DOCUMENT RESUME

ED 072 628		EM 010 713

AUTHOR	Bunderson, C. Victor; And Others
TITLE	The Design of an Abstract Hierarchical Learning Task for Computer-Based Instructional Research. Technical Report Number 2.
INSTITUTION	Texas Univ., Austin. Computer-Assisted Instruction Lab.
SPONS AGENCY	Office of Naval Research, Washington, D.C. Personnel and Training Research Programs Office.
PUB DATE	Aug 71
NOTE	25p.; ARPA Project on Cognitive Abilities and Learning
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	*Computer Assisted Instruction; *Instructional Design; *Instructional Innovation; Research Design; Sequential Learning; *Task Analysis

ABSTRACT

A hierarchical learning task was designed and developed in accordance with an instructional design model to study questions concerning task structure, sequencing, and other instructional design variables. To provide control and generality, the learning task was based on an entirely imaginary science. (RH)

THE DESIGN OF AN ABSTRACT HIERARCHICAL LEARNING TASK FOR COMPUTER-BASED INSTRUCTIONAL RESEARCH

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TECHNICAL REPORT NO. 2

August 1971

PROJECT ON COGNITIVE ABILITIES AND LEARNING
Sponsored By
Advanced Research Projects Agency
ARPA Order No. 1261
Contract N00014-67-A-0126-0006
Program Code No.: NR 154-282/8-13-68 Code 458

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) *Advanced Research Projects Agency* *Washington, D.C. 20301*	2a. REPORT SECURITY CLASSIFICATION *Unclassified* 2b. GROUP

3. REPORT TITLE

THE DESIGN OF AN ABSTRACT HIERARCHICAL LEARNING TASK FOR COMPUTER-BASED INSTRUCTIONAL RESEARCH

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

Technical Report No. 2, August 1971

5. AUTHOR(S) (First name, middle initial, last name)

C. Victor Bunderson, William P. Olivier, Paul F. Merrill

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1971	*24*	*13*

8a. CONTRACT OR GRANT NO. *N00014-67-A-0126-0006* b. PROJECT NO. *NR 154-282/8-13-68 Code 458* c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) *Technical Report No. 2*

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Department of the Navy *Office of Naval Research* *Washington, D.C.*

13. ABSTRACT

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Unclassified

Security Classification

A-31408

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Unclassified
Security Classification

A-31409

THE DESIGN OF AN ABSTRACT HIERARCHICAL LEARNING TASK FOR COMPUTER-BASED INSTRUCTIONAL RESEARCH

Introduction

An instructional design model inspired by a cross fertilization between ideas from the different disciplines of system analysis, curriculum design, and computer programming has been developed by Bunderson (1969). The model originated to provide management and quality control for curriculum development as well as to bridge instructional research and instructional design. This paper describes a hierarchical learning task which has been designed and developed in accordance with the instructional design model to study questions concerning task structure, sequencing, and other instructional design variables.

The learning task described here was based on an imaginary science conceived by Carl Bereiter at the Training Research Laboratory, University of Illinois, for use in studying group interaction problems. Bereiter's ideas were further expanded and developed by David Merrill (1964). He divided the contents of the science into five lessons which consisted of branching-type program frames containing a short passage of material followed by multiple-choice questions. The frames were presented by means of Auto Tutor teaching machines. Merrill (1964, 1966) used the science in a series of studies investigating the effect of knowledge of results and different types of review. Merrill's version of the science was simplified, and an instructional program for presenting the task on the IBM 1500/1800 computer-assisted instruction system was designed according to the instructional design model developed by Bunderson (1969). The imaginary science is called the *Science of Xenograde Systems*. In the present version of the science, a Xenograde System consists of a nucleus with an orbiting satellite. The satellite is composed of small particles called alphons which may also reside in the nucleus. Under certain conditions, a satellite may collide with the nucleus, and the satellite may exchange alphons with the nucleus. The subject matter of the science deals with the principles or rules by which the activity of the satellite and alphons may be predicted. Figure 1 shows a diagram of a Xenograde System.

The use of an imaginary science as a learning task for instructional research assumes that all subjects (Ss) have had no previous experience with the task and thus eliminates the necessity of pretesting and discarding Ss because of their familiarity with the content. With prior knowledge of the task principles held constant, the individual differences in Ss' abilities and learning styles are allowed to exert their effects. Since the structure and content of the science is similar to that of formal science topics, the generality and transferability of research findings will be increased. The abstract and imaginary nature of the subject matter may also conceivably free the instructional designer from preconceived, often subtle, assumptions as to how it should be taught.

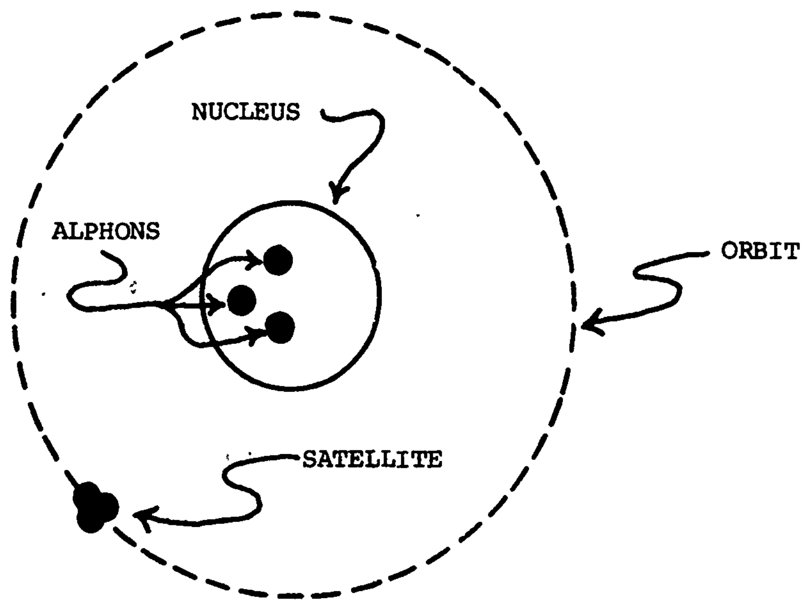


Figure 1.--Diagram of Xenograde System

The use of a computer-assisted instruction system to present the instructional program will facilitate the control of extraneous variables and the experimental manipulation of stimulus events. Scoring, recording of latencies, errors, and unexpected responses can be done automatically for several Ss who may study the instructional program simultaneously. In addition to performing the explicit terminal behavior described below, students who complete this instructional program might improve their general problem-solving skills and should be able to transfer their improved skills to new situations. These general goals of the program may be validated by the use of specific transfer tasks and measures.

On completion of the instructional program, the Ss will be able, with only paper and pencil available, to predict and record the state of the satellite and alphons of a Xenograde System at successive time intervals, given the initial state of a system at time zero. Operationally, the performance of this terminal behavior entails entering numerical values in a Xenograde table which, when completed, shows the state and relationships of the elements of a Xenograde System at several points in time.

Since examples of the rules of the science will be presented by means of Xenograde tables, students must be able to read the tables. Since it is assumed that all students will be deficient in this ability, they are given prior instruction. All students are also instructed and tested in the use of the computer-assisted instruction terminals before taking the instructional program. The rules or laws of the Xenograde Science are relatively simple mathematical relationships which require the student to have addition, subtraction, multiplication, division, and simple algebraic equation manipulation skills. It is hypothesized that induction, general reasoning, and various memory abilities are required to learn the task. The exact relationships of these and other abilities to performance may be tested empirically.

The instructional program is presented on an IBM 1500 computer-assisted instruction system equipped with IBM 1510 terminals, consisting of a keyboard and cathode ray tube, and IBM 1512 image projector terminals. Because of the limited number of terminals, only a few students may take the instructional program at one time. The students are required to schedule and attend two different sessions two weeks apart in order to take the retention and transfer tests. A proctor must be available to assist the students in obtaining the correct instruction materials and to assist them in signing on at the terminals.

The instructional materials may be adapted for presentation on other CAI or non-CAI systems. However, other instructional systems may impose additional constraints on the type of instructional variables which may be manipulated.

Task Analysis

The purpose of a task analysis is to determine what prerequisite or subordinate information and skills a learner must possess before he will be able to achieve the terminal objective of the task. A task analysis should also reveal an efficient sequence for learning the specified subordinate skills.

Gagné (1962) proposed a task analysis procedure which begins with the terminal objective and specifies a hierarchy of subordinate skills where lower-order skills generate positive transfer to ones at a higher level. Gagné's procedure entails beginning with the terminal task and asking the question, "What prerequisite behavior must a student be able to perform before he can learn the new behavior when he is only given instructions?" This question is asked recursively of each prerequisite behavior identified until the assumed student-entering behaviors are reached. This method of task analysis has received some empirical support (Gagné, Mayor, Garstens & Paradise, 1962; Gagné & Paradise, 1961) and has been used rather widely. However, Gagné (1968) has recently suggested that an empirical trial of an initial hierarchy may reveal that each subordinate capability does not generate positive transfer to the higher-order capabilities. If this is the case, the hierarchy must be rearranged.

When Gagné's procedure was used to analyze earlier versions of the Xenograde task, different investigators arrived at considerably different hierarchical structures. Concern over the different results obtained from independent analyses using Gagné's method and experience in writing an algorithm to generate entries in a Xenograde table (the terminal task) precipitated the development of a new method of task analysis. After many false starts in the effort to write the algorithm mentioned above, it became apparent that the most efficient procedure was to work through the terminal task step-by-step as a student, and write the algorithm to correspond with those steps. The algorithm thus defined was an ordered series of steps which a student would use to perform the terminal behavior. An examination of this algorithm revealed that the exact processes or operations required to perform the task had been delineated. Therefore, the specification of an algorithm for performing a terminal task, in effect, specifies the operations or skills which the student must be able to perform, the information or data which the student must have available as inputs for the operations, and the sequence for performing the operations. One of the salient properties of many algorithms, including the one developed to generate a Xenograde table, is that the output from one operation or step may serve as one of the inputs for a succeeding operation. It is quite obvious that the sequence in which the operations of such an algorithm are performed becomes very crucial.

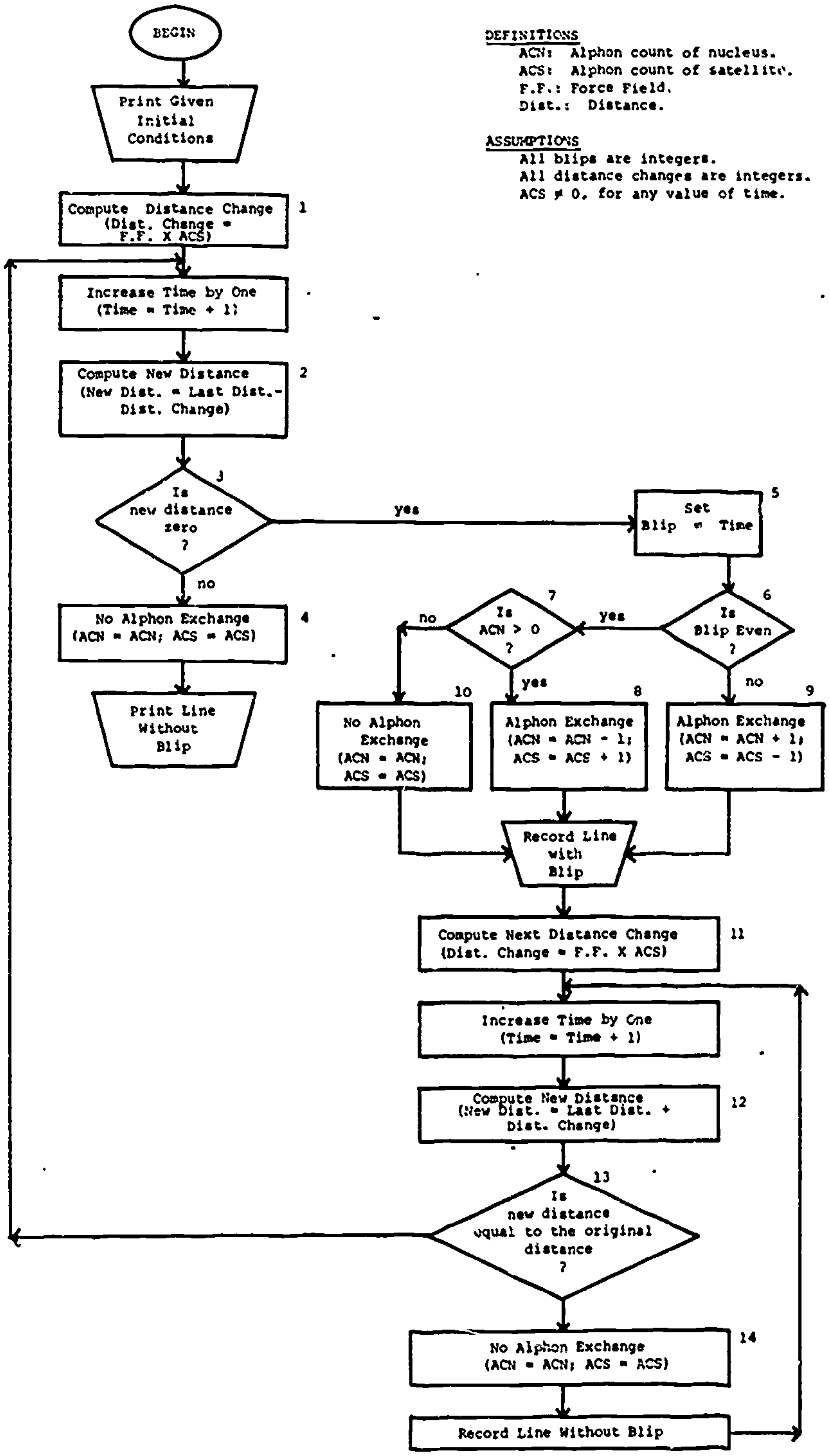
Stolurow (1962) hypothesized that sequential arrangements may be found to make a difference in students' cognitive structure and thereby affect their behavior. If students must follow a series of ordered steps to perform a terminal task, the most effective instructional sequence might be one which corresponds to the order of the steps. Such an instructional sequence should facilitate students' efforts to organize and structure an efficient strategy for performing the task. It may be possible for the student to learn the required operations in a different order and restructure them, but the restructuring process would require unnecessary processing. It is also very probable that low-ability students may have difficulty performing the necessary restructuring.

For many complex tasks, there may be more than one algorithm for performing the terminal behavior. If this is the case, a comparative evaluation of the algorithms should be made. An algorithm should have the following features as delineated by Knuth (1968):

> Each step of the algorithm should be precisely defined and unambiguous; it should produce the correct solution in a finite number of steps; it should have zero or more inputs from a specified set of objects and one or more outputs having a specified relationship to the inputs; and all operations or steps of the algorithm should be sufficiently basic so that they could be done precisely in a finite length of time.

The length of time required to perform the algorithms could be compared in terms of the number of steps that are executed. This comparison could be facilitated by programming the algorithms on a computer and running the program with several trial inputs. The algorithms could also be evaluated in terms of Bruner's (1966) concepts of economy and power. He suggests that economy is a function of the sequence of presentation. One sequence may require storage of information while another may require a more pay-as-you-go type of information processing. The power of a representation can be described as its capacity, in the hands of the learner, to connect matters that, on the surface, seem quite separate. For example, the algorithms might be compared in terms of which one gave the student the power to generate new hypotheses and combinations.

The algorithmic information-processing analysis discussed above was used to analyze the terminal objective of the Xenograde task described in this paper. This procedure entailed the determination of a series of ordered steps comprising an algorithm which a student would use to perform the terminal behavior. Each step of the algorithm consisted of an operation or skill which the student would have to perform in order to complete a Xenograde table. Figure 2 is a flowchart of the ordered steps of the algorithm. The validity of the algorithm was tested by programming it in the Fortran IV computer language and executing the program by a computer with many different initial input conditions. The algorithm could have been validated by stepping through it by hand, using several different initial inputs, but the use of a computer program was more efficient and less time-consuming.



DEFINITIONS
ACN: Alphon count of nucleus.
ACS: Alphon count of satellite.
F.F.: Force Field.
Dist.: Distance.

ASSUMPTIONS
All blips are integers.
All distance changes are integers.
ACS $\neq$ 0, for any value of time.

Figure 2.--Algorithm Flowchart for Xenograde Terminal Task. (Only those operations which the student must perform are numbered. See Figure 3 for the hierarchical sequence of the complex operations formed by combining these simple operations.)

The size of the steps or complexity of the operations specified in the flowchart (Figure 2) is somewhat arbitrary. The degree of complexity allowed for each operation is dependent upon the processing capabilities of the organism or machine which must perform the operations. If the processor is a computer, the operations will need to be quite small and numerous. On the other hand, a human with high cognitive abilities may be able to process more complex operations which are merely combinations of several simple operations. A determination of the optimal complexity for the operations which may be executed by a given population of students seems to be an empirical problem. The complexity of the operations presented in the instructional program described here was determined from an evaluation of the performance of students in the population of interest on pilot versions of the program. In the present instructional program, Steps 1 through 4 of the algorithm flowchart (Figure 2) were combined into one operation, described verbally as follows: The decrease in distance between each time is equal to the value of F.F. x ACS. The remaining steps of the algorithm were combined into sets as shown in Figure 3, and verbal statements of the complex operations encompassed by each set were prepared. The verbal statements of these complex operations are referred to as *rules* in the instructional program and are listed in Table 1. The hierarchical sequence (Figure 3) for presenting the verbal descriptions of each complex operation or rule was made to correspond with the order of the algorithm flowchart steps. Thus, Rule 1, based on Steps 1 and 2 of the flowchart, was presented first, while Rule 10, based on Steps 11 through 13 of the flowchart, was presented last. Since the Xenograde algorithm had several conditional branches and a rule written for each condition, a decision had to be made concerning the sequence for presenting the conditional rules. In the present instructional program, the rule based on the most frequently encountered condition was presented first. All rules based on one conditional branch were presented before rules based on succeeding parts of the algorithm. Rules 1, 2, and 3 (Table 1) were all based on Steps 1 and 2 of the algorithm (Figures 2 and 3). The first two rules were actually special cases of the third and were therefore redundant. Experience with pilot versions of the program had shown that this redundancy was necessary for the student population of interest.

Th subobjectives of the task were developed to correspond with the steps of the algorithm and delineated the necessary input operands which would be given and the type of output behavior which would be expected on completion of each complex operation. Thus, the objectives, given the value of F.F., ACS, and the previous distance, predict the value of the next distance. This objective, which corresponds to the complex operation described by Rule 3 (Table 1), describes the required input operands (F.F., ACS, and previous distance) and the required output behavior (prediction of the value of the next distance). Table 2 contains a list of the subobjectives which correspond to each complex operation or rule.

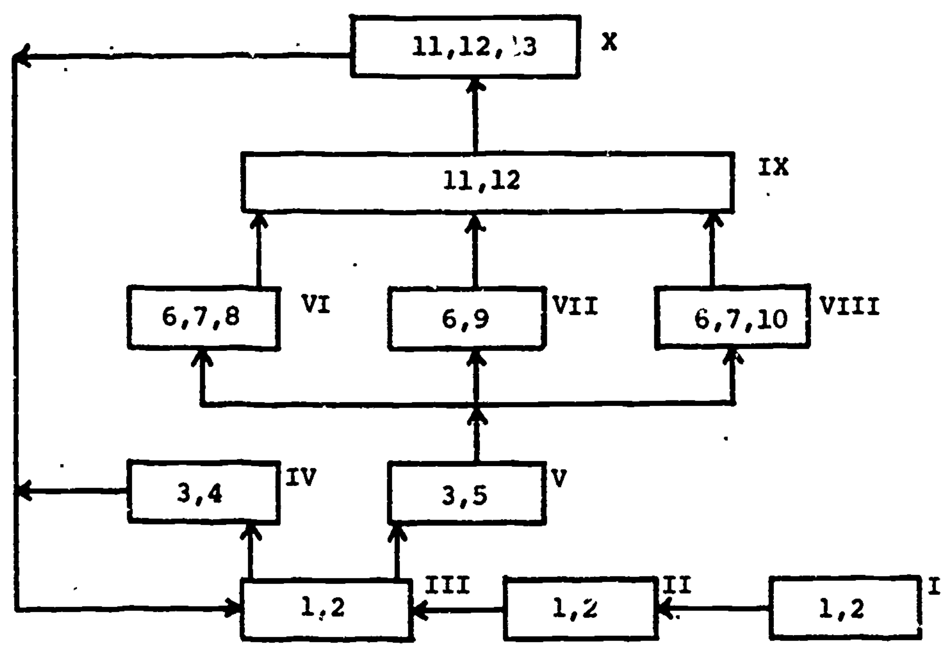


Figure 3.--Hierarchical Sequence for Complex Operations. (Each arabic number refers to the corresponding simple operation in the flowchart in Figure 2. Each roman numeral corresponds to the rules in Table 1 and the objectives in Table 2.)

Table 1.

Rules for the Xenograde Science

1. If F.F. = 1, the decrease in distance between each time is equal to ACS.

2. If ACS = 1, the decrease in distance between each time is equal to F.F.

3. The decrease in distance between each time is equal to the value of F.F. x ACS.

4. ACN and ACS cannot change unless a blip occurs.

5. When the distance becomes zero a blip is recorded whose value is equal to the value of the time.

6. When the blip time is *even, ACN decreases* by one while *ACS increases* by one.

7. When the blip time is *odd, ACN increases* by one while *ACS decreases* by one.

8. If the blip time is *even* and ACN was zero on the previous line, ACN and ACS do *not* change.

9. After a blip occurs, the distance begins to increase each time by the value of F.F. x ACS.

10. After a blip, the distance increases to its value at time zero, then begins to decrease again.

Table 2

Objectives for MENOG

1. Given that F.F. = 1, and the values of ACS and the previous distance, predict the value of the next distance.

2. Given that ACS = 1, and the values of F.F. and the previous distance, predict the value of the next distance.

3. Given the values of F.F., ACS and the previous distance, predict the value of the next distance.

4. Given the previous values of ACN and ACS, and that no blip has occurred, predict the next values of ACN and ACS.

5. Given the value of the time and that a blip has occurred, predict the blip time and the value of the distance at that time.

6. Given the previous values of ACN and ACS, and that the blip time is even, predict the next values of ACN and ACS.

7. Given the previous values of ACN and ACS, and that the blip time is odd, predict the next values of ACN and ACS.

8. Given the previous value of ACS, that the blip time is even, and that ACN was zero on the previous line, predict the next values of ACN and ACS.

9. Given the values of F.F., ACS, and that a blip has occurred, predict the next distance.

10. Given the distance at time zero, predict the maximum value the distance will reach.

Instructional Design: Synthesis

Instructional Materials and Interface Devices

In addition to the statements of the rules and objectives, five simple examples, five complex examples, and five short constructed response tests for each rule and objective were developed for the instructional program. The examples are in the form of partial Xenograde tables which show the activity of the elements of a Xenograde System at several points in time. Each example table demonstrates the relationships described in the corresponding rule. The simple examples are only partial Xenograde tables which contain only those values which are relevant to the relationships described by the rule. The corresponding complex examples contain the same values as the simple displays plus additional values irrelevant to the rule. The short tests each contain three items which were constructed to measure achievement of the corresponding objectives. The items display the necessary inputs and request the correct output which would result from performing the operation, described by the corresponding rule, on the given inputs.

The examples and test items are displayed on the cathode ray tube of the IBM 1510 instructional terminal, and the Ss respond to the test items by means of a typewriter keyboard on the terminal. The statements of the objectives and rules are displayed on the IBM 1512 image projector terminal. The use of these terminal devices connected to the IBM 1500 CAI system make it possible to present and withdraw any display at random under program control, to record the time each display was available, and to record and score each student response.

A printed instruction booklet is also provided which contains an introduction to the science, the purpose and justification of the course, fictitious and humorous background material on the discovery of Xenograde Systems, instructions on reading Xenograde tables, and a treatment-specific explanation of the procedure for learning the task.

Post- and Retention Tests

The original posttest developed to measure achievement of the terminal objective was given on the cathode ray tube terminal and required the student to predict the entries of a Xenograde table, given the initial conditions of the system. In order to prevent cumulative errors, the student was given corrective feedback after making all entries for a given line. Experience using this original posttest revealed that the corrective feedback had an instructional effect. Therefore, new post- and retention tests were developed. The present tests are paper-and-pencil parallel forms with constructed response test items which require the student to make entries in a Xenograde table, but each item is independent to avoid the necessity of providing corrective feedback. However, the items are sequenced so as to simulate the processing of a continuous algorithm.

Transfer Test

A transfer task was developed to measure students' ability to transfer their skills to a new learning task. The task consisted of a booklet containing two Xenograde tables and 24 constructed response items. The students were required to infer three higher-order rules of the science from the tables and make predictions based on the inferred rules. The present version of the test contains twice as many items as the original version.

Course Flow and Individualization

Figure 4 is a flowchart which graphically demonstrates the several treatment branches available in the present instructional program. All students receive a copy of the printed instruction booklet described earlier and are instructed and tested on the use of the CAI terminal.

Students who take Treatment Branch I receive a statement of the first rule on the image projector (IP) while the first simple example of the rule is simultaneously displayed on the cathode ray tube (CRT). After studying the rule and example, the student responds to a short three-item constructed response test where he is required to predict certain values using the operation described by the previously displayed rule. (The rule and example are removed before the test items are presented.) If the student responds correctly to two of the three test items, he is given the next rule in the sequence; otherwise, he is given another simple example of the same rule followed by another three-item test. This sequence of new examples followed by a test is repeated until the student responds correctly to two of the three items. If five examples of the same rule are given, the student is branched to the next rule regardless of his performance on the three-item test. Following completion of all 10 rules, each student is given the paper-and-pencil posttest. Two weeks later all students are given a retention test and a transfer test.

Students who take Treatments II and V follow the same basic procedure as those who take Treatment I, except those in Treatment V receive statements of the objectives rather than statements of the rules, and those in Treatment II are not given statements of either rules or objectives. Those students in Treatments II and V must infer their own rules from the examples which are presented.

Treatments VIII, VI, and VII are respectively identical to Treatments I, II, and V, except that students in the former groups receive complex examples of the rules rather than the simple examples received by students in the latter treatments. In Treatment IX, students also receive complex examples, but they are presented both rules and objectives with the examples.

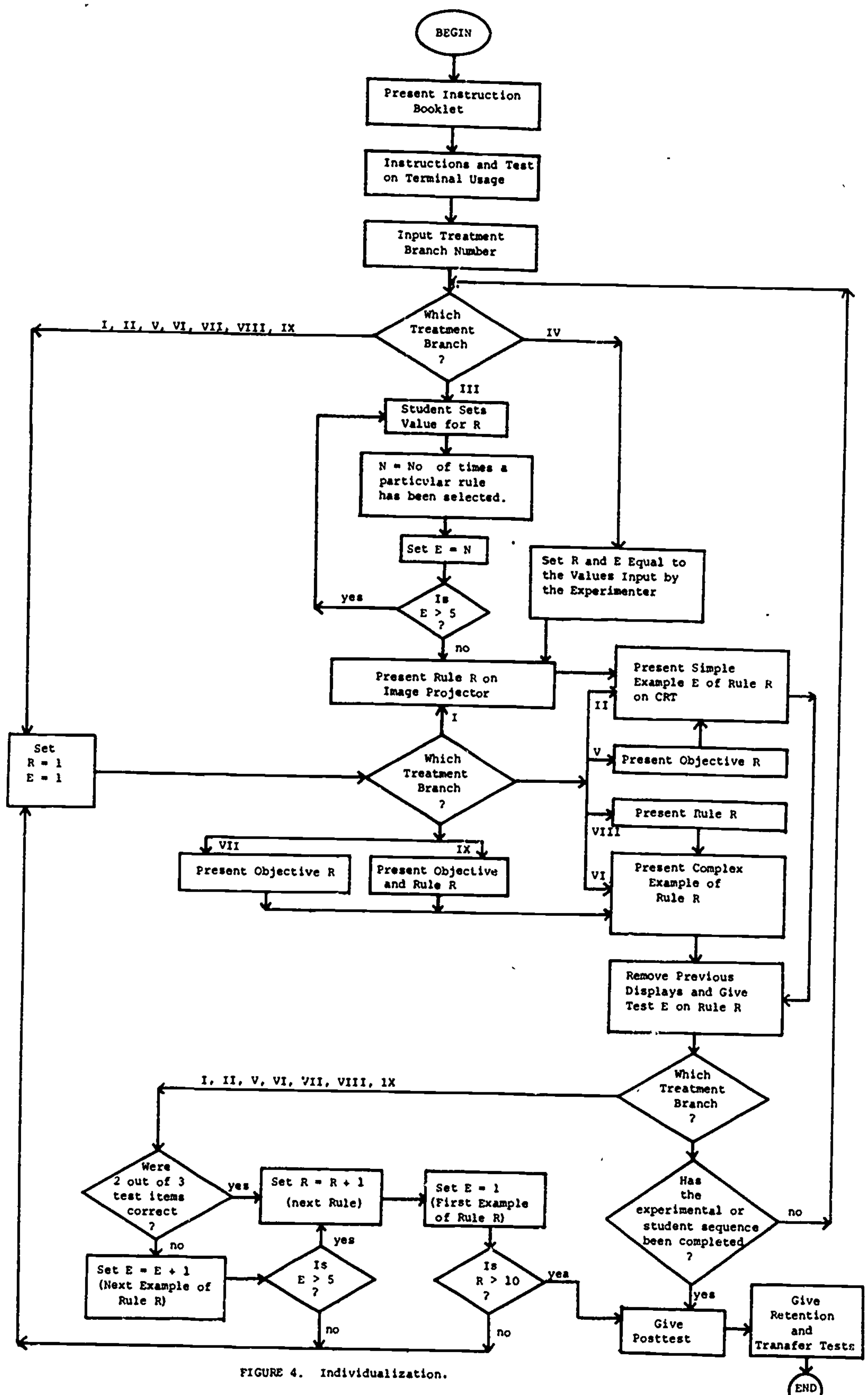


FIGURE 4. Individualization.

Students who are given Treatment III receive statements of the rules and simple examples, but they are allowed to select their own sequence for receiving the rules. If they select a rule more than once, they are presented the next example of the rule. However, they are only permitted to receive up to five examples of the same rule. The experimenter must set the sequence for the presentation of rules and simple examples for students in Treatment IV. This sequence may be completely random, but it must be determined and input to the computer before each student in Treatment IV begins the program.

Author's Draft

The instructional program was programmed in the Coursewriter II computer language. All instructional treatments described above are operational. Other instructional treatments could be added by revising the control section of the program. Several of the instructional treatments were actually added after the basic program became operational.[1]

A list of the rules is found in Table 1; a list of the objectives is found in Table 2.

Task Revision

In the early stages of adapting Merrill's (1964) version of the imaginary science for presentation on the CAI system, an algorithm for generating a Xenograde table, given any values for the initial conditions, was written. This algorithm would have been relatively easy to program in Fortran or APL, but the algorithm was programmed in Coursewriter II so that the tables could be displayed in real-time on the cathode ray tube terminals. The Coursewriter II program allows a student to enter the initial conditions of a Xenograde System through the keyboard and then generate a Xenograde table which is based on the initial conditions input by the student. The terminal task used by Merrill (1964) was analyzed according to the procedure suggested by Gagné and Paradise (1961), and a learning hierarchy was determined. From this analysis, 13 rules or laws governing the activity of Xenograde Systems were specified.

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[1]Arrangements for obtaining listings or tape copies of the program, plus copies of the image projector film strips, can be made by writing to the Computer-Assisted Instruction Laboratory, The University of Texas at Austin, Austin, Texas. Copies of all the example and test item frames plus copies of the written materials (instruction booklet, posttest, retention test, and transfer test) have been deposited with the American Documentation Institute; order from ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington, D.C., 20540.

An instructional program was written which is based on the Coursewriter II program for generating Xenograde tables. A pilot study was conducted to determine if students could learn the science using Xenograde tables as examples of the rules of a Xenograde System. The first students to take the course were divided into four groups: (1) Students in Group I were given written statements of the 13 rules of the science. With each rule, they were given values for the initial conditions of a Xenograde table. The student input these values by the terminal keyboard, and a Xenograde table was generated and displayed on the cathode ray tube. After making certain requested observations on special forms, the student received three test items to assess his comprehension of the rule. If two of the three items were answered correctly, the student proceeded to the next rule. If two of the three test items were answered incorrectly, the student input new values and received another example of the rule and three new test items. This procedure was followed until all 13 rules were mastered. (2) Students in Group II followed the same procedure as those in Group I, except they were not given written statements of the rules. Their task was to discover the rules by observing the generated examples. (3) Students in Group III were required to learn the task by manipulating the initial conditions with values of their own choosing and generating their own examples. They were not given written statements of the rules, values to manipulate, or test items. (4) Students in Group IV were required to generate their own tables without receiving values to manipulate or written rules, but they were required to take the test items. After learning the 13 rules of the science, all students were given the terminal task.

Students in Groups III and IV found the task to be very difficult and frustrating. All needed encouragement and assistance in order to remain with the task and complete it. They also took an excessive amount of time to complete the task. Although some students in these groups did as well as those in other groups on the posttest, it was decided not to pursue Treatments III and IV any further at that time because of the confounding which would result from giving the necessary help and encouragement without proper controls. An item analysis revealed that Ss in both Groups I and II also had considerable difficulty learning several of the principles.

In order to decrease the level of difficulty of the science, the set of possible initial conditions which could be input to the computer was limited to include only those initial conditions which would generate only integral values. This restriction required the elimination of two difficult rules. Two other rules were each divided into two separate rules, which provided smaller steps. Many students in Group I used the written rules in a "cookbook" fashion while taking the test items. Therefore, the rules and initial condition values were recorded on film so that they could be presented on the image projector and removed from view while the students responded to the test items.

After the above revisions were made, another pilot study was conducted using two additional groups of students who received basically the same treatments as Groups I and II described above. The results of this pilot study revealed that the rules governing alphon exchange were still very difficult, and the students still took an excessive amount of time to learn the science and required help from the experimenters (Es) in order to complete the task. In addition to the above, students' performance on the terminal task was mediocre. The generation of Xenograde tables required an excessive amount of computer time, which could not be justified since the students were given the initial conditions to input to the computer. The students were asked to record portions of the generated tables in order to focus their attention on the relevant data in each table. Recording this information, of course, became quite tedious and allowed them to have past examples available at all times.

The original rules governing alphon exchange were completely revised since they were too difficult to learn by using Xenograde tables as examples without additional expository guidance. Since the original task had undergone considerable revision at this point, another complete task analysis was conducted. Discrepancies between the hierarchical structures determined by the independent use of the Gagné procedure for task analysis by different Es precipitated the search for and development of a new method of task analysis. Therefore, the revised terminal task was subsequently reanalyzed using the algorithmic information-processing analysis procedure described earlier. An instructional program for teaching the revised version of the science was also designed, as explained earlier in this paper. This new instructional program did not generate the Xenograde tables, but merely displayed previously stored tables. By storing the tables rather than generating them, it was possible to control what portions of the tables would be displayed and to decrease the computer-processing time.

Validation of the Task

The present version of the instructional program has been used in three instructional research studies which have been reported in detail elsewhere (Bunderson, Olivier, & Merrill, 1971; Olivier, 1971; Merrill, 1970). Olivier (1971) found that Ss who were required to learn the rules in the sequence specified by the algorithmic information-processing analysis performed significantly ($p < .01$) higher on the terminal task than Ss who were required to learn the rules by other sequences. Olivier also found that Ss who went through the instructional program obtained significantly higher scores on the posttest than Ss in a control group who took the posttest without going through the instructional program. Merrill (1970) found that Ss who completed the task were able to respond correctly to 77% of the posttest items and only required a mean of 12 examples to learn the task. Results from all three studies showed that there was very little decrease in terminal task performance over a two-week retention interval.

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