highest score in all three treatment groups.

The reader is referred to the sharp contrasts between Student sk 5 (first style) on the one hand and Students sk 2 and sk 8 (second style) on the other. The achievements are comparable, the learning methods are not. A similar contrast occurs between the learning style of Student sk 4 and that of Student sk 13.

It appears also that not all students benefitted equally from a given branching sequence. In the low ability group, the branching sequences of Students sk 6 and sk 7 are comparable, yet the scores differ by 14 points. Also Student sk 3 (medium ability) outscored Student sk 1 (high ability) by 13 points with essentially the same branching sequence.

These examples, admittedly, portray what has happened with particular individuals using a particular program. As such, the results cannot be generalized. However, they do suggest that the incidence of such differences may be quite widespread.

These evident differences in learning styles point to existing differences in cognitive styles and to the possibility of the CAI programs exploiting such differences.

The above comments also explain in great part the relatively large increase in achievement from low ability students to medium ability students in the SRG as well as the relatively small increase from medium to high ability students in the same group. Further, in view of the fact that a branching program is much superior to a linear program in exploiting differences in learning rates, background knowledge and cognitive styles, the same comments may account for the relatively superior but stable achievement over all ability levels in the IRG. The superior achievement of the high ability students within DRG may indicate that these students are not as dependent on individualized instruction as students of lesser ability.

Treatment x Knowledge Level Differences. The superior achievement of the IRG students would appear to be due primarily to the cybernetic facility built into their program and secondarily to an adaptation to individual differences in rate and in knowledge acquisition. The differential application of these two facilities in the two CAI groups would, moreover, explain the superior achievement of the IRG students over the DRG students.

Treatment x Algorithmic Level Differences. The same two facilities of CAI--maximized in a branching program--would give CAI students a distinct advantage in algorithmic items. Meaningful branching may also assist students to recognize algorithmic types, thus giving them a further advantage in problems involving the application of an algorithm. One would expect, therefore, that any superior achievement on algorithmic items should appear in the group of IRG students.

Achievement Differences due to Progress. The significantly higher achievement of the faster over the slower group of CAI students is explained readily by an examination of the constitution of the two groups. The fast group, being made up of nine high ability students, three medium ability students and three low ability students, presumably had the greater achievement potential and, therefore, should have achieved higher scores. One could infer, however, that rapid progress through the material is accompanied by a mastery of that material. This inference is open to some question, though, since some of the scores in the slower group were considerably higher than some of those in the faster group. The range of scores in the former was from 26 to 62, while in the latter it was from 29 to 73.

Summary Statements. The profiles of cell means in the treatment x ability grouping (Figure 6, page 112) suggests that the CAI programs may have been more suitable for low ability students and that, in the case of the IRG program, a ceiling on achievement may have been imposed on the brighter students. The rather uniform achievement of the high ability students over all treatments may indicate that these students are attuned to feedback, the source, format, and sequence of feedback not being so critical for them, and that they are better able to sift out relevant information and theory regardless of the method of instruction.

Educational Implications

Theoretical Implications. The experimental findings of this study have lent significant support to the underlying theoretical framework outlined in Chapter III. The verification of the key hypotheses has added considerable confidence in the postulates from which they were deduced. The following assumptions of the theoretical rationale, in particular, appear to be substantiated by the data of this research:

1. Variations in learning rate and background knowledge play an important role in the learning of an individual. Instruction which takes such variation into consideration should prove to be superior to instruction which disregards it.

2. Cybernetics as a prominent contributing factor to success in instruction appears to be a very reasonable tenet of educational theory. Relevant feedback, according to this assumption, contributes materially to the learning of the student. Considerable credence has been given to cybernetics as sound educational theory by the findings of this study.

3. Many education theorists today maintain that progress in learning is dependent in part on the adaptation of instructional style to the cognitive styles of the learners. Some support for this assumption is given in this study by the actual performance of

individual students. Because cognitive style is involved particularly in higher level thinking, its contribution to achievement has received some support from this study. Such support, however, is inconclusive since the differences between treatments at the problem solving level were not significant.

In addition to the theoretical implications originating from the objectives of this investigation, there are those which arise out of other aspects of CAI. Some of these speak in favor of CAI, others militate against it. Brown (1969) has outlined a number of these aspects. The present study agrees with Brown's conclusions regarding programming time, which can be a very serious drawback to the use of CAI, and regarding social participation, the lack of which can also become a negative feature of this mode of instruction when it is used extensively.

Three aspects, mentioned by Brown, did not appear to have had particularly detrimental effects in the present experiment. The first of these is the psychological threat which the computer is supposed to present to some students. Dick (1970) suggests that "because of the highly 'electronic' nature of CAI, it might be expected that, at least during early exposure to the medium, boys would be more interested in the device while girls might be intimidated (p. 35)." Neither Dick's nor Brown's fears received any substantiation in the study at hand. Responses and comments of the participating students to the questionnaire did not reveal any concerns of the type mentioned.

Whereas Brown maintains that complex human endeavors cannot be analyzed into precise units suitable for presentation by a mechanical device, results from the two programs indicate that even a mathematical concept as complex as logarithms can be taught effectively by mechanical presentation.

Brown, in paraphrasing Gentile, speaks of no CAI theory from which learning principles can be deduced appropriate to the situation, concluding that "finally and most crucial, adaptation to individual differences must prove itself superior to teaching aimed at the mean of the group (p. 20)." The findings of this investigation show that CAI is indeed superior for low ability students to teaching aimed at the mean of the group and is at least as good for medium and high ability students.

Practical Implications. The strategies which have been outlined earlier and which were employed in the CAI treatments have shown that they can hold their own as educational strategies and that they are superior to the more conventional strategy in many instances. Specifically, this study has indicated that computer assisted instruction can produce better achievement in factual and algorithmic materials and at least as good achievement in higher level thinking as can classroom instruction. It has shown further that low ability students learn more readily from CAI than from classroom teaching.

The practical implications are clear. Since CAI can be used very effectively in teaching material at different levels of sophistication to students who vary greatly in achievement and ability, it behooves educators to promote the use of CAI wherever it is economically feasible and administratively practical.

<u>Cost Analysis</u>. Programming and equipment costs are factors to be considered in any attempt to use CAI. The time involved in writing the linear program used in this study may give the reader some appreciation for the programming costs. A conservative estimate of the researcher's time spent at writing the basic program would be 1200 hours. At a conservative $4.00 per hour, the cost for producing this 10-hour program would be $4800.

It should be noted that this cost would not be exhorbitant if terminal facilities were available to serve a large body of students. Given such facilities, the above-mentioned $4800 could be used to serve 4800 students, thus averaging a mere $1.00 per student for an instructional period of ten hours. Equipment costs, of course, would have to be added to the above and would raise the cost per student appreciably.

One should also note that the writing of a branching program, after the basic program has been written, requires considerably less time. Even a rather liberal estimate of the number of hours used in inserting the required branches to the linear program of this experiment would certainly not exceed 200 hours. Thus both linear and branching programs could be produced at an approximate programming cost of $5600.

3. CONCLUSIONS

Before stating the conclusions, the writer wishes to draw attention to the very conservative nature of several features of this study. Firstly, the writer's experience as a teacher is certainly much superior to his experience as a programmer. Whereas he had fourteen years as a teacher to assist him in teaching the group designated SRG, he had only the experience gleaned from APL programming during the course of the pilot study to guide him in devising the program. It is reasonable to assume that the good results obtained from the IRG and the DRG would be decidedly better if the experience of fourteen years of programming could have been incorporated into the two programs. Further, it is quite possible that the quality of the branching program would be affected most by this lack of experience. One might assume, therefore, that the IRG students would have benefitted most from the added experience and that the rather stable achievement of the IRG might also have shown a distinct and even significant upward trend.

Secondly, the Scheffe's test is considered generally to be quite conservative as a test for significant differences between means (Winer, p. 88). Thus the appearance of significant differences wherever the Scheffe test was applied should be construed to imply great confidence in the actual existence of differences between the groups being compared.

Keeping the above in mind, the following inferences appear to be valid conclusions from the data of the study.

1. The effectiveness of each of the three treatments considered in this investigation depends upon the ability level of the student. The disparity in achievement between treatments is greatest at the low ability level where the IRG is superior to DRG which, in turn, is superior to the SRG.

2. The IRG treatment is superior to both DRG and SRG at the knowledge level, superior only to the SRG at the algorithmic level, and superior to neither at the problem solving level.

3. When considering ability level as well as problem difficulty level, the only difference occurs at the knowledge and low ability level where the IRG is superior to both DRG and SRG.

4. Students progressing farthest in a CAI program score significantly higher on achievement tests, that is, program coverage is accompanied by content mastery to some extent.

5. No changes in attitude toward mathematics are produced by CAI in the course of a 10-hour instructional period.

6. No differences in attitude to CAI between IRG and DRG students are brought about in ten hours at the computer.

Generally, a well-written branching program induces significant branching on the part of individual students and produces superior results in achievement. A linear program, on the other hand, does have some distinct advantages over conventional classroom instruction.

4. RECOMMENDATIONS FOR FURTHER RESEARCH

The investigation and its results indicate a number of paths which future research might fruitfully pursue. These will be outlined briefly as a concluding section of this study.

Replications. The present study had many restrictions placed upon it. It should, therefore, be replicated in other schools, at other grade levels, and with other topics and subject matter. The investigation should also be extended to cover a longer period of time in order to ascertain the long range effects of CAI on achievement in regular curricular programs and on student attitudes toward CAI in mathematics. Such research could establish the extent to which the results of this study can be generalized as well as the degree of stability of induced attitudes.

Refinement. Several important characteristics of the treatment under investigation operated together to produce the results which have been reported. A number of investigations should be devised to ascertain the relative effectiveness of each of these features. These include problem difficulty level, abstractness of material, intermingling of theory and application, and learning styles.

Such separation of features might answer questions such as the following: Would achievement at any given problem difficulty level be affected if instruction were confined to that level? Is CAI more effective for concrete material, or is achievement dependent to some extent on the degree of abstraction? What kinds of skills and information are best imparted through CAI? Would the separation of theory from application and practice produce different results? Are any learning styles more effective through CAI than other styles, and how can these styles be implemented to best advantage in a CAI program? To what extent are the cognitive learning styles identified in a study by Dienes and Jeeves (1965) related to student performance and preference?

Closely related to the last query is the question, do students learn more effectively from written instructions than they do from oral instructions by a teacher, or are the superior results reported in the study due to other considerations?

Learning Factors. What factors affect a student's ability to learn through CAI? Are these factors related in some way to personality variables? Do aggressive students, for example, prefer CAI where they can be somewhat more active and where they can work more individually and independently?

What has been the relative contribution toward the superior results obtained in the experiment of each of the four bases mentioned under theoretical rationale outlined in Chapter IV? How important is it to exploit variations in learning rates and background, to utilize cognitive styles, to employ cybernetics and to transmit important gestalts in the process of instructing individuals?

Of what importance is attending behavior in CAI? Is it different in CAI than in more conventional instructional modes? Does it deteriorate, remain constant, or improve as CAI is used more and more extensively? What features of CAI contribute to the attending behavior of students learning by this mode of instruction?

Branching. How is the branching facility of the computer used most effectively in CAI? Should more choice be given to the student in determining the direction and the content of the instruction to be presented, and are students mature and insightful enough to make intelligent decisions? Is there an optimum amount of branching and, if so, does this depend on the ability and the personality of the student? Should branching incorporate more differentiation in types of activities, in kinds of assignments and in complexity of theory?

Combination of Methods. Research should be designed to determine which objectives of mathematics learning are most appropriate to CAI. Which mathematical concepts, for instance, are taught more efficiently by CAI than by classroom instruction? Which ideas would be taught best by using some combination of CAI and teacher instructions? If a combination is used, what are the relative merits of preceding classroom instruction by CAI and vice versa?

These and many other issues are crucial to the effective use of CAI in the future. It remains for research to find satisfactory answers for these questions.

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APPENDIX A

COURSE DESCRIPTION

1. Objectives
2. Content
3. Interdependencies of Topics

OBJECTIVES

1. To recognize a logarithmic function if the defining equation is in:
   a. exponential form, b. logarithmic form.
2. To be able to apply the relationship between the exponential and logarithmic functions; in particular, a. to change an equation in exponential form to one in logarithmic form and vice versa, b. to use such changes to solve simple logarithmic equations.
3. a. To sketch the graph of a logarithmic function.
   b. To recognize the graph of a logarithmic function from its characteristics.
   c. To interpret and to use the graph of a logarithmic function.
4. a. To recognize and b. to complete true statements concerning properties of logarithms, especially those related to:
   (i) the logarithm of unity
   (ii) the logarithm of a product,
   (iii) the logarithm of a quotient,
   (iv) the logarithm of a power (root)
   (v) logarithm of n as undefined when n is less than zero.
5. To prove the basic laws of logarithms.
6. To use tables in finding logarithms of numbers (base 10):
   a. To use scientific and decimal notation,
   b. To find the characteristic of the logarithm of a number,
   c. To find the mantissa of the logarithm of a number.
7. To find the antilogarithm of a logarithm.

8. To perform the following types of computations using logarithms:
   a. Multiplication,
   b. Division,
   c. Powers (roots),
   d. Combinations of the preceding.
9. To solve various types of non-routine problems involving one or more of the facts, skills and applications implied in the above objectives.

CONTENT OF THE COURSE

Basic Facts and Theory

1. Definition of the logarithm function
2. Relationship to the exponential function
   a. Graph
   b. Equivalent equations and functions
3. Properties of logarithms with respect to operations involving logarithms:
   a. Statements
   b. Proofs
4. Main types of logarithms
   a. Natural logarithms } Graphs
   b. Common logarithms }
      (i) Significance of position of decimal
      (ii) Significance of sequence of digits

Applications and Skills

1. Form changes
   a. Logarithmic to exponential
   b. Exponential to logarithmic
2. Solving for the unknown in $\log_x y=z$, where the unknown is:
   a. y, b. z, c. x
3. Evaluating expressions involving one or more logarithms
4. Validity of properties of logarithms illustrated

5. Alternative expression for one involving logarithms:

   a. Expand, b. Contract

6. Using the properties in solving sentences involving logarithms

7. Simplifying expressions using the properties of logarithms

8. Finding logarithms using Knott's Tables:

   a. Scientific notation, b. Characteristic, c. Mantissa

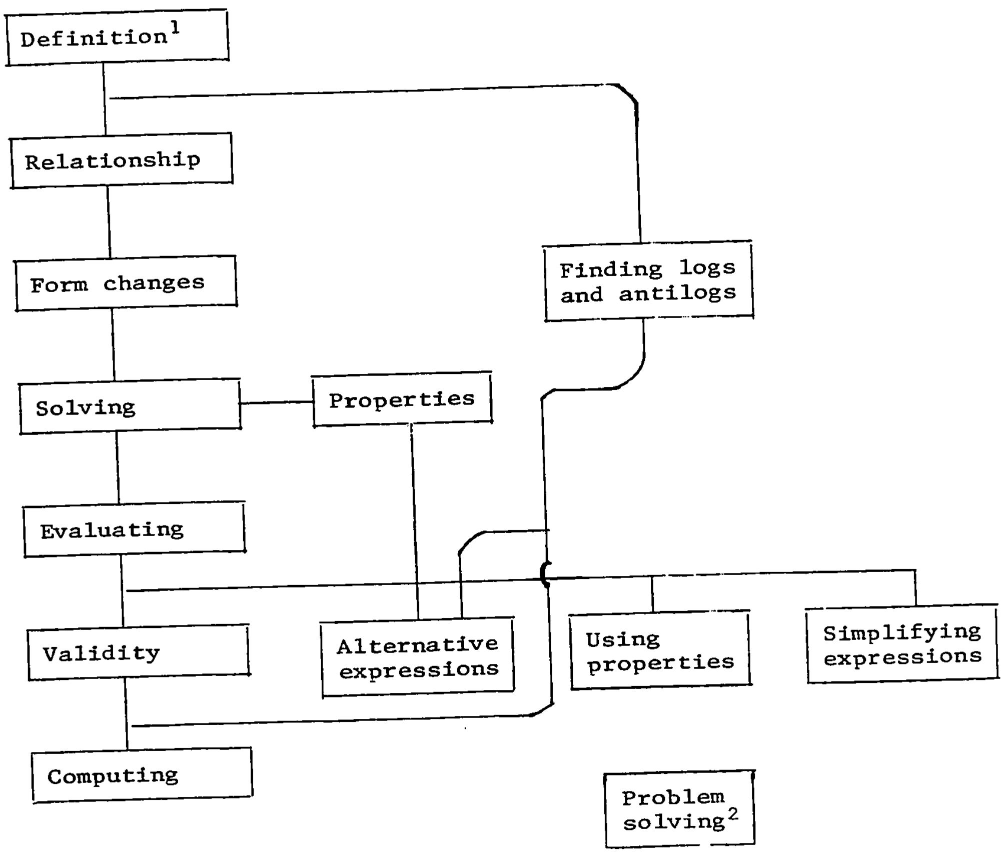
9. Finding antilogarithms, using Knott's Tables:

   a. Determining the sequence,

   b. Placing the decimal

10. Computing with the aid of logarithms

11. Non-routine problem solving, interspersed among the above



1. Words used for topics are the initial words of each of the main topics in the table of contents.

2. Problem solving, since introduced at various levels, may depend on any one or a number of the above topics.

Figure 9

Main Interdependencies Among Topics

APPENDIX B

TREATMENTS INFORMATION

1. Basic Program
2. Description of Loops
3. SRG Instructional Activities

OUTLINE OF BASIC PROGRAM

A. Relationship to exponential function

1. Definitions compared
2. Defining equations compared
3. Practice
4. Domain and range compared
5. Practice
6. Graph
7. Important characteristics of graph and function
8. Interpretation and use of graph
9. Check on knowledge

B. Definition of logarithm

1. Examples
2. Practice
3. Definition
4. Quiz

C. Form changes

1. Examples: log equations to exponential equations
2. Examples: exponential equations to log equations
3. Practice
4. Quiz

D. Solving $\log_x y=z$

1. For y, given x and z }
2. For z, given x and y } errors → hints → try again
3. For x, given y and z }
4. Quiz, including more difficult items

E. Evaluating expressions

1. Examples involving one logarithm
2. Practice
3. Example involving two or more logarithms
4. Practice
5. Quiz

F. Properties of logarithms

1. Statement
2. Proof
3. Check on knowledge, including some proofs by completion
4. Review of basic properties

G. Alternative expressions using the properties

1. Introductory comments and explanations
2. Example: expand
3. Practice
4. Example: contract
5. Practice
6. Quiz

H. Validity of properties illustrated

1. Example
2. Exercises

I. Solving for x, using the properties

1. Examples

2. Exercises

J. Simplifying expressions, using the properties

1. Examples using expansion

2. Examples using contraction

3. Practice

K. Using Knott's Tables

1. Scientific notation

a. Review

b. Practice

c. Relationship to logarithms

2. Characteristic

a. Relationship to scientific notation

b. Practice

c. Quiz

3. Mantissa

a. Use of tables

b. Practice

c. Quiz on characteristic and mantissa

4. Antilogarithm

a. Use of tables

b. Placing decimal

c. Practice

d. Quiz

L. Computing with the aid of logarithms

1. Types: Multiplication, division, etc.

2. Sequence for each

a. Illustration

b. Practice

c. Quiz

M. Enrichment, including problem solving

DESCRIPTION OF LOOPS

Loop 1. The student scored too low on the ability to change the form of the logarithmic equations. Theory is presented again, and a set of ten questions is given to the student.

Loop 2. The student scored too low on equivalent exponential equations. More practice is given, and the student is branched back to Loop 1 if his score is still too low.

Loop 3. The student is given the option of attempting the proof of the quotient property of logarithms.

Loop 4. The student is given further practice in applying the basic properties of logarithms. If the student shows specific weaknesses, he is branched according to the need revealed.

Loop 5. The student is given further assistance and practice in solving logarithmic equations.

Loop 6. The student has shown insufficient mastery of scientific notation for numbers. The instruction and the quiz are repeated. If the student still does not meet the requirements, theory from a different point of view followed by a new quiz is presented.

Loop 7. Too many errors on the determination of the characteristic introduces more practice with the option of further instruction before attempting the new set of problems.

Loop 8. The student, having scored less than 80% on the mantissa quiz, is given the option of further instruction before attempting more problems. If he chooses not to and scores less than 80% on the new set, he is branched back to the instructions.

Loop 9. A score of less than 80% on logarithms shunts the student to a second set of 20 questions. The answers are analyzed and the student still having too many errors is looped back on the basis of error type.

Loop 10. A further set of ten questions on antilogarithms is presented to the student whose score is less than 80%. Other students are given the option of attempting this set also.

Loop 11. Students who obtained less than four of the six product and quotient computations are branched back on the basis of the wrong answers given. Others are given an option as to looping procedure.

Loop 12. The student is given the option of entering this loop, which consists of a set of more difficult computations.

Loop 13. A set of less difficult computations is presented to students who have not performed too satisfactorily on computations thus far. Those students solving the new set are given the option of entering loop 12.

Loop 14. All students have the option of a review of theory before proceeding with an examination of everything learned in the program. Each is allowed a maximum of four choices from the list presented to them.

Loop 15. All students making one or more errors in the set on computations are given the choice of attempting incorrectly solved problems again.

OUTLINE OF INSTRUCTIONAL ACTIVITIES CONDUCTED WITHIN SRG

Day 1.

1. Explanation of the project (10 minutes)
2. Importance of logarithms (5)
3. Review of powers (20)
    a. Properties
    b. Definitions
    c. Definition of exponential function
    d. Graph of exponential function
4. Introduction of logarithmic function (20)
    a. Comparison of logarithmic and exponential functions (10)
        i. Definition
        ii. Domain and range
        iii. Variables
        iv. Graph
    b. Two forms of the defining equation (10)
        i. Presentation
        ii. Practice

Day 2.

1. Review (10)
2. Quiz (15)
3. Characteristics of graphs of logarithmic functions (15)
    a. Domain and range
    b. Nature of the curve
    c. Relationship of logarithmic curves to exponential curves

4. Practice (10)

Day 3.

1. Question period (10)
2. Quiz (10)
3. Properties illustrated (20)
    a. Product
    b. Quotient
    c. Powers and roots
4. Practice (10)

Day 4.

1. Brief review of properties illustrated (5)
2. Two illustrations regarding the use of properties (7)
3. Problems for practice (8)
4. Quiz and discussion (15)
5. Proof of theorems (20)
    a. Presentation of theorem 1 (5)
    b. Student proof of theorem 2 (10)
    c. Presentation of theorem 3 (5)

Day 5.

1. Brief review of three theorems - in words (8)
2. Examples of application of theorems (10)
3. Practice (15)
4. Quiz and checking of answers (17)

Day 6.

1. Two systems of logarithms (8)
2. Presentation of a miniature logarithmic table (5)
3. Missing logarithms (5)
4. Two parts of a logarithm (5)
5. Characteristic of the logarithm (10)
   a. Scientific notation
   b. Obtaining the characteristic from scientific notation
6. Mantissa of the logarithm (20)
   a. Finding the mantissa, 3 digits
   b. Relationship to the sequence of digits

Day 7.

1. Review of characteristic and mantissa (5)
2. Use of the ADD column for the fourth digit (10)
3. Practice (5)
4. Quiz (10)
5. Checking of answers and discussion (7)
6. Antilogarithms (13)
   a. Meaning
   b. Sequence of digits
   c. Placement of decimal

Day 8.

1. Relationship of antilogarithms to logarithms (12)
2. Practice with antilogarithms (4)
3. Quiz on antilogarithms (10)
4. Checking of answers and discussion (8)
5. Introduction to computations using logarithms (4)
6. Computations; products (12)
    a. Example
    b. Practice

Day 9.

1. Attitude questionnaire (12)
2. Review (12)
    a. Properties of logarithms
    b. Computing products
3. Further computations (30)
    a. Division (8)
    b. Powers (5)
    c. Roots (9)
    d. Computations (8)

APPENDIX C

TESTS AND MEASUREMENTS

1. Achievement Test: Logarithms A
2. Achievement Test: Logarithms B
3. Attitude to Mathematics Test: A Mathematics Study
4. Attitude to CAI: Computer Sessions Questionnaire
5. Categorization of Examination Items

Name ____________________

Block: ________

Math 20 Logarithms A

A. Select the correct alternative and place the corresponding letter in the blank at the left. (2 marks each)

____ 1. Log 1000 = a) 0 b) 1 c) 2 d) 3

____ 2. Log $10^{0.4562}$ = a) .4562 b) $10^{.4562}$ c) 10 d) 1.4562 e) 4.562

____ 3. If $\log_b 10 = p$ and $\log_b 2 = q$, then $\log_b 20$ = a) pq b) p + q
c) p^q d) q^p e) 2(p+q)

____ 4. Which of the curves on the right would be the graph of $\{(x,y) \mid y = \log_2 x, x \in +R\}$?

____ 5. $\log_x 1$ = a) x b) 1 c) 0 d) $\frac{1}{x}$

____ 6. Log $\sqrt{B}$ = a) 3 log B b) $\frac{\log B}{3}$ c) $\sqrt{\log B}$
d) $\frac{\log B}{\log 3}$ e) $\log \frac{B}{3}$

____ 7. Log 2a = a) 2 log a b) log a + log 2
c) log 2 + a d) a log 2 e) log (2 + a)

____ 8. If $\log_m 7 = \frac{1}{3}$, then the value of m is a) 49 b) 2.333
c) 21 d) 343 e) 1.913

____ 9. If $\log_x y = 1$, then x = a) 0 b) 10 c) y d) 1

____ 10. Given the function $\{(x, y) \mid y = 3^x, x \in R\}$, which of the following is the defining equation of the inverse function?
a) $y = 3^{-x}$ b) $x = 3^{-y}$ c) $y = \frac{3}{x}$ d) $y = 3^{1/x}$ e) $x = 3^y$

____ 11. Solve for x, using logarithms: $x = \frac{0.7365}{0.0038}$ a) -1+.8672
b) -4+.2874 c) 2.2874 d) 193.8 e) 189.4

____ 12. Log $3^x \cdot 3^x$ = a) $\log_3 x^2$ b) 2 log 3^x c) log 9^{2x} d) 2 log 9^x

____13. The value of $5^{\log_5 125}$ is a) 3 b) 5 c) 125 d) $\frac{1}{3}$

____14. Solve for x: log 2x − log 15 = 1 − $\log_3 x$ a) $\sqrt{\frac{15}{6}}$ b) 25

c) 5 d) none of these

____15. $\text{Log}_2 2^3$ = a) 8 b) 2 c) 3 log 2 d) 3 e) 9

____16. If log 21.7 = 1.3365 and log 2.16 = 0.3345, then log $\frac{21.7}{2.16}$ =

a) 1.6710 b) .0020 c) 1.0020 d) 3.9955

____17. $\frac{1}{2}$ [2 $\log_a$ b + $\frac{1}{3}$ $\log_a$C − 3 $\log_a$d] = a) log $\sqrt{\frac{b^2 \sqrt[3]{C}}{d^3}}$

b) $\log_a \sqrt{\frac{2bc}{9d}}$ c) $\log_a \sqrt{\frac{b^2 + \sqrt[3]{C}}{d^3}}$ d) $\log_a \sqrt{\frac{b^2 \sqrt[3]{C}}{d^3}}$

____18. If $\log_{10} x$ = 2, then x = a) 2 b) 4 c) 12 d) 20 e) 100

____19. If y = $\log_2 x$ and z = 2^x, then a) y < z b) y > z

c) $|y|$ < z d) none of these

____20. Log_b x is undefined for <u>all but one</u> of the following − which is the one? a) x = 0 b) x < 0 c) b = 1 d) b = 0 e) b < 0

B. Answer the following. Show any important steps. (Marks as shown)

(2) 21. The antilog of −2 + .4871 is ____________.

(3) 22. Find the characteristic of log N if:

a) N = 631.5 x 10^{-5} The characteristic is __________.

b) N = 346.2 x 8.421 x .00542 The characteristic is _________.

(2) 23. If log N = z, then N is called the _________ of z.

(3) 24. What is the X- intercept of the graph of y = log x?

(4) 25. Express in terms of the logs of the letters involved:

a) $\log \pi r^2 =$

b) $\log\sqrt{M N^3}$

(3) 26. How many digits are there in the numeral corresponding to 3^{50}?

(3) 27. Simplify: $10^{1 + \log 10}$

(2) 28. If $\log_b x^2 = 1.7802$, what is $\log_b x^3$?

(2) 29. Given $\log_z 3 = 0.4712$, calculate $\log_a 3^8$.

(4) 30. For what values of x does it hold that:

a) $\log_c x = 0$?

b) $x^{\log_x C} = C$?

(3) 31. If $10 < x < 100$, what is the range of $\{(x,y) \mid y = \log x\}$?

(3) 32. Comment on the solution set of the system of equations:

$\{y = x$
$\{y = \log x$

(4) 33. Complete the proof below by filling in the blanks:

Theorem: $\text{Log}_a b = \log_c a \cdot \log_a b$

Proof: Let $\log_a b = m \leftrightarrow$ __________

Let $\log_c a = n \leftrightarrow$ __________

$\therefore a^m =$ ______ $= b$

$\therefore c^{\_\_} = b$

Hence $\log_c b =$ ______ $\cdot$ ______

i.e. $\log_c b =$ ______ $\cdot$ ______

(4) 34. If $f(x) = 3^x$ and $g(x) = \log_3 x$, find:

a) $f[g(x)]$

b) $g[f(x)]$

(4) 35. Solve the system: $\{ \log_3 x + \log_2 y = 5$
$\{2 \log_3 x - \log_2 y = 1$

(4) 36. In how many years will \$100 double itself if it is invested at 4% compounded annually?

Name ____________________

Block: ________

Math 20 Logarithms B

A. Select the correct alternative and place the corresponding letter in the blank to the left. (2 marks each)

____ 1. The characteristic of log .00027 is a) -4 b) -3 c) -5 d) .4314

____ 2. If log 6.72 = 0.8274, then antilog 3.8274 is a) 6720 b) 827.4 c) 3 d) 6.72

____ 3. The statement $5^4 = 625$, written in logarithm, would read a) $\log_4 625 = 5$ b) $\log_5 4 = 625$ c) $\log_4 5 = 625$ d) $\log_5 625 = 4$

____ 4. How many zeros precede the first significant digit in N if log N = -20 + .3562? a) -20 b) 20 c) 19 d) 21

____ 5. Log $\sqrt[3]{.0479}$ = a) .8934 b) -1 + .5601 c) .3632 d) 7.823 e) -.8934

____ 6. Log 1 = a) $10^1 = x$ b) 0 c) 1 d) 10

____ 7. The graphs of the functions $y = 2^x$ and $y = \log_2 x$ are symmetric about: a) the Y-axis b) the X-axis c) the line, y = x d) the line, y = -x e) none of these.

____ 8. If log x = a, then log $\sqrt[3]{x}$ = a) $\sqrt[3]{a}$ b) 3a c) $\frac{a}{3}$ d) a-3

____ 9. If a ≠ 0, then $\log_a a$ = a) 0 b) 1 c) -1 d) undefined

____10. The graph of the function {(x,y) | y = log x } passes through: a) the origin b) quadrants 2 & 4 c) quadrants 1, 2 and 3 d) quadrants 1 & 4 e) quadrants 3 and 4

____11. If $\log_{64} x = -\frac{3}{2}$, then x = a) $\frac{1}{512}$ b) $\frac{1}{10}$ c) -512 d) $-\frac{1}{16}$

____12. Log $\sqrt{\frac{32^3}{6}}$ = a) 2 (3 log 32 - log 6) b) $\frac{3}{2}$ (log 32 - log 6) c) $\frac{1}{2}$ ($\frac{1}{3}$ log 32 - log 6) d) $\frac{1}{2}$ (3 log 32 - log 6)

____13. $\log_3 10$ = a) 0.4771 b) 1.4771 c) 9.5229 d) 2.4771 (e) 2.096

____14. If log x = log 1 + log 2 + log 3 + log 4 + log 5, then x = a) 6 b) 15 c) 36 d) 55 e) 120

____15. If $-1 + .7521$ is subtracted from $-3 + .4695$, the answer is a) .7174 b) $-1 + .7174$ c) $-2 + .7174$ d) $-3 + .7174$

____16. If $\log_2 64 = 2x$, then x = a) 3 b) 6 c) 12 d) 16 e) 32

____17. If $\log_3 3x = \log_3(2x + 3)$, then 2^{-x} = a) 3 b) $\frac{1}{8}$ c) 8 d) $\frac{1}{3}$ e) 3

____18. $\text{Log}_2 \sqrt{32 \times 512}$ = a) 6 b) 7 c) 8 d) 9 e) 10

____19. Antilog 3 = a) .1995 b) 1.995 c) 477.1 d) 1000

____20. Which one of the following graphs could depict f^{-1} if $f = \{(x,y) \mid y = \log_2 x, x \varepsilon {}^{+}R\}$

B. Answer the following. Show any important steps. (Marks as shown)

(2) 21. The log of a number is positive if the number is ____________.

(3) 22. Given that log 2.112 = 0.3247, state the number whose logarithm is

a) 2.3247 The number is ____________.
b) $-.6753$ The number is ____________.

(2) 23. If log N = 2.7361 and log M = $-4 + .5684$, find $\underline{\log}$ M N

(4) 24. Write two forms of the defining equation of the inverse function of $\{(x,y) \mid y = 2^x, x\varepsilon \, {}^{+}R\}$.

(3) 25. a) Which is the greater, $\left(\frac{3}{2}\right)^{20}$ or 10^3?

b) By how much is it greater? (Use 4 significant digits)

(2) 26. If $0 < x < 1$, then the range of the function, log x is __________.

(3) 27. What is the slope of the graph of $\{(x,y) \mid y = \log x\}$ at the point (1, 0)?

(2) 28. Express as a single logarithm: $\log_b a + \log_b 5 - \log_b 3$

(2) 29. Write an equivalent equation which does not involve logarithms: $\log t = \log \pi + \frac{1}{2}(\log \ell - \log g)$

(4) 30. Solve the system of equations: $\begin{cases} 5^{x+2y} = 25 \\ \log_2 (x+y) = 2 \end{cases}$

(3) 31. Express y in terms of x, given that $\log y - \log x = 2$

(4) 32. Solve for x: $\log (x - 3) + \log x = \log 28$

(4) 33. By filling in the blanks, complete the proof below:

Theorem: $\log_b N^p = \log_b N$

Proof: Let ____________ $\leftrightarrow b^r = N$

$\therefore N^p =$ ____________

$\therefore \log_b N^p =$ ____________

i.e. $\log_b N^p =$ ____________

(4) 34. The volume of a sphere is given by the formula, $V = \frac{4}{3} \pi r^3$

Find the ratio of the radii of 2 spheres whose volumes are 768 c.c. and 225 c.c.

(4) 35. Simplify: $\log (x + \sqrt{x^2 - 1}) + \log (x - \sqrt{x^2 - 1})$

(4) 36. The number of bacteria in milk doubles every 3 hours. If the number of bacteria at mid-day is N, what is the number of bacteria at mid-day one week later. (Use 4 significant digits in your answer.)

A MATHEMATICS STUDY

The best answer to each statement is your own first impression. There are no right or wrong answers. Your responses will be kept confidential. (Your teacher will not see them; the results will in no way affect your grades.)

Think carefully but do not spend too much time on any one question. Let your <u>own</u> personal experience guide you to choose the answer which best expresses your feeling and/or experience.

Do not write on the question booklet.

PLEASE MARK A RESPONSE FOR EVERY STATEMENT.

1. I find most mathematics lessons:
   a. extremely interesting.
   b. quite interesting.
   c. interesting.
   d. not very interesting.
   e. not interesting at all.

2. A knowledge of mathematics for any job at all is:
   a. most important.
   b. very important.
   c. quite important.
   d. of small importance.
   e. not important.

3. If I did not have to take mathematics, I would like school:
   a. much less.
   b. a little less.
   c. same as now.
   d. a little better.
   e. much better.

4. Mathematics is:
   a. the most important subject.
   b. one of the more important subjects.
   c. just as important as any other subject.
   d. not as important as some of the other subjects.
   e. the least important subject.

5. I find problem solving:
   a. extremely interesting.
   b. quite interesting.
   c. interesting.
   d. not very interesting.
   e. not interesting at all.

6. When I have difficulty with a new topic in my mathematics course, I ask my teacher to clarify the section:
   a. very frequently.
   b. frequently.
   c. sometimes.
   d. hardly ever.
   e. never.

7. If books about mathematics were available, I would:
   a. read most of them.
   b. read some of them.
   c. look at the diagrams and pictures.
   d. page through some of them.
   e. never look at them.

8. If someone says mathematics classes are worthless and a waste of time, I would:
   a. strongly disagree.
   b. tend to disagree.
   c. not take a side.
   d. tend to agree.
   e. strongly agree.

9. When I do my homework, my mathematics is:
   a. always done first.
   b. often done first.
   c. usually done first.
   d. sometimes done first.
   e. never done first.

10. I find mathematics puzzles:
   a. extremely interesting.
   b. quite interesting.
   c. sometimes interesting.
   d. not very interesting.
   e. not interesting at all.

11. I would be interested in taking other subjects that make use of:
   a. a great deal of mathematics.
   b. quite a bit of mathematics.
   c. some mathematics.
   d. a little mathematics.
   e. no mathematics.

12. If given the opportunity to join one of the following clubs, I would prefer a:
   a. mathematics club.
   b. science club (physics)
   c. science club (chemistry)
   d. science club (geology)
   e. literary club

13. If I could receive one of the following magazines for a year, I would pick:
    a. a mathematics magazine for high school students.
    b. a magazine combining science and mathematics for high school students.
    c. a science magazine for high school students.
    d. a geology magazine for high school students.
    e. a literary magazine for high school students.

14. When I study my mathematics course, I most often:
    a. make written summaries of the sections covered.
    b. do additional problem solving.
    c. do many drill questions.
    d. memorize the formulas given in the text.
    e. look over some work done previously.

15. If I listed my courses in order of preference, I would place mathematics:
    a. first.
    b. second.
    c. third.
    d. fourth.
    e. fifth.

16. Whenever mathematical problems are presented to us for solving, I get:
    a. a great deal of satisfaction in working them out.
    b. quite a bit of satisfaction in working them out.
    c. some satisfaction in working them out.
    d. very little satisfaction in working them out.
    e. no satisfaction in working them out.

17. My mathematics course has made:
    a. mathematics enjoyable for me.
    b. mathematics a pleasant course.
    c. me feel indifferent towards mathematics.
    d. mathematics an uncomfortable experience for me.
    e. me strongly dislike mathematics.

18. I feel my mathematics teacher:
    a. enjoys teaching mathematics.
    b. gets some pleasure in teaching mathematics.
    c. gets some satisfaction in teaching mathematics.
    d. neither likes nor dislikes teaching mathematics.
    e. dislikes teaching mathematics.

19. When I do mathematics homework, I am usually:
    a. keenly interested.
    b. interested.
    c. somewhat interested.
    d. not too interested.
    e. not interested at all.

20. When we start a new topic in mathematics, I am usually:
    a. extremely interested.
    b. interested.
    c. somewhat interested.
    d. not too interested.
    e. not interested at all.

21. The average amount of time I spend on homework assignment in mathematics takes the following time per day:
    a. more than one hour.
    b. 3/4 to one hour.
    c. 1/2 to 3/4 hour.
    d. 1/4 to 3/4 hour.
    e. 0 hours to 1/4 hour.

22. When I get an assignment in mathematics:
    a. I do it immediately.
    b. I do it eventually.
    c. I may get it done.
    d. I put it off as long as possible.
    e. I don't do it.

23. Most of my work in this class is done:
    a. to satisfy my curiosity about mathematics.
    b. to gain competence in mathematics.
    c. to get a good mark.
    d. to just pass the class.
    e. to put in the time allotted to mathematics.

24. During mathematics lessons, I feel:
    a. extremely confident in myself.
    b. quite confident in myself.
    c. confident in myself.
    d. a little unsure of myself.
    e. very unsure of myself.

COMPUTER SESSIONS QUESTIONNAIRE

The following are opinions which might be expressed by students who have worked on the computer. For each opinion, please circle whether you agree (A), are undecided (U), or disagree (D).

1. I enjoyed the computer periods.	A U D
2. Working at the computer has increased my mathematical knowledge.	A U D
3. I feel that I worked under less pressure in the classroom than at the computer.	A U D
4. The computer periods provided a welcome break from classroom routine.	A U D
5. I am not sure what I learned during the computer periods.	A U D
6. I was often bored at the computer.	A U D
7. I found the computer periods more interesting than regular work from a textbook.	A U D
8. I feel that I would be wasting my time often at the computer than in a classroom.	A U D
9. I learned to rely on myself more while working at the computer.	A U D
10. I enjoyed working on my own at the computer.	A U D
11. I liked working from typewritten instructions more than from teacher-given directions.	A U D
12. After several computer sessions, I become more confident in my ability to the questions and exercises without asking a teacher for help.	A U D
13. I think I would have understood each type of exercise better if the teacher had taught the class and then assigned practice work.	A U D
14. I would rather do assignments from a textbook than work at a computer terminal.	A U D

15. I see no value in the computer as far as the learning of logarithms is concerned. A U D

16. I believe that I would get bored sooner at the computer than in a math classroom. A U D

17. I believe that I would learn logarithms better in a classroom than at a computer. A U D

18. Using the computers in teaching math would make math more interesting to me. A U D

19. Using the computers for practice exercises would make the assignments less boring for me. A U D

20. Practice exercises are more effective when done in the classroom than when done at the computer. A U D

21. I was well satisfied with the computer as a teacher. A U D

22. I was well satisfied with the progress I made at the computer. A U D

23. While working at the computer, I often felt confused or lost because the theory was not clear to me. A U D

24. I felt that I was held back by the computer more than I would have been in a classroom. A U D

Rank the following items by using the number 1 to indicate best, the number 2 to indicate second best, the number 3 to indicate third best and the number 4 to indicate fourth best.

25. I liked working at the computer because:
    _____ it was something completely new to me.
    _____ it took me away from the classroom situation.
    _____ I didn't feel that my every move was being watched now.
    _____ it allowed me to work at my own rate.

26. I gained most from the computer because:
    _____ it checked most of my answers.
    _____ it made me rely more on myself.
    _____ it kept a record of my progress for most exercises.
    _____ it gave me confidence that I was making good progress.

Rank the following as drawbacks in computer learning, Use 1 to indicate least, 2 to indicate second least, . . . 4 to indicate greatest drawback.

27. _____ difficulty in reading from the screen (finding place, etc.)
    _____ difficulty in typing answers (finding keys, etc.)
    _____ inflexibility of the computer (that is, the computer not accepting answers which were different but correct forms of the required answer.)
    _____ time wasted waiting for questions.

28. The aspects which I like least about computer learning were:

29. The aspects which I like most about computer learning were:

30. If you have any suggestions for improvements on a second try of this kind, write them in the space below.

CATEGORIZATION OF EXAMINATION ITEMS

Categories

Factual items. A factual item requires pure recall or repetition of facts, relationships, and/or procedures in the exact form in which they have been presented previously.

Algorithmic items. An algorithmic item requires the knowledge and application of a previously studied algorithm, sequence of steps, or generalized approach to a problem.

Problem solving items. A problem solving item requires the student to go beyond facts and algorithms, thereby involving him in an analysis or synthesis of the problem in order to discover a new approach or technique or to use some novel combination of facts and algorithms.

Criteria

For a detailed description of these items and illustrations of each, the reader is referred to Avital's knowledge items (factual), comprehension and application items (algorithmic), and open search items (problem solving). They are described fully by Avital (1968) in Chapters II, III, and IV. Key ideas and phrases are as follows.

Knowledge items "Knowledge, the lowest category, involves pure recall or repetition of material in the exact form in which it was presented. Memorization of facts, definitions, rules, procedures, and theories falls into this category, but if the student is expected to translate a fact into a new form or to recognize a rule stated in a different way from that in which it was presented, he is demonstrating performance in a higher category (p. 8)."

Algorithmic items "The categories of Comprehension and Application are those in which the material requires the psychological process of generalization or simple transfer. The difference between the two categories in the amount of novelty in the new situation as compared with the situation from which the concept must be transferred or generalized.

In mathematical performance, the use of algorithms such as manipulative skills, the production of examples to illustrate given definitions or statements, and the passage from words to mathematical symbols and vice versa are all cases of comprehension, provided the basic statements or rules involved have been learned before, that is, are items of knowledge (p. 10)."

Problem solving items "At both levels of algorithmic thinking, Comprehension and Application, the student has readily available a step-by-step procedure which leads from the problem to its solution. To perform well at this level the student needs an accumulation of well-comprehended knowledge composed of appropriate procedures, algorithms, and references in the form of words or other symbols so that when such a referent or algorithm is needed, it can easily be retrieved and applied. When no straight forward procedure or algorithm provides a complete solution, we deal with higher-level problem-solving mechanisms. Analysis and Synthesis, the two higher-level categories of our application of the *Taxonomy* to mathematics, embrace this type of problem-solving. . .

A way needed for solving the given problem. The essential characteristic is nonroutine manipulation of previously learned material and, at a higher level, discovery of relationships among previously unrelated concepts and propositions.

These criteria make clear once again that the student's previous learning is decisive in determining to what category a given problem belongs. The availability of a large number of rules and experience with combinations of such rules can make a problem much less complex by bringing it down to the level of stimulus generalization.

The difference between algorithmic thinking and open search is essentially that between *reproductive* and *productive* thinking. This description of the two levels may be the most useful to the teacher in attempting to use our classification of mathematical performance if the student must simply *reproduce* a fact or a well-defined procedure that he has been exposed to, his performance is on the level of Knowledge or algorithmic thinking (Comprehension or Application). If the student must *produce* something that is entirely new to him, he will be engaged in higher-level problem-solving (p. 19)."

APPENDIX D

FINDINGS RELATED TO THE STUDY

1. Student Comments Relative to CAI
2. Student Rankings of CAI Aspects
3. Branching Loops Entered by IRG Students
4. F Values in Applying Hartley's F_{max} Test
5. Treatment x Problem Difficulty Profile
6. Ability x Problem Difficulty Profile
7. Response Performance on Major Assignments

COMPILATION OF STUDENTS' COMMENTS TO OPEN-ENDED QUESTIONS ON COMPUTER SESSIONS QUESTIONNAIRE

#28 The aspects liked least:

1. Inability to question the computer or to go back to material presented earlier
2. Inflexibility of the computer in its acceptance of answers
3. Timing too fast on some of the questions ("but really I am too slow.")
4. Time lapse between space bar and the next display
5. Lack of opportunity to correct mistakes
6. Bus ride (a Kindergarten bus!)
7. "No aspects I didn't like."

#29 The aspects liked most:

1. Ability to proceed at one's own rate
2. Correction of mistakes and the explanation of errors made
3. Change from the classroom - a break from routine
4. Experiment was interesting and made mathematics fun ("I didn't get bored.")
5. Opportunity to work on one's own
6. Branching back when the material was not understood
7. Freedom from worry about giving wrong answers
8. Ability to keep one's attention
9. Computer forcing one to work ("Had to work much harder than in the classroom")

10. Method enabling one to remember learned material
11. Immediate checking of answers
12. Absence of real pressure to work - a desire to work instead
13. Individualized instruction resulting in better understanding
14. Clarity of instructions, "not like some teachers"
15. "Cool sayings, like 'Relax! Big Brother ain't watching you!! That was neat; all in all, it was cool."

#30 Suggestions for improvement (other than those implied in #28):

1. Should be used in chemistry and science
2. Should spend more time each day learning at the computer, perhaps the full 80 minutes - 55 minutes <u>not</u> enough
3. Should introduce more examples, including some harder ones
4. Possibly should give more encouragement, "although I had fine encouragement"
5. "I don't know how you could improve it. I thought the whole idea was great." (Note: this last comment came from a student who was very reluctant about becoming part of the experimental group.)

TABLE XVII

GAI STUDENTS' RANKINGS OF SEVERAL ASPECTS OF COMPUTER LEARNING

#25	A	2*	1	1	3	2	1	1	2	2	2	1	4	1	1	2	4	2	4	1	3	1	3	3	1	4	2	54**
	B	3	2	2	2	3	2	2	3	4	4	4	3	2	2	4	3	1	3	2	1	2	4	2	3	2	3	68
	C	4	3	4	4	4	3	3	4	3	3	3	2	3	3	3	2	4	2	4	4	3	2	4	4	3	4	85
	D	1	4	3	1	1	4	4	1	1	1	2	1	4	4	1	1	3	1	3	2	4	1	1	2	1	1	53
#26	A	4	1	2	1	1	1	1	2	2	2	3	2	1	1	4	3	2	3	3	1	1	2	2	1	2	3	51
	B	2	2	1	2	3	2	3	1	1	3	1	1	2	2	1	2	1	2	1	3	2	1	4	3	1	1	48
	C	3	3	3	4	4	3	2	4	4	4	2	3	3	3	3	4	3	4	4	4	3	4	3	4	3	4	88
	D	1	4	4	3	2	4	4	3	3	1	4	4	4	4	2	1	4	1	2	2	4	3	1	2	4	2	73
#27	A	1	1	4	1	1	4	1	2	4	2	2	1	1	1	1	1	4	3	1	2	1	2	1	1	1	4	48
	B	3	2	1	2	3	3	3	3	3	3	3	2	2	2	4	2	2	2	2	1	2	1	2	3	2	2	60
	C	4	3	2	3	4	2	2	4	2	4	4	4	3	3	3	4	1	4	4	4	3	4	3	4	4	1	83
	D	2	4	3	4	2	1	4	1	1	1	1	3	4	4	2	3	3	1	3	3	4	3	4	2	3	3	69

* The lowest score indicates the greatest preference.

** Total for all students.

#25 I liked working at the computer because:
A. I didn't feel that my every move was being watched now.
B. it took me away from the classroom situation.
C. it was something completely new to me.
D. it allowed me to work at my own rate.

#26 I gained most from the computer because:
A. it kept a record of my progress for most exercises.
B. it gave me confidence that I was making good progress.
C. it checked most of my answers.
D. it made me rely on myself more.

#27 The drawbacks in computer learning from least to greatest are:
A. difficulty in reading from the screen (finding place, etc.)
B. difficulty in typing answers (finding keys, etc.)
C. time wasted waiting for questions.
D. inflexibility of the computer in accepting answers in different but correct form.

TABLE XVIII

LOOPS TAKEN BY INDIVIDUAL STUDENTS GROUPED ACCORDING TO ABILITY

High	sk 0	3	5	8	13				
	sk 1	4	5	8	9	10	11		
	sk 2	2	3	4	9	11			
	sk 9	1	2	3	5	8	9		
	sk 10	1	2	3	4	5	8		
Medium	sk 3	3	4	5	8	9	11		
	sk 4	3	5						
	sk 11	4	5	6	8				
	sk 12	3	4	11	12	13			
	sk 13	1	2	3	5	7	9	11	
Low	sk 5	3	5	7					
	sk 6	1	2	3	4	5	6	7	
	sk 7	1	2	3	4	5	7	8	9
	sk 8	1	2	3	5	7	8	9	
	sk 14	3	4	5	9	10	11		

TABLE XIX

COMPUTED F VALUES FOR TESTING THE HOMOGENEITY OF ERROR VARIANCE

		Low	Medium	High
SRG	Factual	292.8	56.0	96.0
	Algorithmic	129.0	46.0	98.8
	Problem solving	35.2	120.0	30.0
DRG	Factual	159.6	283.2	180.8
	Algorithmic	61.2	166.0	99.2
	Problem solving	102.8	8.8	38.8
IRG	Factual	99.8	212.8	58.8
	Algorithmic	136.0	110.0	67.2
	Problem solving	151.2	132.8	50.8

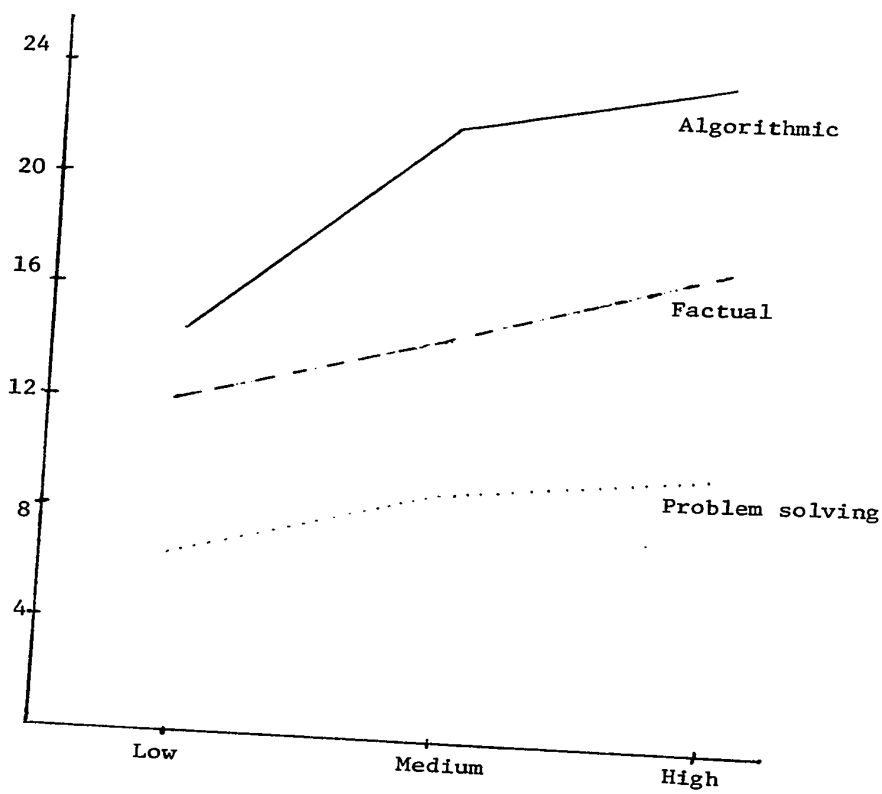


Figure 10

Profile of Cell Means in the Ability x Problem Difficulty Grouping

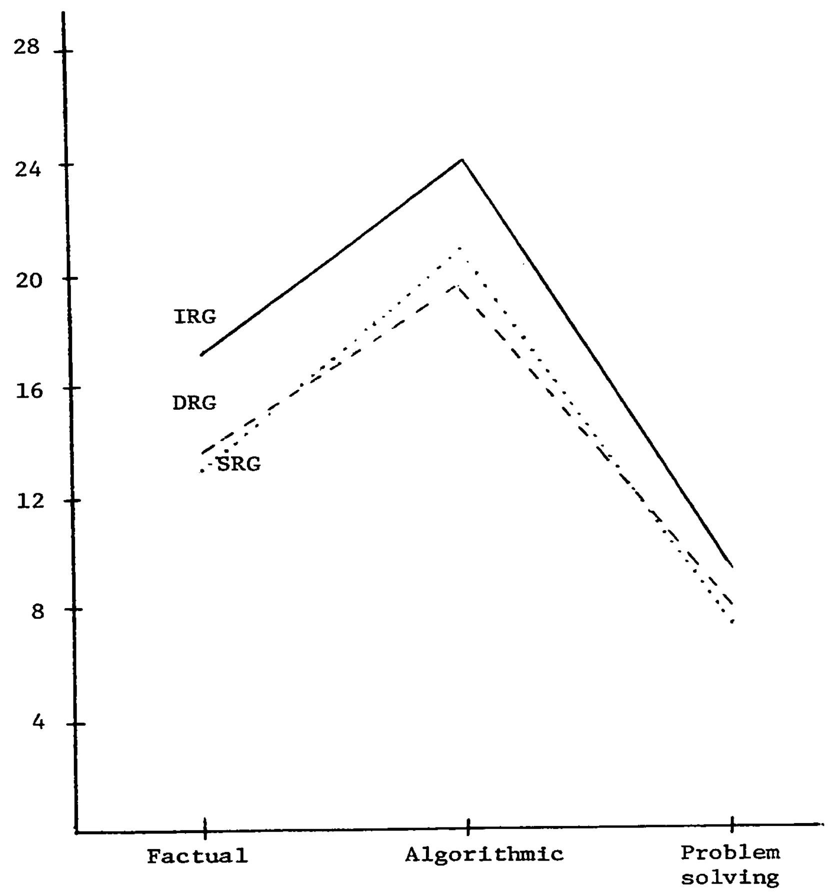


Figure 11

Profile of Cell Means in the Treatment
x Problem Difficulty Grouping

TABLE XX

STUDENTS' RESPONSE PERFORMANCE ON MAJOR ASSIGNMENTS

		Qu1	Sec10	Show6	Expa2	Char	Mant	Mant5	Log2	Anti2	Comp
sk 0	C	9	7	9	9	9	9	9	18	16	5
	W	0	0	0	0	0	0	0	0	0	0
	U	1	3	1	1	1	1	1	2	3	5
	T-O	0	0	0	0	0	0	0	0	0	1
sk 1	C	8	7	8	6	9	9	8	15	13	1
	W	0	0	0	0	0	0	0	0	0	0
	U	2	3	2	3	1	1	0	2	7	1
	T-O	0	0	0	1	0	0	2	3	0	0
sk 2	C	8	6	9	3	10	10	9	19	12	1
	W	0	0	0	0	0	0	0	0	0	1
	U	2	4	1	6	0	0	0	0	6	2
	T-O	0	0	0	1	0	0	1	1	2	1
sk 9	C	8	6	8	6	9	9	8	17	14	3
	W	0	0	0	0	0	0	0	0	0	0
	U	2	4	2	6	1	1	2	2	6	0
	T-O	0	0	0	0	0	0	1	0	0	0
sk 10	C	7	5	6	6	9	8	9	16	0	0
	W	0	0	0	0	0	0	0	1	0	0
	U	3	5	4	3	0	2	0	3	0	0
	T-O	0	0	0	1	1	0	1	0	0	0
sk 3	C	10	7	7	7	10	10	8	19	16	0
	W	0	0	0	0	0	0	0	0	0	0
	U	0	3	3	3	0	0	1	0	1	0
	T-O	0	0	0	0	0	0	1	1	3	1
sk 4	C	7	7	8	5	9	9	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0
	U	2	3	2	4	1	0	0	0	0	0
	T-O	1	0	0	1	0	1	0	0	0	0
sk 11	C	2	8	6	3	10	4	2	0	0	0
	W	0	0	0	0	0	0	0	0	0	0
	U	8	2	4	6	0	3	5	0	0	0
	T-O	0	0	0	1	0	3	3	0	0	0

TABLE XX (continued)

sk 12	C	8	9	8	3	10	10	10	16	17	5
	W	0	0	0	0	0	0	0	0	0	0
	U	2	1	2	7	0	0	0	3	3	5
	T-O	0	0	0	0	0	0	0	1	0	0
sk 13	C	5	7	8	6	7	7	9	16	7	0
	W	0	0	0	0	0	0	0	0	0	0
	U	5	3	2	4	3	1	0	3	9	2
	T-O	0	0	0	0	0	2	1	1	4	0
sk 5	C	8	7	8	8	7	10	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0
	U	2	2	2	1	2	0	0	0	0	0
	T-O	0	1	0	1	1	0	0	0	0	0
sk 6	C	5	4	7	6	7	7	0	0	0	0
	W	0	0	0	0	0	0	0	0	0	0
	U	5	6	3	4	3	3	0	0	0	0
	T-O	0	0	0	0	0	0	0	0	0	0
sk 7	C	10	5	8	3	6	6	8	19	9	0
	W	0	0	0	0	0	0	0	0	0	0
	U	0	5	2	6	4	3	1	1	10	0
	T-O	0	0	0	1	0	1	1	0	1	0
sk 8	C	9	6	7	5	8	9	7	18	16	0
	W	0	0	0	0	0	0	0	0	0	0
	U	1	3	2	4	1	1	1	1	2	0
	T-O	0	1	1	1	1	0	2	1	2	0
sk 14	C	7	7	8	6	10	8	9	15	14	0
	W	0	0	0	0	0	0	0	0	0	0
	U	3	3	2	4	0	2	1	4	5	0
	T-O	0	0	0	0	0	0	0	1	1	0

APPENDIX E

DATA USED IN THE ANALYSIS

1. Achievement Scores in the Treatment Groups
2. Scores on Remai's "A Mathematics Study"
3. Scores on the Computer Sessions Questionnaire
4. Summary of Responses on Key Exercises

TABLE XXI

ACHIEVEMENT SCORES IN THE TREATMENT GROUPS

	SRG			DRG			IRG		
	d_1*	d_2	d_3	d_1	d_2	d_3	d_1	d_2	d_3
High	28	28	10	8	20	1	22	30	20
	14	17	6	18	31	12	16	23	10
	0	14	11	12	24	14	18	30	8
	28	23	14	20	22	7	22	26	3
	26	22	12	24	26	10	10	16	5
Medium	14	21	10	14	26	9	22	29	11
	16	28	12	24	21	7	10	23	9
	22	21	18	2	17	6	8	17	5
	12	20	4	12	9	5	24	30	19
	16	20	6	6	22	7	12	26	8
Low	4	10	2	22	19	4	24	23	7
	0	12	8	4	20	6	16	15	6
	12	23	5	10	14	7	18	21	12
	10	16	1	8	28	12	22	23	13
	4	15	4	12	17	5	14	26	5

* d_1-Knowledge level, d_2-Analysis level, d_3-Problem solving level

TABLE XXII

IRG SCORES ON REMAI'S "A MATHEMATICS STUDY"

	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
sk 0	3	3	4	3	3	4	3	5	4	3	5	5	2	4	4	4	4	4	3	5	5	4	84*
	4	4	3	4	5	1	1	3	4	5	3	1	1	3	3	3	3	3	2	3	3	3	65**
sk 1	3	2	3	3	1	4	2	3	1	1	1	2	2	4	3	5	2	3	1	4	3	2	55
	2	4	5	5	1	1	1	4	2	2	1	2	5	3	4	3	5	4	2	4	5	5	70
sk 2	4	3	2	3	2	4	2	2	3	3	3	1	3	3	3	5	2	3	1	3	3	2	60
	3	4	5	4	2	2	2	2	4	3	3	1	3	5	3	3	4	5	1	5	5	5	74
sk 3	3	3	4	3	2	4	2	4	4	2	2	4	3	4	4	5	4	3	3	4	3	4	74
	3	3	3	3	3	1	4	3	3	2	1	3	5	3	3	3	3	3	4	3	4	3	66
sk 4	3	1	3	4	4	5	5	3	1	1	1	3	1	5	3	5	2	3	1	3	2	2	61
	4	2	5	5	3	1	2	5	1	2	2	4	1	4	1	3	2	5	1	4	2	1	60
sk 5	3	3	1	4	1	4	1	3	1	2	2	3	3	5	3	4	3	3	4	4	3	2	62
	5	3	1	4	1	4	3	4	1	1	1	5	3	2	3	5	3	3	3	5	3	4	67
sk 6	3	3	1	4	1	4	3	4	3	1	1	5	4	4	4	5	4	5	3	5	3	4	74
	3	3	1	3	2	3	5	5	2	2	2	5	3	1	3	4	3	3	3	4	3	4	67
sk 7	3	3	3	3	1	3	3	5	1	1	3	3	3	3	1	5	3	1	3	2	2	3	58
	3	3	3	4	3	2	3	3	3	1	3	1	3	3	3	4	3	3	4	3	3	5	66
sk 8	4	3	2	4	1	3	5	2	3	4	3	1	3	3	3	5	4	3	2	3	2	3	66
	3	4	4	4	1	1	3	2	4	3	3	1	3	4	5	3	4	3	2	5	3	2	67
sk 9	3	3	2	4	1	1	2	3	3	3	3	1	3	5	4	5	2	3	1	3	2	2	59
	1	5	1	3	2	4	2	4	2	4	5	2	5	3	3	3	5	3	2	2	4	1	66
sk 10	2	3	3	4	2	4	3	4	3	1	1	3	4	4	3	5	4	4	2	5	4	2	70
	4	4	5	4	1	2	4	2	4	2	1	5	2	5	3	3	3	3	4	3	3	5	72
sk 11	3	3	5	4	2	4	2	3	3	1	1	1	4	4	4	5	3	4	5	4	4	3	72
	3	1	5	3	3	2	2	2	4	1	1	3	5	3	3	3	3	3	2	3	3	5	63
sk 12	2	5	3	3	3	5	4	4	4	4	3	5	4	4	5	5	3	4	1	5	4	4	84
	3	3	3	5	4	2	3	3	3	3	3	3	3	3	3	3	5	3	2	3	3	3	69
sk 13	2	3	3	3	1	4	2	3	2	1	3	2	4	5	3	4	4	4	1	3	3	2	62
	3	3	3	5	5	2	3	3	3	3	3	3	3	3	3	3	4	3	2	3	3	3	69
sk 14	3	3	3	4	1	4	2	3	2	2	3	3	3	3	2	4	3	2	1	3	3	2	59
	4	5	4	3	1	2	2	4	4	1	4	2	3	5	3	3	5	4	1	5	5	2	72
total																							1000
																							1013

* Pre-test scores

** Post-test scores

TABLE XXIII

DRG SCORES ON REMAI'S "A MATHEMATICS STUDY"

	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
st 0	4	3	4	3	2	4	2	3	4	3	3	1	2	4	3	5	3	3	1	3	5	5	68
	4	3	4	2	2	4	1	4	3	3	3	1	3	3	3	4	2	3	1	3	3	3	62
st 1	2	3	2	3	1	1	2	3	3	1	1	1	2	4	3	5	2	4	3	3	3	1	53
	4	4	1	4	2	2	2	4	5	1	2	1	5	3	4	3	2	3	1	4	2	1	60
st 2	2	1	4	4	1	3	2	1	1	1	1	1	1	5	1	3	2	3	2	2	3	1	45
	3	2	3	4	1	4	2	3	2	1	1	2	3	4	4	3	3	3	3	4	3	2	60
st 3	3	2	4	4	1	4	2	4	2	1	1	4	3	5	4	2	3	4	2	4	3	3	65
	5	1	5	3	1	3	2	1	1	1	2	2	3	4	5	3	3	3	2	3	4	2	59
st 4	3	3	2	5	1	3	5	3	3	3	1	1	4	4	4	5	4	4	1	5	3	4	71
	3	1	3	3	2	4	1	5	2	1	3	3	2	3	2	2	1	5	1	1	4	2	53
st 5	1	3	3	4	2	4	2	2	3	1	4	1	2	3	3	3	2	3	1	3	4	3	57
	4	3	4	3	4	2	1	4	4	4	3	1	5	4	3	3	4	4	3	4	5	4	76
st 6	4	3	4	3	4	5	2	5	3	3	1	5	4	5	3	3	4	4	2	5	4	2	78
	3	4	5	3	3	1	1	3	4	1	1	2	3	5	5	3	3	3	5	3	3	2	66
st 7	4	3	2	4	1	5	2	3	3	2	3	5	3	3	3	3	3	2	1	3	4	2	64
	3	5	1	3	4	2	2	4	4	2	4	3	1	3	4	3	5	5	1	3	3	2	67
st 8	3	3	3	3	1	5	5	4	1	1	1	2	1	5	5	5	3	3	4	5	3	2	68
	3	4	1	3	4	1	1	5	5	2	2	3	2	3	4	3	4	5	1	3	3	2	64
st 9	3	3	1	4	1	3	5	1	2	3	3	2	4	1	4	5	5	4	2	3	4	4	67
	4	3	3	3	1	1	3	4	5	5	3	1	3	3	3	3	5	4	4	3	4	3	71
st 10	3	3	2	3	2	4	2	2	3	2	4	1	3	4	3	3	2	2	2	2	3	2	57
	5	5	5	2	4	1	2	4	5	4	3	2	5	4	4	3	3	3	2	5	5	1	77
st 11	3	3	3	3	1	4	2	3	2	1	1	1	2	5	2	2	4	4	1	3	2	2	52
	3	3	3	3	1	1	4	3	5	1	4	4	4	3	5	5	4	3	2	5	2	1	69
st 12	3	3	3	4	2	4	3	4	4	5	4	5	4	4	4	4	2	3	1	4	3	3	76
	4	3	4	4	2	4	3	4	4	5	4	5	4	4	4	5	3	3	3	2	3	3	80
st 13	4	3	4	2	4	5	5	4	4	5	4	4	5	4	4	5	4	4	3	5	4	4	90
	5	3	3	4	3	2	3	3	3	3	3	5	3	3	3	3	3	3	3	3	3	3	70
st 14	2	3	2	3	4	4	2	3	2	1	1	2	2	3	4	5	4	4	5	4	3	2	65
	1	5	5	5	2	5	1	3	4	2	1	5	4	5	3	3	3	3	3	3	5	5	76
total																							967
																							1010

TABLE XXIV

SRG SCORES ON REMAI'S "A MATHEMATICS STUDY"

	2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
sa 1	3	3	3	4	2	3	2	3	3	2	4	1	5	4	4	4	2	3	1	4	4	3	67
	3	3	4	3	2	4	2	3	3	2	3	1	4	4	4	4	2	3	1	3	3	4	65
sa 2	3	3	4	5	4	4	2	4	3	1	1	5	3	5	3	1	3	5	1	2	3	4	69
	2	2	2	2	1	3	3	3	5	2	4	5	3	3	4	1	2	4	2	4	3	2	62
sa 3	5	3	3	4	4	5	5	5	4	5	4	2	4	5	5	1	4	3	3	5	4	2	85
	5	4	3	3	4	5	2	4	4	4	4	2	4	4	5	1	4	3	1	4	4	2	76
sa 4	3	3	3	3	2	2	3	4	2	1	1	1	1	3	3	3	3	3	2	4	3	2	55
	3	3	3	3	2	2	3	3	3	1	1	1	1	3	4	2	3	3	2	4	3	3	56
sa 5	3	3	3	4	4	3	2	4	3	4	4	4	3	3	3	1	2	4	2	4	3	4	70
	3	3	4	4	4	4	2	4	3	4	4	4	4	4	4	1	3	4	1	4	4	4	77
sa 6	5	3	4	1	1	5	3	4	2	4	3	1	3	3	4	5	4	4	1	4	4	3	71
	4	3	3	2	1	5	3	4	3	2	3	1	3	3	4	5	4	4	1	3	3	3	67
sa 7	4	4	3	2	2	4	4	5	3	3	4	4	4	5	4	4	3	5	2	4	4	4	81
	4	4	5	2	1	4	4	5	3	3	3	4	4	5	4	5	2	4	1	5	4	4	80
sa 8	3	3	5	4	1	4	4	4	4	1	1	4	4	5	5	5	4	4	2	5	5	4	81
	3	4	4	4	1	4	4	4	4	1	1	4	4	4	4	4	4	4	2	5	3	4	76
sa 9	2	2	2	2	1	3	2	1	3	1	3	1	2	1	1	4	1	1	1	3	2	1	40
	3	2	2	2	1	3	2	2	1	1	3	1	3	3	3	5	1	2	1	3	2	1	44
sa 10	3	2	2	2	2	4	2	3	3	2	2	4	3	3	3	5	3	3	3	3	3	2	62
	3	1	2	1	1	4	2	3	1	2	2	4	2	3	3	5	3	2	2	3	3	2	54
sa 11	2	1	2	1	3	2	3	4	1	2	2	2	1	4	1	3	1	2	1	2	4	1	45
	2	1	2	2	1	1	4	2	2	2	2	1	1	2	2	4	1	2	1	2	2	1	40
sa 12	3	3	1	4	2	3	4	2	3	1	1	4	3	2	4	3	3	4	3	3	3	2	61
	5	3	1	4	2	3	5	1	3	1	1	5	4	3	3	4	3	4	2	4	2	2	65
sa 13	4	3	2	4	5	4	2	3	1	2	1	5	2	3	3	4	3	3	1	5	3	1	64
	4	4	3	5	2	5	2	4	3	1	1	5	2	3	4	5	3	4	1	3	3	2	69
sa 14	3	1	3	2	2	4	3	1	1	3	2	2	3	3	2	3	3	2	1	3	3	1	49
	2	1	2	2	1	3	5	2	1	3	3	2	1	3	2	5	2	2	1	3	2	1	49
sa 15	2	3	1	1	1	1	1	2	3	1	1	1	2	2	2	4	1	3	1	2	2	2	39
	3	3	1	2	1	4	1	2	3	1	1	1	4	2	1	3	2	2	1	2	2	2	44
total																							939
																							923

TABLE XXV

IRG SCORES ON THE COMPUTER SESSIONS QUESTIONNAIRE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
sk 0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	71
sk 1	3	1	1	3	3	3	3	3	1	3	3	1	3	3	2	3	3	3	2	2	2	3	3	2	59
sk 2	3	3	2	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	1	3	68
sk 3	3	2	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	2	3	3	3	2	67
sk 4	2	2	1	3	3	3	3	3	3	3	2	3	3	3	3	2	2	3	3	3	2	3	1	2	61
sk 5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	2	3	2	69
sk 6	3	2	3	3	3	3	3	3	3	3	3	3	1	3	3	3	2	3	3	3	3	2	3	3	67
sk 7	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	71
sk 8	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3	3	3	3	3	3	3	3	2	69
sk 9	3	2	3	3	3	3	3	3	2	3	2	2	3	3	3	3	3	3	3	2	3	3	2	2	65
sk 10	3	3	1	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	68
sk 11	3	2	3	3	2	3	3	3	3	3	2	3	2	3	3	3	1	3	3	1	3	1	1	1	58
sk 12	3	2	2	3	2	3	3	3	2	3	3	3	3	3	3	2	3	3	3	3	3	3	1	2	64
sk 13	3	3	1	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	2	1	3	2	3	2	64
sk 14	3	3	1	3	3	2	2	3	3	3	3	2	3	2	3	3	3	1	3	3	3	3	3	3	64
total	44	37	33	45	43	44	44	45	39	44	40	40	41	44	43	43	41	43	43	37	43	40	35	34	985

TABLE XXVI

DRG SCORES ON THE STUDENTS' QUESTIONNAIRE

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	total
st 0	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	2	3	70
st 1	3	3	3	3	3	3	3	3	2	3	3	2	3	3	3	3	3	3	2	3	3	3	2	2	67
st 2	3	3	3	3	3	3	3	3	3	3	3	1	3	3	3	3	3	2	3	3	3	3	3	2	68
st 3	3	2	3	3	3	3	3	3	3	3	2	3	2	3	3	3	3	3	3	2	2	3	3	3	67
st 4	3	2	1	3	3	3	3	3	2	3	2	3	2	3	2	1	3	2	3	1	2	3	3	2	58
st 5	3	3	3	3	3	3	1	3	1	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	66
st 6	3	3	3	3	3	3	3	3	2	2	2	2	3	3	3	3	2	2	2	2	2	2	1	2	59
st 7	3	1	1	3	2	3	3	3	2	3	2	1	1	3	3	3	1	3	2	2	3	1	1	3	53
st 8	3	2	3	3	2	3	3	3	3	3	2	1	2	3	3	3	2	2	1	3	3	2	3	3	61
st 9	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	1	3	2	3	3	3	3	3	2	67
st 10	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3	1	3	3	2	3	2	67
st 11	3	3	1	3	2	3	3	3	3	3	2	3	3	3	3	3	3	3	3	3	2	3	1	3	65
st 12	3	3	3	1	2	3	3	3	3	3	3	3	2	2	3	3	3	3	3	3	3	3	2	3	66
st 13	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	71
st 14	3	3	2	2	3	3	3	2	3	3	2	3	3	3	3	3	2	3	2	3	3	2	1	2	62
total	45	40	38	42	41	45	43	44	39	44	36	35	39	45	44	41	40	38	37	40	41	39	34	37	967

TABLE XXVII

SUMMARY OF IRG RESPONSES BY ABILITY LEVELS FOR KEY EXERCISES

		qu 1			sec 10			show 6			expa 2			char		
		c*	w	t	c	w	t	c	w	t	c	w	t	c	w	t
high	sk 0	9	1	0	7	3	0	9	1	0	9	1	0	9	1	0
	sk 1	8	2	0	7	3	0	8	2	0	6	3	1	9	1	0
	sk 2	8	2	0	6	4	0	9	1	0	3	6	1	10	0	0
	sk 9	8	2	0	6	4	0	8	2	0	6	4	0	9	1	0
	sk 10	7	3	0	5	5	0	6	4	0	6	3	1	9	0	1
medium	sk 3	10	0	0	7	3	0	7	3	0	7	3	0	10	0	0
	sk 4	7	2	1	7	3	0	8	2	0	5	4	1	9	1	0
	sk 11	2	8	0	8	2	0	6	4	0	3	6	1	10	0	0
	sk 12	8	2	0	9	1	0	8	2	0	3	7	0	10	0	0
	sk 13	5	5	0	7	3	0	8	2	0	6	4	0	7	3	0
low	sk 5	8	2	0	7	2	1	8	2	0	8	1	1	7	2	1
	sk 6	5	5	0	4	6	0	7	3	0	6	4	0	7	3	0
	sk 7	10	0	0	5	5	0	8	2	0	3	6	1	6	4	0
	sk 8	9	1	0	6	3	1	7	2	1	5	4	1	8	1	1
	sk 14	7	3	0	7	3	0	8	2	0	6	4	0	10	0	0

* c - correct answers, w - wrong and unrecognized answers

t - timed out answers

TABLE XXVII (continued)

		mant			mant 5			log 2			anti 2			comp 2		
		c*	w	t	c	w	t	c	w	t	c	w	t	c	w	t
high	sk 0	9	1	0	9	1	0	18	2	0	16	3	1	5	5	0
	sk 1	9	1	0	8	0	2	15	2	3	13	7	0	1	1	0
	sk 2	10	0	0	9	0	1	19	0	1	12	6	2	1	1	2
	sk 9	9	1	0	8	2	0	17	2	1	14	6	0	3	0	0
	sk 10	8	2	0	9	0	1	16	1	3	**					
medium	sk 8	10	0	0	8	1	1	19	0	1	16	1	3			
	sk 4	9	0	1												
	sk 11	4	3	3	2	5	3									
	sk 12	10	0	0	10	0	0	16	3	1	17	3	0	5	5	0
	sk 13	7	1	2	9	0	1	16	3	1	7	9	4	0	2	0
low	sk 5	10	0	0												
	sk 6	7	3	0												
	sk 7	6	3	1	8	1	1	19	1	0	9	10	1			
	sk 8	9	1	0	7	1	2	18	1	1	16	2	2			
	sk 14	8	2	0	9	1	0	15	4	1	14	5	1			

* c - correct answers, w - wrong and unrecognized answers

t - timed out answers

** Student did not reach this set of exercises.