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AUTOMATED TEACHING METHODS USING LINEAR PROGRAMS.

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IN THIS EXPERIMENT, 186 FRESHMAN ENGINEERING STUDENTS STUDIED ELEMENTARY PROBABILITY BY THESE INSTRUCTIONAL METHODS--(1) MULTIPLE CHOICE TEACHING MACHINES, (2) FREE-RESPONSE TEACHING MACHINES IN INDIVIDUAL BOOTHS AND IN CLASSROOMS, (3) PROGRAMED TEXTS REQUIRING OVERT RESPONSES AND GIVING CORRECT ANSWERS, (4) PROGRAMED TEXTS REQUIRING NO OVERT RESPONSES, (5) "PROGRAMED" LECTURERS AND (6) STANDARD LECTURERS. THE STUDENTS FIRST TOOK AN ENGINEERING APTITUDE TEST, ON WHOSE BASIS THEY WERE RANKED AND THEN RANDOMLY ASSIGNED TO GROUPS. THEY WERE TESTED FOR LEARNING IMMEDIATELY AFTER INSTRUCTION. RESULTS INDICATED NO SIGNIFICANT DIFFERENCE IN STUDENT LEARNING BY ANY OF THE PROGRAMED METHODS, BUT ALL OF THE PROGRAMED METHODS WERE SIGNIFICANTLY MORE EFFECTIVE THAN THE STANDARD LECTURE. LEARNING TIME WAS SIGNIFICANTLY DIFFERENT FOR THE VARIOUS METHODS, MACHINE METHODS REQUIRING MOST TIME AND LECTURE METHODS LEAST TIME. (MS)

DECEMBER 1960

DEPARTMENT OF ENGINEERING

# automated teaching methods using linear programs

REPORT NO. 60-105

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# AUTOMATED TEACHING METHODS USING LINEAR PROGRAMS

A comparison between multiple-choice teaching machines, free-response teaching machines, programmed textbooks requiring overt responses, programmed textbooks requiring no overt responses, programmed lecturers, and a standard lecturer.

AUTOMATED LEARNING RESEARCH PROJECT

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## FOREWORD

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## ABSTRACT

Evidence, not all of which supports the application of the reinforcement theory of learning to simple auto-instructional or machine devices using linear programs, is provided by an experiment wherein 186 freshmen engineering students studied elementary probability by differeht teaching methods. Multiple-choice teaching machines, free-response teaching machines in individual booths, free-response teaching machines in a classroom, programmed textbooks requiring overt responses and providing "correct" answers, programmed textbooks requiring no overt responses, "programmed" lecturers, and standard lecturers are compared. The results indicate that there is no significant difference between the performance of the students learning by any of the programmed machine, programmed textbook, or programmed lecturer methods, and all of the programmed methods are significantly better than the standard lecture. The time required for learning is significantly different for the various methods --the longest time being required by the machine methods and the shortest time by the lecture methods.

## I. INTRODUCTION

The Automated Learning Research Project in the Department of Engineering, University of California, Los Angeles, is directed toward the investigation of the basic properties of auto-instructional systems. The aims of the project are:

A. To provide a comprehensive model of the generalized automated teaching system.

B. To express this model in mathematical terms.

C. To determine the magnitude of the constants in such a mathematical expression.

D. To determine a method for evaluating some of the variables of current interest.

1. Mode of presentation
2. Rate of presentation
3. Sequence of presentation
4. Type of information

5. Device complexity
6. Programming effort
7. Level of learning

E. To explore the computer functions in an automated teaching system.

F. To develop mathematical and experimental techniques for treating learning as a self-organizing system.

The research program was divided into a number of phases. The primary goal of phase I was to develop a top quality teaching program for use as a test vehicle in obtaining data from subsequent experiments. As part of this phase, a pilot study was conducted during May 1960 in which 51 freshmen engineering students were taught the elements of probability by various auto-instructional and lecture techniques. The pilot study provided a check on the comprehensibility, reliability, and validity of the programmed instructional material, the screening tests, the criterion tests and the subjective questionnaires used during the subsequent experiment. Also, experimental control and computational techniques were developed during the pilot study. Assumptions on normality and homogeneity of variances were verified at this time. Some of the results of the pilot study are mentioned in Section III of this report. Complete details of the pilot study are available in:

Report No. 60-53
A Pilot Study-Automated Learning Research Project
Department of Engineering
University of California, Los Angeles

## II. EXPERIMENT OBJECTIVES

A. To test the hypotheses that the mean performance of students (as measured by criterion test scores) are equal if the students are taught by the following methods:

1. All teaching methods: *MCM vs. FRMC vs. FRMB vs. PTR vs. PTNR vs. $T_1$ vs. $T_2$ vs. $T_3$

*See footnote on following page.

2. Classroom vs. Booth environment: FRMC vs. FRMB

3. Multiple-choice vs. Free response: MCM vs. (FRMC & FRMB)

4. Overt responses vs. No overt responses: PTR vs. PTNR

5. Machines vs. Programmed textbooks: (MCM & FRMC & FRMB) vs. (PTR & PTNR)

6. Different programmed lecturers: $T_1$ vs. $T_2$

7. Auto-instruction vs. Programmed lectures: (MCM & FRMC & FRMB & PTR & PTNR) vs. ($T_1$ & $T_2$)

8. Programmed lectures vs. Standard lecture: ($T_1$ & $T_2$) vs. $T_3$

9. Auto-instruction vs. Standard lecture: (MCM & FRMC & FRMB & PTR & PTNR) vs. $T_3$

B. To test the hypotheses that the mean performances of students (as measured by criterion test scores) are equal if compared according to the following aptitude quarters:

1. All aptitude quarters: **$Q_1$ vs. $Q_2$ vs. $Q_3$ vs. $Q_4$

2. $Q_1$ vs. $Q_2$

3. $Q_2$ vs. $Q_3$

4. $Q_3$ vs. $Q_4$

---

*MCM: Multiple choice teaching machine
FRMC: Free-response teaching machines in a classroom
FRMB: Free-response teaching machines in individual booths
PTR: Programmed textbooks requiring overt responses
PTNR: Programmed textbooks requiring no overt responses
$T_1$: Programmed lecturer
$T_2$: Programmed lecturer
$T_3$: Standard lecturer

**Aptitude quarters based on Lower Division Engineering Examination (LDEE). $Q_1$ is low-scoring quarter, $Q_4$ is high-scoring quarter.

C. To test the hypotheses that the mean performances of students (as measured by criterion test scores) are equal if compared according to teaching methods and aptitudes (interactions) as follows:

1. All teaching methods and four quarters

2. Machines vs. Programmed textbooks and four quarters

3. Auto-instruction vs. Programmed lectures and four quarters

4. Programmed lectures vs. Standard lectures and four quarters

5. Auto-instruction vs. Standard lecture and four quarters

D. To test the hypotheses that the mean learning times of students are equal if the students are taught by the following methods:

1. All teaching methods: MCM vs. FRMC vs. FRMB vs. PTR vs. PTNR vs. $T_1$ vs. $T_2$ vs. $T_3$

2. Classroom vs. Booth environment: FRMC vs. FRMB

3. Overt responses vs. No overt responses: PTR vs. PTNR

4. Multiple-choice vs. Free response: MCM vs. FRMC

5. Multiple-choice vs. Programmed textbook: MCM vs. PTR

E. To test the hypotheses that the mean learning times of students are equal if compared according to the following aptitude quarters:

1. All aptitude quarters: $Q_1$ vs. $Q_2$ vs. $Q_3$ vs. $Q_4$

2. $Q_1$ vs. $Q_2$

3. $Q_2$ vs. $Q_3$

4. $Q_3$ vs. $Q_4$

F. To test the hypotheses that the mean learning times of students are equal if compared according to teaching methods and aptitudes (interactions).

G. To find the linear relationships between the variables: LDEE, criterion test scores, learning time, criterion test time, and student "liking" the teaching method.

## III. DESCRIPTION OF EXPERIMENT

### SUBJECTS

The pilot study had indicated that a sample size greater than 150 students would be required to give a powerful test of the hypotheses. Therefore, all 186 students enrolled in the seven sections of the Freshman Engineering Laboratory Course at the University of California at Los Angeles participated in this experiment. The students in the Freshman Engineering Laboratory Course were selected for this experiment because:

1. They had previously taken the Lower Division Engineering Examination (LDEE), an aptitude-type test, the results of which could be used to divide the students into aptitude quarters.

2. The pilot study had indicated that there was little or no previous knowledge among freshmen students of the subject matter which would be taught in the experiment, and also that there was very little correlation between such previous knowledge as did exist and performance during the experiment.

3. The subject matter which would be taught during the experiment was sufficiently similar to the material normally taught during the first weeks of this course that it could be incorporated into the normal requirements of the course. This was done to avoid the question of transferability of results from ad hoc experiments.

### MODES OF INSTRUCTION

Two types of teaching machines, two types of programmed textbooks, and two types of lecturers were used.

One of the machines used was a Skinner type Free Response Machine (FRM), a mechanical device for the controlled presentation of a carefully constructed sequence of instructional items. (See Figure A-1 for a description of the FRM.) The other machine was an electromechanical Multiple Choice Machine (MCM) which automatically advances the sequence of instructional items after the student makes the "correct" choice from three alternatives. If a wrong choice is made, the machine scores the error on a cumulative counter and marks the item. The student must then make the "correct" response to advance the instructional material to the next item. (See Figure A-3 for a description of the MCM.)

Both types of machines were available in prototype models only, and a number of operating difficulties were encountered during the pilot study. Most of these difficulties were eliminated by some minor modifications to the machines, and by using a continuous paper feed located external to the machines, instead of fan-folded paper feed locked in the machines. As a result of these modifications the machines operated without any major mishaps during the experiment.

During the pilot study, a delay in the delivery of some of the machines resulted in there being more students available than machines for them to work on (simultaneously). A cardboard masking device was hurriedly improvised which could be used with the same programmed instructional material as used in the FRM. (See Figures A-5 and A-6.) The results of the pilot-study indicated that students performed as well after receiving instruction with this non-mechanical device as after receiving instruction with the mechanical or electromechanical devices. This prompted the introduction of programmed textbooks into the current experiment. In using a programmed textbook, the student reads an item of instruction, writes his response next to the item, turns the page to see the "correct" response, turns the page to see the next item, and so on. (See Figure A-7 for a description of the programmed text.) These programmed texts (PTR) require an overt response by the student, and provide an immediate feedback to the student as to the correctness of his response.

Both features are consistent with the current theories for presenting auto-instructional material to students. Another, often quoted, feature of such auto-instructional material, is that the items of instruction be so ingeniously sequenced and, generally, broken down into such small steps so that the students will respond correctly to 90 - 95% of the items.

At this point, we conjectured that if the auto-instructional material was indeed contrived to insure 90 - 95% correct responses, then perhaps the overall learning of the students might not be seriously impaired by the absence of feedback to the student about the correct answer. We therefore introduced another type of programmed text (PTNR) which required no overt responses and provided no "reinforcement" of the correct answer, other than the statements in each item. (See Figure A-8 for a description of the PTNR.)

During the pilot study, we had two groups of students, each taught by a different instructor. These groups were to have served as controls for comparing automated instruction against "normal" instruction. The results indicated that students who had the "normal" instruction performed as well as students who had received the programmed instruction. However, a review of the tape recordings made during the "normal" lecturers indicated that the lecturers were performing in anything but a "normal" manner. They were performing like "programmed" lecturers. Indeed, both lecturers were so familiar with the closely ordered sequence of items developed for use with the automated devices, that they were actually trying to preserve the same method of presentation, merely translating the written statements of the programmed material into oral form. This was perhaps attributable to the conscious attempt which was made to keep subject matter <u>content</u> the same for all modes of instruction. The lecturers probably had difficulty in separating equality of subject matter content from equality of pedagogical technique. Therefore, in the current experiment, we used the same two instructors and called them Programmed Lecturers ($T_1$ and $T_2$). In addition, we used a third instructor (who was not familiar with the programmed sequence of instructional items) to teach a control group. This Standard Lecturer ($T_3$) was given a topic outline (in this case, a group of probability formulas), an example of the kind of examination (criterion test) which the students would have to take, and a number of marked reference books which covered the selected topics in detail. Two half-hour consultations were held with this Standard Lecturer to discuss the questions he had concerning the subject matter.

## INSTRUCTIONAL MATTER

The instruction given the students was on elementary probability. The original sequence of 230 items was developed more or less in accordance with the concepts enumerated in:

Roe, A. & Moon, H., "Analysis of Course Content for Individual Learning", Automated Teaching Bulletin, Vol. 1, No. 3, Summer 1960.

After the pilot study, an analysis of how students responded to each of the items in the instructional sequence, and how they performed on the criterion test, resulted in modifications to the original sequence, and also elimination of some instructional items which were irrelevant to the performance tested in the criterion test. The revised sequence contained 192 items. Identical items were used in the FRM and PTR. Identical items with the addition of two "wrong" responses for each item were used in the MCM. Identical items, with the response given in the item, were used in the PTNR. The programmed instructors loosely followed the same sequence of items. (See Appendix B for samples from each of the instructional materials.) The intent was to cover the same topics at the same level of difficulty and intensity in each one of the programmed modes of instruction.

## ENVIRONMENTS

There were two machine environments. One was provided by five booths, especially built for machine use, in one room of the laboratory. The other was provided by three rows of large library tables in a separate, larger room. (See Figures A-9 and A-10 for photographs of these two environments.)

Students were convened in standard classrooms for study with the programmed textbooks, and in other classrooms for hearing the programmed and standard lectures.

## PROCEDURES

On the basis of scores on the Lower Division Engineering Examination required of all students before admission to the Department of Engineering, the students were divided into quarters (without their knowing it) and were then randomly assigned from each quarter to the various groups.

A preliminary meeting was held with the instructors of the Freshman Engineering Laboratory sections to explain the nature and purpose of the experiment. They were asked not to mention the study to their students or discuss anything related to it with them.

The students were not informed that they were participating in an experiment, and since they were all new to the University, they could be expected to accept almost any teaching method without too much surprise. The experiment was conducted during the regular scheduled hours of the various class sections. At a previous class meeting, each student had been given a card directing him to the appropriate lecture room or laboratory room.

Upon arrival at the laboratory, each student was instructed to find his name on a place card taped on the table beside each device. Each name card bore the following information:

> The instructional device you will be using is intended to help you learn. You will not be scored or graded on your efforts on this device. However, you will be given a short quiz afterwards. So use your time with the device for learning.

No further instructions were given. Proctors serviced the machines when necessary, and if students asked questions about any item, the proctors were non-committal as to interpretation. Each student progressed through the programmed material at his own rate, and upon completion of the program was given a brief opinion questionnaire and the examination materials (see Appendix B-8, B-9, B-10) which he handed in after finishing the examination.

In the lecture groups, the students were informed that they would be given a brief quiz at the end of the lecture and that they could take notes if they wished. The lectures were tape recorded. At the end of each lecture, these students were given a brief questionnaire and the examination materials. The students were not permitted to use their notes or scratch pad during the examinations.

In all groups the examinations were identical, but the questionnaires were somewhat different for the automated learning and lecture groups. The questionnaire for the automated learning groups was intended to sample student evaluation of the automated method, materials and environment, and the questionnaire for the lecture groups dealt with evaluation of the instructor, the materials and environment.

## IV. RESULTS

The results of this experiment are substantially the same as those obtained during the pilot study. An analysis of variance, comparing the criterion test scores of students who learned by the various methods of instruction, failed to indicate any significant difference between the different methods, considered all together. (See Appendix C-3.)

When comparing pairs of teaching methods, we find no significant difference in criterion test performance between those students who used the Free-Response Machines in the individual booth environment vs. those who used the same machines in a classroom environment. Nor is there a significant difference in performance between students who used the Free-Response Machines vs. those who used the Multiple Choice Machines. Likewise, there is no indication that the programmed textbook with responses results in a significantly better performance than the programmed textbook without responses. Also, machine methods do not result in significantly different criterion test performances than the programmed textbooks. However, the students who had the programmed lectures, and the students who used the programmed auto-instructional material in the machines and the textbooks, did perform significantly better than the students who had the standard lecture.

While the various methods of presenting programmed material resulted in approximately equivalent performances by the students on the criterion test, the time that the students took in learning by the various methods of instruction was significantly different. The lectures were delivered in considerably less time than the mean time taken by the students who paced themselves on the machines and programmed texts. The students using those devices which did not require the composition of a written answer, namely, the Multiple Choice Machines and the Programmed Texts With No Responses, took significantly less time for learning than the students who used the Free Response Machines and the Programmed Texts With Responses.

As expected, the students in the lower aptitude quarters did not score as high in the criterion tests as the students in the upper quarters, and also, the lower quarter students took longer to complete the learning task than the upper quarter students. However, there is no significant indication that any one of the teaching methods is better than another for students of a particular aptitude quarter, either on the basis of criterion test performance or learning time.

In examining the linear relationships between the variables (Appendix C-4) we find the amount of time the individual students took to complete the criterion test was not significantly correlated to the aptitude rating of the student, but the amount of time taken to complete the criterion test, did correlate significantly with the test scores. Contrasted to this is the result that the individuals with high aptitude scores took less time during the learning phase. Also, the less time the individual took during the learning phase, the more time was taken during the criterion test.

The students' subjective opinion about the various teaching methods, as indicated by the "liking" ratings, did not correlate either with their aptitude nor with their performance on the criterion test. The divergent opinions of the students, as also shown in their comments (see Appendix F), indicates that such subjective opinions are mediated by factors other than educational aptitude or performance.

The average percentage of incorrect responses made by students using the MCM and PTR (where records of errors were kept) was less than

11%. This figure could be used, with some caution, in evaluating the difficulty level (or adequacy) of the programmed teaching material.

## V. CONCLUSIONS

For linearly programmed subject matter there appears to be little justification for preferring one mode of presentation over another, insofar as the effect on the level of student performance is concerned. It seems that the important variable is the program of instruction, and if this has been carefully conceived, then the particular method of presenting the program does not significantly influence the level of student performance. Some of the hardware currently being used to display programmed material may therefore be unnecessary, particularly if it takes longer for a student to complete a given programmed course with the device than with a simple printed textbook version.

We should also recognize that some machine features, such as anti-cheat mechanisms and the recording of particular items which are missed, do not necessarily enhance student learning, but rather are convenient features for the experimenter who wishes to evaluate student performance or particular items of the teaching program. If the emphasis is on using a more or less perfected program for student learning, then many of the machine features are unnecessary and may actually impede student learning. If the emphasis is on improving the program, then most machine devices currently employed could be improved upon to facilitate this task. If one wishes to simultaneously teach and to improve the program (and this may well be the direction in which future device capabilities will evolve) then some new thinking and relatively sophisticated hardware will be required (See Roe, A., Lyman, J., & Moon, H., "The Dynamics of an Automated Teaching System", Automated Teaching Bulletin, Vol. 1, No. 4, Winter 1960.)

We were not surprised to find that the difference between using multiple-choice items vs. recall or free-response items (the subject of much previous dispute) and the difference between individual booth and classroom environments, did not significantly affect student learning.

Perhaps the most significant discovery made during the experiment was that overt student responses, followed by immediate feedback on the "correct" response did not enhance student learning but merely increased the time necessary for performing the learning tasks. While the current concepts of programming material still depends very much upon "arranging appropriate contingencies of reinforcement" to ellicit specified student performance, some questions are now raised concerning the validity of the reinforcement theory of learning, particularly as applied to B. F. Skinner's "appropriate teaching machine", (see Skinner, B.F., "Teaching Machines" Science, Vol. 128, No. 3330, October 24, 1958, pp. 969-977).

While it would be imprudent to attempt to generalize from the results of this series of experiments to all types and levels of course material, and to all student ages and backgrounds, it appears that experimental data does not coincide with some of the currently publicized advantages of certain auto-instructional techniques, particularly as applied to linearly programmed material. This does not mean that proper programming of instructional material is not beneficial to the student. On the contrary, the program itself seems to be the important factor, and the method or device for displaying the program will depend on the economical and environmental circumstance that prevails in each particular case.

Even when emphasizing the importance of the programmed material, we must exercise some caution. One student, who failed to read the instructions at the beginning of the programmed textbook, read down the page instead of from page to page with the result that the sequence of items he saw were numbered: 1, 40, 79, 118, 157; 2, 41, 80, 119, 158; 3, 42, 81, 120, 159; and so on. This student still managed to get a high score on the criterion test. This "accident" leads us to ponder on the concepts used in sequencing instructional items.

In conclusion, we feel that present theories and auto-instructional techniques are inadequate to achieve the goals of effective individualized instruction, and that a workable automated teaching system will require further analytical and hardware development.

FIGURE A-1

FREE RESPONSE MACHINE (FRM). Learning items appear under transparent window at left of machine. Student responds on tape at right of machine, then turns knob which moves a transparent window over the student's response and simultaneously uncovers the correct response (under black mask at center of machine).

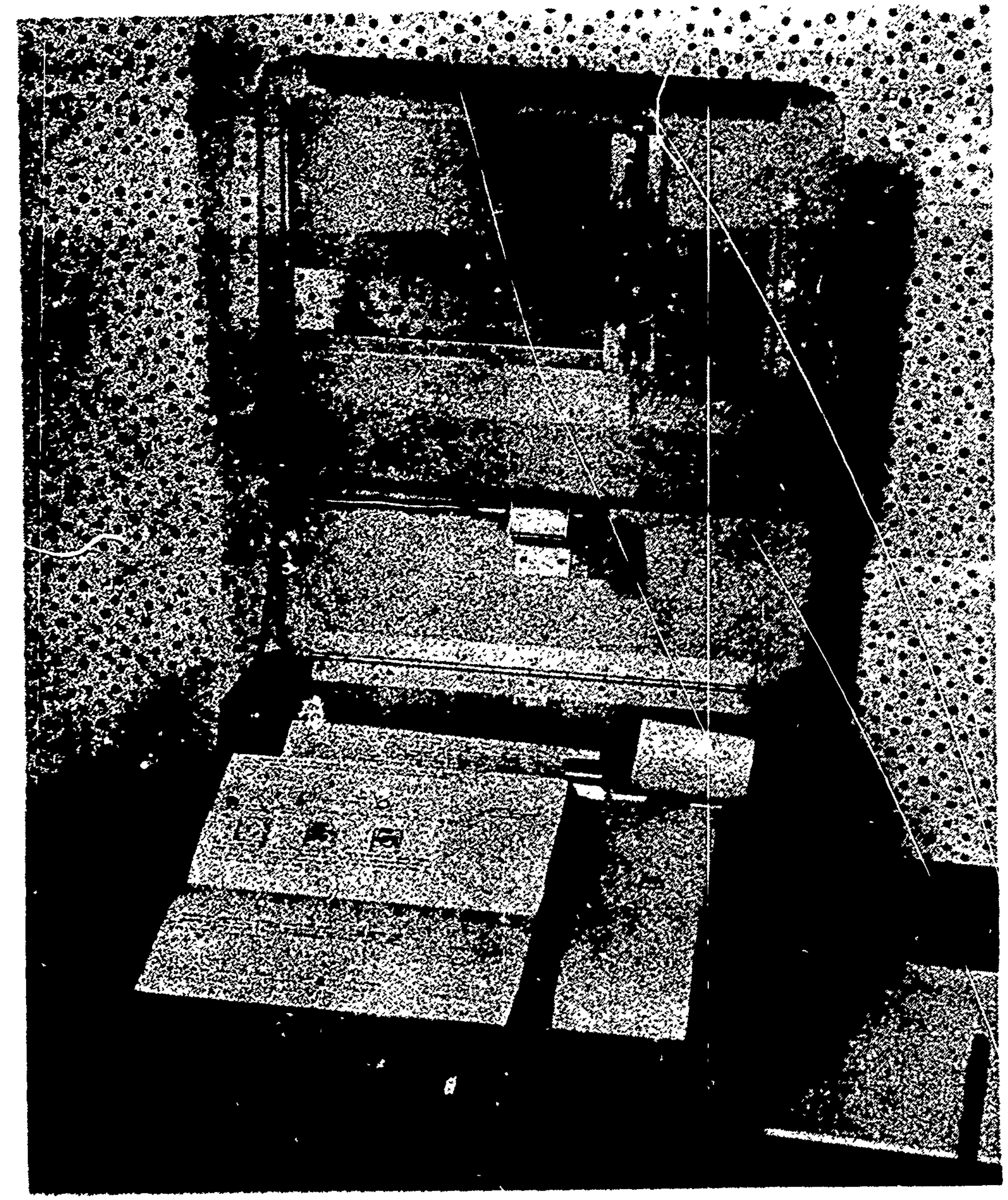


FIGURE A-2

FREE RESPONSE MACHINE, showing internal mechanism, programmed learning material, and separate student response tape. The back of the program and response tapes are marked each time a student records an error.

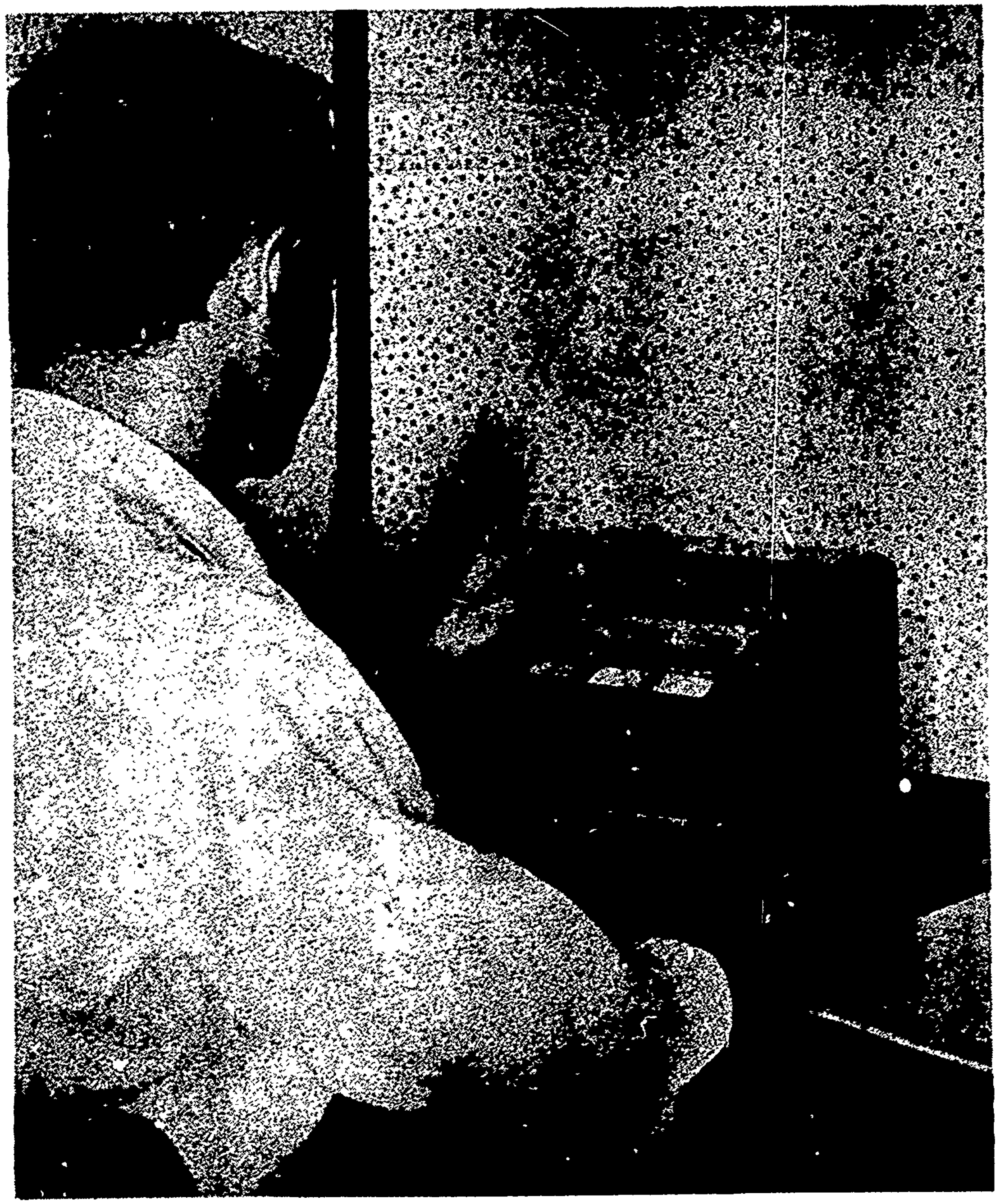


FIGURE A-3

MULTIPLE CHOICE MACHINE (MCM). Learning items appear under the large transparent window. Student responds by depressing the small transparent windows covering the answer of his choice.

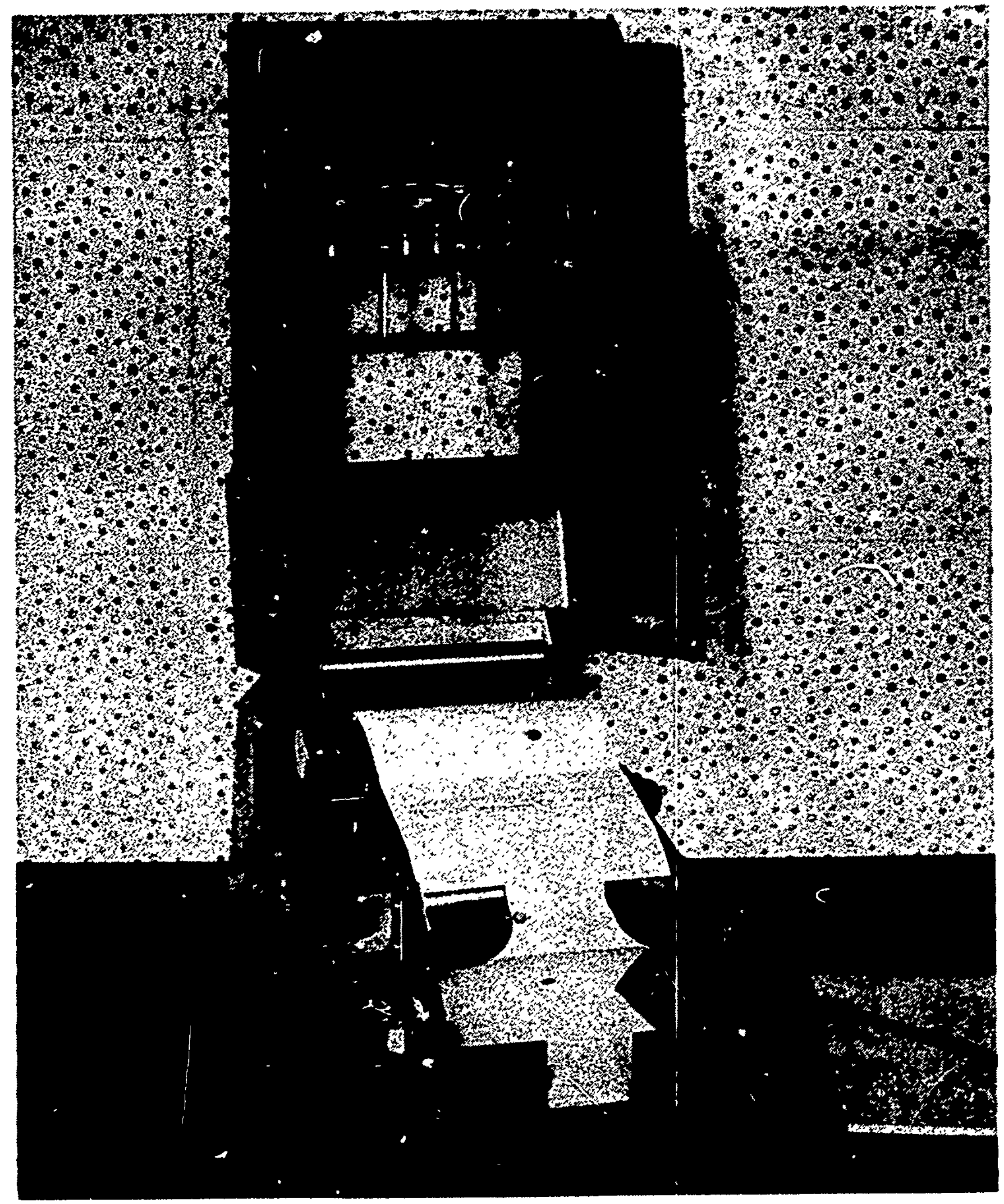


FIGURE A-4

MULTIPLE CHOICE MACHINE, showing internal mechanism for automatic advancing of the programmed learning material.

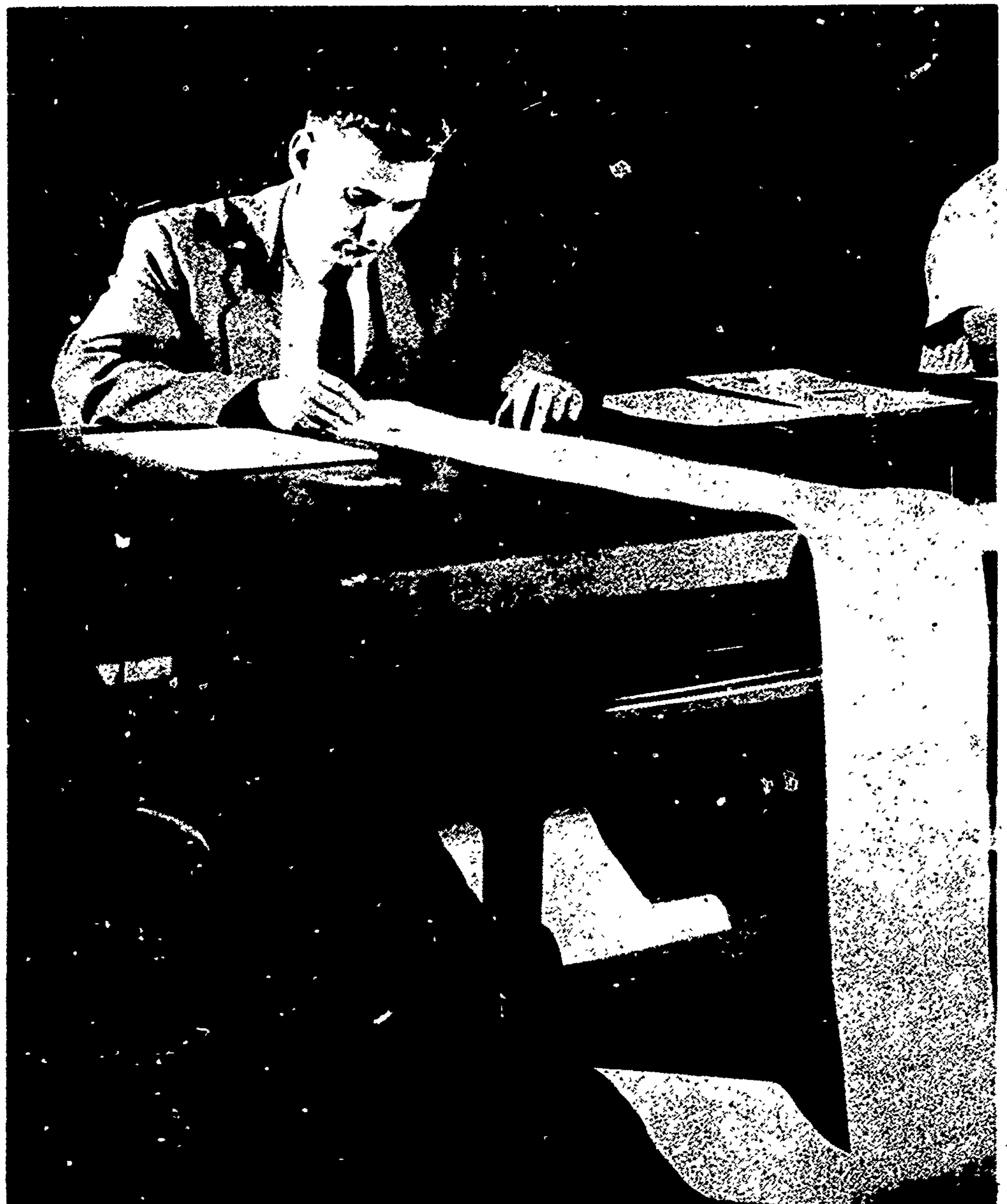


FIGURE A-5

MASKING SLIP (M.S.) A non-mechanical device used presenting programmed learning material to students during the pilot study.

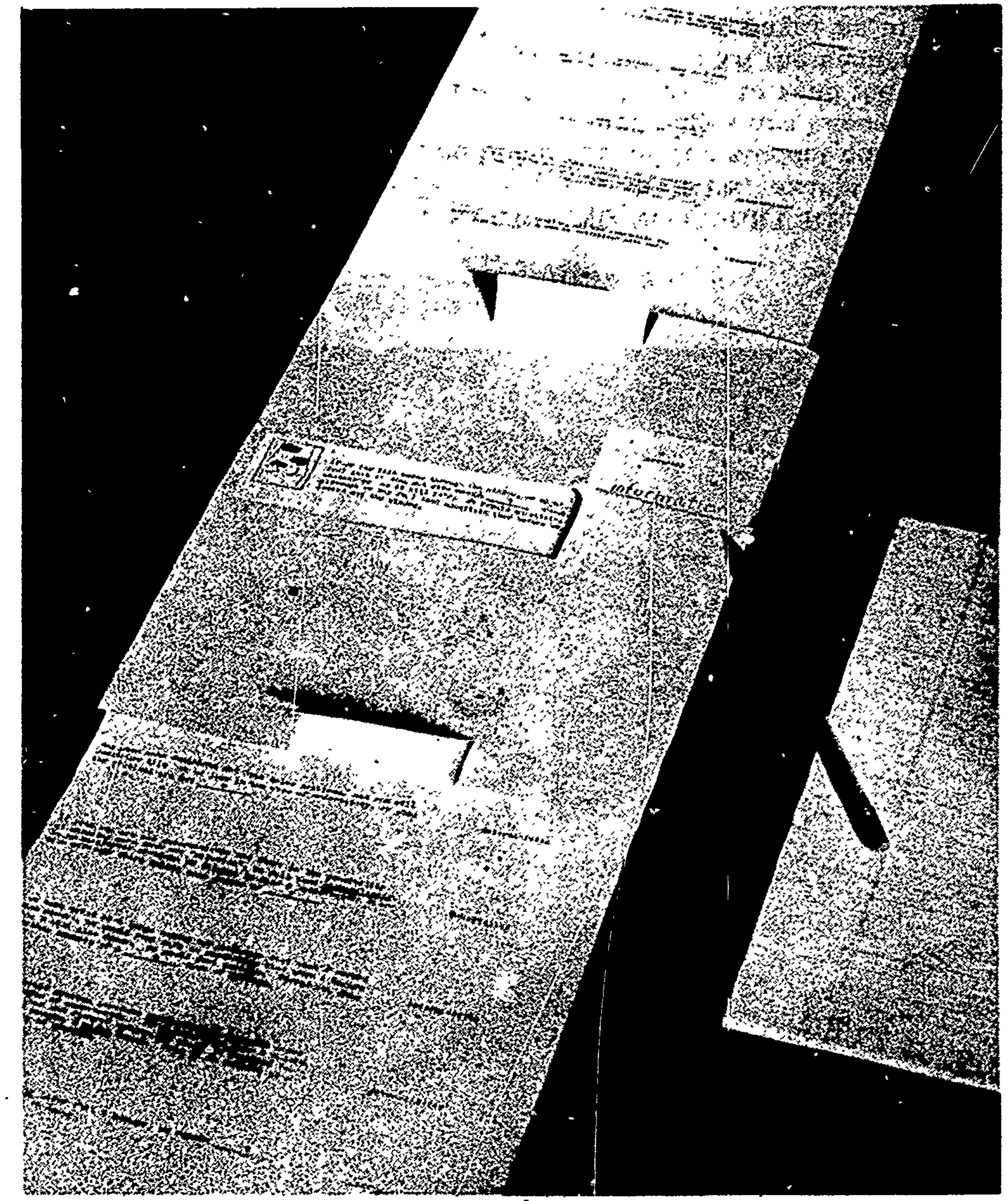


FIGURE A-6

MASKING SLIP, improvised from cardboard file folders, during the pilot study.

FIGURE A-7

PROGRAMMED TEXT REQUIRING AN OVERT RESPONSE (PTR). Each paragraph between the heavy black lines is a completion type item, identical to those used in the Free Response Machines. The student writes his response to an item, then turns to the next page which is an "answer" page, to verify the correctness of his response. The next item in the sequence of instruction is found on the page following the "answer" page.

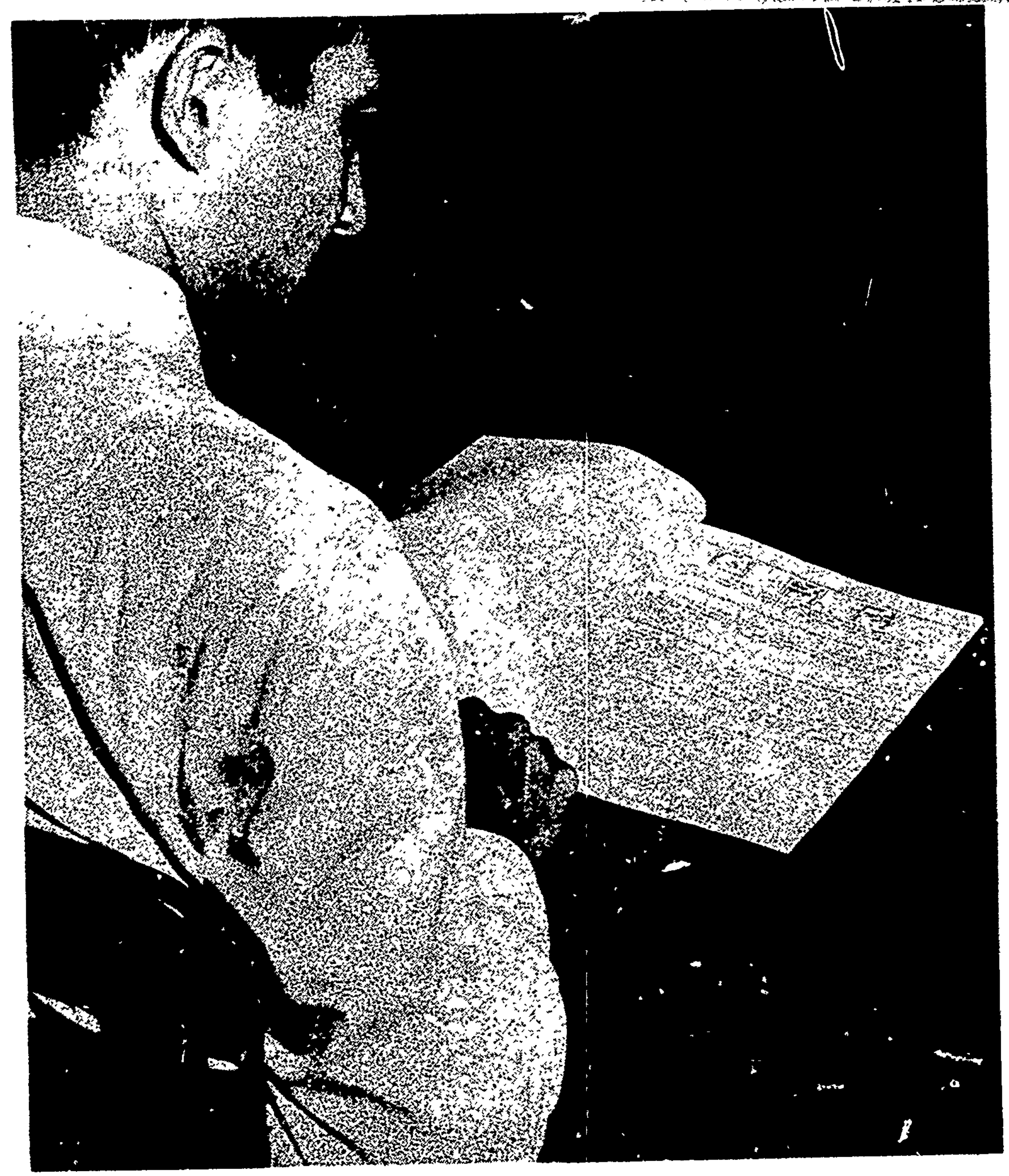


FIGURE A-8

PROGRAMMED TEXT REQUIRING NO OVERT RESPONSE (PTNR). The items are identical to those in the PTR, except that complete statements are made; no blank spaces for student completion are provided, and therefore no "answer" pages are needed. The student merely reads an item, turns the page to read the next item, and so on. Note that in both PTR and PTNR the sequence of items is from page to page, rather than down the page, as in conventional texts.

FIGURE A-9

BOOTH ENVIRONMENT

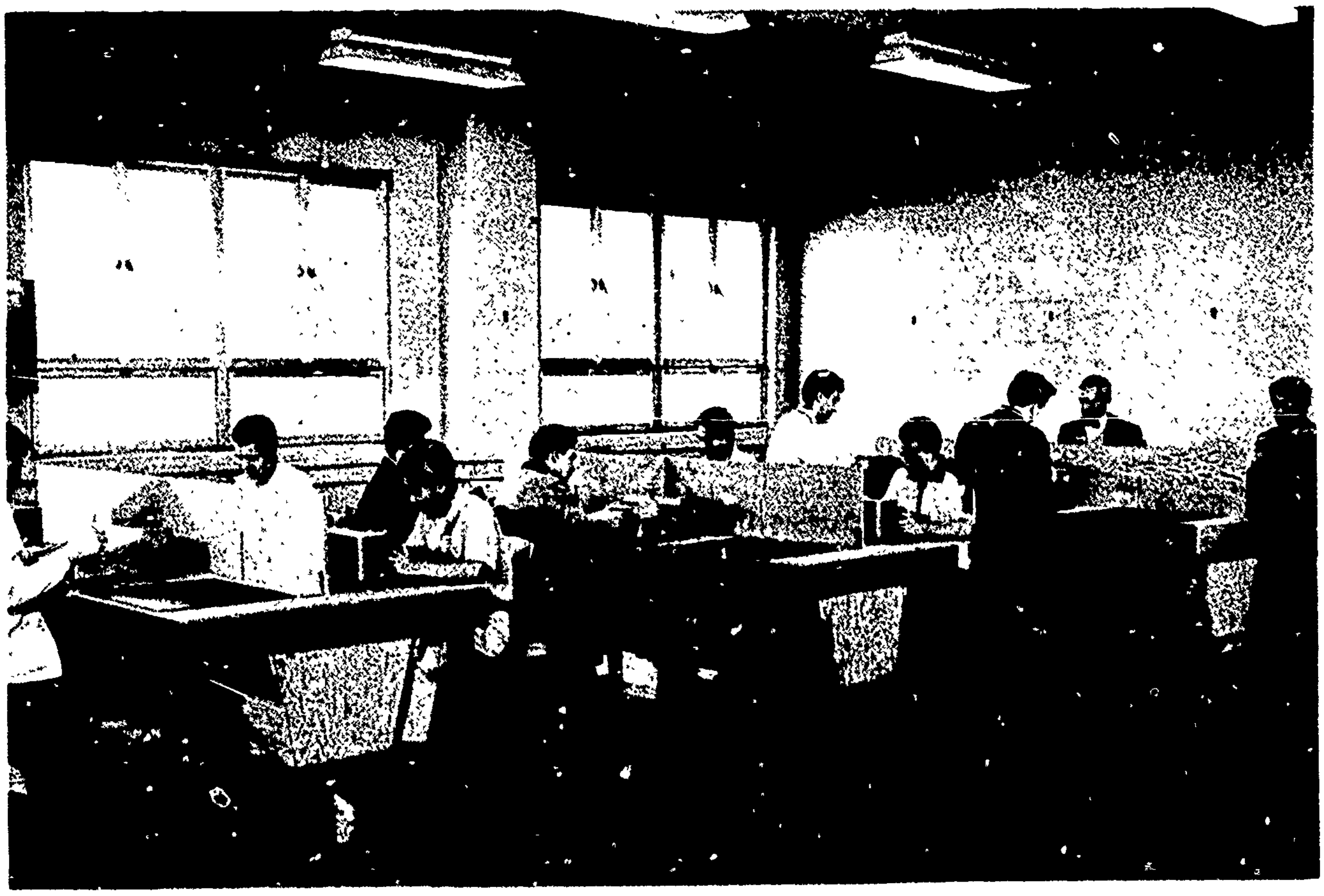


FIGURE A-10

CLASSROOM ENVIRONMENT. Bins under the tables are for storing rolls of program sheets and response tapes, which are fed continuously through the machines. Both Free Response Machines and Multiple Choice Machines were used in this classroom.

# APPENDIX B

## 1. FREE RESPONSE MACHINE PROGRAM SAMPLE

(Learning Items)

Correct Response, Concealed in FRM While Student Composes His Response

122 So far you have studied about the probability of a single event, P {A} ; the probability of either one or another of two or more possible events, P {A or B} ; the probability of joint events, P {AB} ; and the probability of the union of events, P {A∪B} ; that is, the probability of either A or B occurring when it is possible for ___?___ A and B to occur in the same trial.

both

123 The probabilities were represented as some fractional value, generally obtainable by dividing n by N. The values of n and N are not always easy to find by simple counting procedures. Two computational methods used in finding the values of n and N are PERMUTATIONS and COMBINATIONS. The distinction between ___?___ and combinations depends upon whether or not the things we are interested in have distinguishable ORDERED arrangements.

permutations

124 The first three letters of the alphabet can be arranged in six different orders, abc, acb, bac, bca, cab, cba. As you can see, each of the six sets of letters contains the same three letters but in a different _______ arrangement.

ordered

125 If the number of objects or events to be ordered is small, one can make all the possible ordered arrangements, as we did with the first three letters of the alphabet, and count them. However, if the number of objects is larger, it is more convenient to calculate the number of possible ordered arrangements. In the case of the first three letters of the alphabet, this is done by 3 x 2 x 1 = 6, which is the same ___?___ of possible ordered arrangements we prepared in the preceding item.

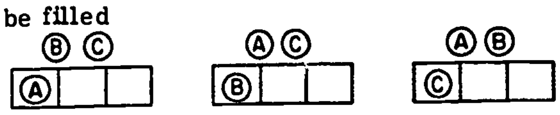
number

126 We calculated the number of possible ordered arrangements of the first three letters of the alphabet by 3 x 2 x 1 = 6. To illustrate why this method is used, let us use three balls, labelled A, B, and C, and a box divided into three cells.


How many different balls can we choose from to fill cell 1?

3

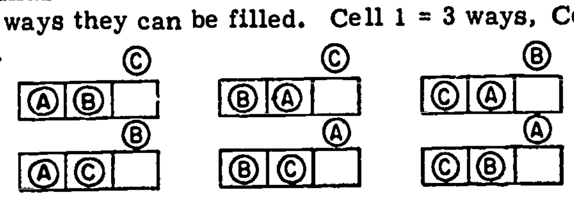
127 Cell 1 can be occupied by ball A, or B, or C. There are then three different ways (balls) by which Cell 1 can be filled. If we fill Cell 1 in each of the three different ways, it can be filled



We can see that regardless of which of the three balls is chosen to fill Cell 1, when Cell 1 is filled, there are ___?___ balls left from which we can choose to fill Cell 2.

two

128 This illustration shows Cells 1 and 2 filled in all the possible ways they can be filled. Cell 1 = 3 ways, Cell 2 = 2 ways.



We can see in this illustration that there is only one way (ball) left to fill cell 3 when cells 1 and 2 are filled. Thus, there are 3 x 2 x 1 = _____ ways in which 3 balls can fill 3 cells.

6

129 The first six letters of the alphabet can be arranged in $6 \times 5 \times 4 \times 3 \times 2 \times 1 = 720$ different ordered arrangements. Each ordered arrangement is called a PERMUTATION. Therefore, there are 720 possible ___?___ of the first six letters of the alphabet.

permutations

130 A permutation is an ___?___ arrangement.

ordered

131 In arranging the first 5 letters of the alphabet in all the possible permutations, there are:

n = 5 possibilities for the first choice
n - 1 = 4 for the second choice
n - 2 = 3 for the third
n - 3 = 2 for the fourth
n - 4 = 1 for the fifth

Permutations = (5) (4) (?) (2) (1) = 120

3

132 Now we can write the general equation for calculating the permutations of n things. Permutations = n(n-1)(n-1)... (1). The row of dots indicates omission of intermediate values. The figure (1) at the end, indicates the end of the series of values, because any series of this sort always ends in 1. If there are 6 things to be ordered, then n = 6.

Permutations = (6)(6-1)(6-2)(6-3)(6-4)(6-5)
= (6)(5) (4) (?) (?) (1).

3, 2

133 If there are 8 things, n = 8.

Permutations = (8)(7)(6)(5)(4)(3)(2)(1)
= n(n-1) ( ? ) ( ? )......(1).

n-2, n-3

134 In multiplication, each of the numbers multiplied together is called a factor. In Permutations = (6)(5)(4)(3)(2)(1), each of the numbers multiplied together is a factor. Likewise, in the formula for permutations, Permutations = n(n-1)(n-2).....(1); n and each expression inside parentheses is a ___?___.

factor

135 The symbol n!, read "n-factorial", stands for the number of factors which must be multiplied together to obtain the number of permutations of n events or objects. Thus, n! = n-factors = n(n-1)(n-2).....(1). Therefore, the general formula for permutations of n things is easily written: Permutations = ___?___.

(Hint: n - factorial).

n!

136 n! stands for the number of different ___?___ of n objects or n events.

permutations
or ordered arrangements

137 If there is a chair for each student, 5 students can be seated in n! = 5! = (5)(4)(3)(2)(1) = 120 different ways (permutations). The first four letters of the alphabet can be arranged in n! = ___?___ = (4)(3)(2)(1) = 24 permutations.

4!

138 If n = 8, n! = 8! = ___?___. (Write the factors.)

(8)(7)(6)(5)(4)(3)(2)(1)

# APPENDIX B

## 2. MULTIPLE CHOICE MACHINE PROGRAM SAMPLE

122 So far you have studied about the probability of a single event, P {A} ; the probability of either one or another of two or more possible events, P {A or B} ; the probability of joint events, P {AB} ; and the probability of the union of events, P {A U B} , that is, the probability of either A or B occurring when it is possible for __?__ A and B to occur in the same trial.

[either] [both] [neither]

123 The probabilities were represented as some fractional value, generally obtainable by dividing n by N. The values of n and N are not always easy to find by simple counting procedures. Two computational methods used in finding the values of n and N are PERMUTATIONS and COMBINATIONS. The distinction between __?__ and combinations depends upon whether or not the thing we are interested in has distinguishable ORDERED arrangements.

[permutations] [probabilities] [computations]

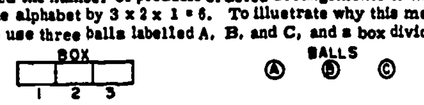
124 The first 3 letters of the alphabet can be arranged in six different orders: abc, acb, bac, bca, cab, cba. As you can see, each of the six sets of letters contains the same 3 letters but in a different ________ arrangement.

[ordered] [style of] [probable]

125 If the number of objects or events to be ordered is small, one can make all the possible ordered arrangements, as we did with the first 3 letters of the alphabet, and count them. However, if the number of objects is larger, it is more convenient to calculate the number of possible ordered arrangements. In the case of the first 3 letters of the alphabet, this is done by 3 x 2 x 1 = 6, which is the same ________ of possible ordered arrangements we prepared in the preceding item.

[number] [style] [combination]

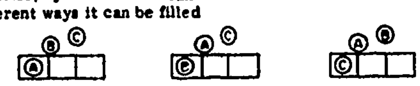
126 We calculated the number of possible ordered arrangements of the first 3 letters of the alphabet by 3 x 2 x 1 = 6. To illustrate why this method is used, let us use three balls labelled A, B, and C, and a box divided into three cells:




How many different balls can we choose from to fill cell 1?

[1] [3] [2]

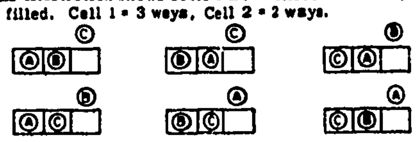
127 Cell 1 can be occupied by ball A, B or C. There are, then, 3 different ways (balls) by which cell 1 can be filled. If we fill cell 1 in each of the 3 different ways it can be filled



we can see that regardless of which of the 3 balls is chosen to fill cell 1, when cell 1 is filled, there are __?__ balls left from which we can choose to fill cell 2?

[3] [1] [2]

128 This illustration shows cells 1 and 2 filled in all the possible ways they can be filled. Cell 1 = 3 ways, Cell 2 = 2 ways.



We can see in this illustration that there is only one way (ball) left to fill cell 3, when cells 1 and 2 are filled. Thus, there are 3 x 2 x 1 = __?__ ways in which 3 balls can fill 3 cells.

[different] [6] [identical]

129 The first six letters of the alphabet can be arranged in 6 x 5 x 4 x 3 x 2 x 1 = 720 different ordered arrangements. Each ordered arrangement is called a PERMUTATION. Therefore, there are 720 possible ____________ of the first 6 letters of the alphabet.

[permutations] [combinations] [identical groups]

130 A permutation is an ____________ arrangement.

[identical] [ordered] [neither identical nor ordered]

131 In arranging the first 5 letters of the alphabet in all the possible permutations, there are

n = 5 possibilities for the first choice
n-1 = 4 for the second choice
n-2 = 3 for the third
n-3 = 2 for the fourth
n-4 = 1 for the fifth

Permutations = (5) (4) (?) (2) (1) = 120

[n-4]  [3]  [n-3]

---

132 By what we have seen we can write the general equation for calculating the permutations of n things.

Permutations = $n(n-1)(n-2)\ldots(1)$

The row of dots indicates omission of intermediate values. The figure (1) at the end indicates the end of the series of values, because any series of this sort always ends in 1. If there are 6 things to be ordered, then n = 6.

Permutations = $(6)(n-1)(n-2)(n-3)(n-4)(n-5)$
= $(6)(6-1)(6-2)(6-3)(6-4)(6-5)$
= (6) (5) (4) (?) (?) (1)

[4, 3]  [3, 2]  [n-1, n-2]

---

133 If there are n things, n = 8.

Permutations = $(8)(7)(6)(5)(4)(3)(2)(1)$
= n(n-1) ( ? ) ( ? )...(1)

[n-2, n-3]  [n-3, n-4]  [6, 5]

---

134 In multiplication, each of the numbers multiplied together is called a factor. In permutations = (6)(5)(4)(3)(2)(1), each of the numbers multiplied together is a factor. Likewise, in the formula for permutations: permutations = $n(n-1)(n-2)\ldots(1)$; n and each expression inside parentheses is a __________.

[factor]  [multiple]  [trinomial]

---

135 The symbol n!, read "n-factorial", stands for the number of factors which must be multiplied together to obtain the number of permutations of n events or objects. Thus, n! = n-factors = $n(n-1)(n-2)\ldots(1)$. Therefore, the general formula for permutations of n things is easily written: Permutations = __?__. (Hint: n-factorial.)

[n(n-1)(n-2)...(r)]  [n(n-1)(n-2)...(n)]  [n!]

---

136 n! stands for the number of different __________ of n objects or n events.

[combinations]  [permutations]  [like orders]

---

137 If there is a chair for each student, 5 students can be seated in n! = 5! = (5)(4)(3)(2)(1) = 120 different ways (permutations). The first four letters of the alphabet can be arranged in n! = __?__(4)(3)(2)(1) = 24 permutations.

[5!]  [4!]  [24!]

---

138 If n = 5, n! = 5! = __?__.
(Identify the factors)

[(5)(4)(3)(2)]  [(5)(3)(4)(2)(1)]  [(5)(4)(3)(2)(1)]

---

139 In previous examples we arranged all the n things in the possible different n! permutations (orders). In the case of the first four letters of the alphabet, n=4; therefore, there were n! = __?__ permutations. (Identify the final answer.)

[24]  [10]  [12]

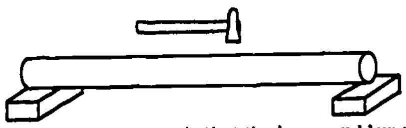
---

140 If all of n objects are taken at a time, the number of permutations = n! That is, if n objects are taken n at a time, permutations = n! If there are n objects and we want to know the possible permutations if we take less than n at a time, we say we take n objects "r" at a time. Thus, "r" is an arbitrary symbol standing for some number less than n. If we have four objects and we want to take them in pairs (2 at a time) n = 4, and r = __?__.

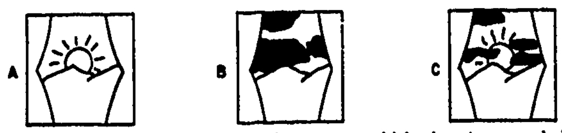
[n]  [2]  [4]

## APPENDIX B

## 3. SAMPLE FROM: PROGRAMMED TEXT WITH RESPONSES

| page 11 | page 12 |
|---|---|
| 5<br><br>Would you be certain or uncertain that the hammer blow would not break the tough steel rod? | 5<br>certain (that the rod would not be broken) |
| 44<br>Let a trial be a single toss of a coin. There is only one head on a coin. Therefore, there is only <u>one</u> possible occurrence of <u>heads</u>. If A = heads, thus, in<br>$P\{A\} = \frac{n_A}{N}$, $n_A$ = ________.<br>(the number of possible occurrences of the event <u>heads</u>). | 44<br>1 |
| 83<br>*In cases like flipping a coin or rolling a die, replacement is not a problem; it has already been taken care of. The head and tail remain on a coin, and all the six numbers on a die remain on the die. However, when something can be removed in a trial, we must consider whether or not that something will be ____________ before the next trial.* | 83 |
| 122<br>So far you have studied about the probability of a single event, $P\{A\}$; the probability of either one or another of two or more possible events, $P\{A \text{ or } B\}$; the probability of joint events, $P\{AB\}$; and the probability of the union of events, $P\{A \cup B\}$; that is, the probability of either A or B occurring when it is possible for ____________ A and B to occur in the same trial. | 122<br>both |
| [illegible]<br>Permutations = $\frac{n!}{2!\,1!\,1!\,1!}$.<br>In how many different permutations can the letters of the word PAPAL be arranged? (Note the kinds of letters and the number of each kind.) | 161<br>$\frac{5!}{2!\,2!\,1!} = 30$ |

6




If you think it might rain during the day, you could look out your window and try to forecast from what you see whether it will rain. Which view above (A, B or C) would make you most certain that it would rain?

45

When we toss an ordinary balanced coin, it can land either <u>heads</u> or <u>tails</u> (if the possibility of standing on edge is eliminated). Therefore, the number of <u>all</u> possible events on a single toss (trial) of a coin is two (heads or tails).

In $P\{A\} = \frac{n_A}{N}$, N = ______, (the number of all possible events on a toss of a coin).

84

Two girls and 3 boys are in a room. To calculate the probability that a blindfolded person will first choose a girl, then choose a boy, we must know if the first person chosen will remain (be replaced) in the group or sent out of the room. A = girl, B = boy. If the first person is replaced in the group, then

$P\{AB\} = P\{A\}\, P\{B\} = \frac{2}{5} \times \frac{3}{5} = \frac{6}{25}$. However, if the first

person is sent out of the room, only 4 persons would be left for the second

123

The probabilities were represented as some fractional value, generally obtainable by dividing n by N. The values of n and N are not always easy to find by simple counting procedures. Two computational methods used in finding the values of n and N are PERMUTATIONS and COMBINATIONS. The distinction between ________________ and combinations depends upon whether or not the thing we are interested in has distinguishable ORDERED arrangements.

[illegible]
of abc, there would be 3 subgroups, and each subgroup would have only one member, because there is only 1 (a), 1 (b) and 1 (c). Thus,

$\frac{n!}{n_1!\,n_2!\,n_3!} = \frac{(3)(2)(1)}{(1)(1)(1)} = \frac{6}{1} =$ ________.



6

B

45

2

84

4

123

Permutations

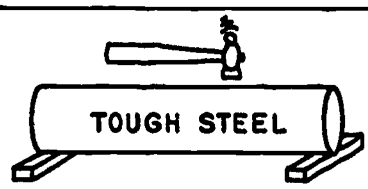
6

## APPENDIX B

## 4. SAMPLE FROM: PROGRAMMED TEXT NO RESPONSE



5




You would be certain that the hammer blow would not break the tough steel rod.

44

Let a trial be a single toss of a coin. There is only one head on a coin. Therefore, there is only one possible occurrence of heads. If A = heads, thus, in

$$P\left\{A\right\} = \frac{n_A}{N}, \quad n_A = 1$$

83

In cases like flipping a coin or rolling a die, replacement is not a problem: it has already been taken care of. The head and tail remain on a coin, and all the six numbers on a die remain on the die. However, when something can be removed in a trial, we must consider whether or not that something will be replaced before the next trial.

122

So far you have studied about the probability of a single event, $P\left\{A\right\}$; the probability of either one or another of two or more possible events, $P\left\{A \text{ or } B\right\}$; the probability of joint events, $P\left\{AB\right\}$; and the probability of the union of events, $P\left\{AUB\right\}$, that is, the probability of either A or B occurring when it is possible for both A and B to occur in the same trial.

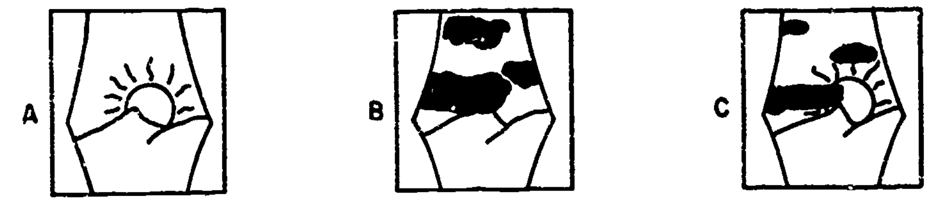
[illegible]
The number of different permutations [illegible] the letters of the word [illegible] can be arranged is:

Permutations = [illegible]

The different permutations of the letters in the word PAPAL are:

$$\frac{5!}{2!\,2!\,1!} = 30$$

6




If you think it might rain during the day, you could look out your window and try to forecast from what you see whether it will rain. View B would make you most certain that it would rain.

45

When we toss an ordinary balanced coin, it can land either heads or tails (if the possibility of standing on edge is eliminated). Therefore, the number of all possible events on a single toss (trial) of a coin is two (heads or tails).

In $P\{A\} = \frac{n_A}{N}$, N = 2.

84

Two girls and 3 boys are in a room. To calculate the probability that a blindfolded person will first choose a girl, then choose a boy, we must know if the first person chosen will remain (be replaced) in the group or sent out of the room. A = girl, B = boy. If the first person chosen is replaced in the group, then

$P\{AB\} = P\{A\}\,P\{B\} = \frac{2}{5} \times \frac{3}{5} = \frac{6}{25}$. However, if the first person chosen is sent out of the room, only 4 persons would be left for the second choice. In this case $P\{AB\} = \frac{2}{5} \times \frac{3}{4}$ or $\frac{3}{5} \times \frac{2}{4}$.

123

The probabilities were represented as some fractional value, generally obtainable by dividing n by N. The values of n and N are not always easy to find by simple counting procedures. Two computational methods used in finding the values of n and N are PERMUTATIONS and COMBINATIONS. The distinction between permutations and combinations depends upon whether or not the thing we are interested in has distinguishable ORDERED arrangements.

[illegible]

To use Permutations = $\frac{n!}{n_1!\, n_2!\, n_3! \cdots n_k!}$ to calculate the permutations of abc, there would be 3 subgroups, and each subgroup would have only one member, because there is only 1 (a), 1 (b) and 1 (c). Thus,

$$\frac{n!}{n_1!\, n_2!\, n_3!} = \frac{(3)\,(2)\,(1)}{(1)\,(1)\,(1)} = 6.$$

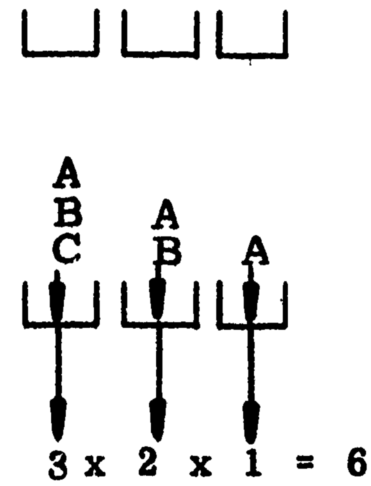
## APPENDIX B

## 5. TRANSCRIPTION FROM PROGRAMMED LECTURE - $T_1$

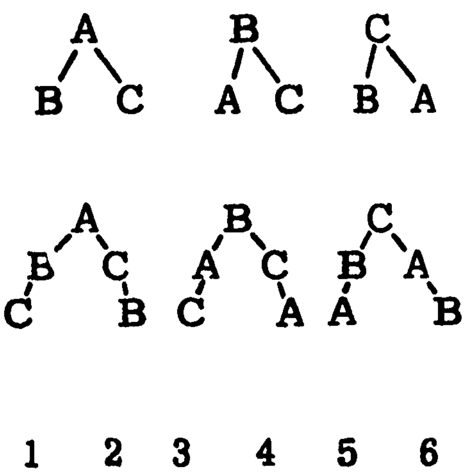
Let's say we have three events, A B C, three things, it does not matter, just A B C. We can handle it because we are engineers with high mathematical knowledge. We have A, B, and C and we are interested in how many ordered sequences of A, B and C we can get. Let's say we have three bins and we are making choices for what goes into our bins. How many choices do we have if we are throwing these things in. How many choices do we have for the first bin? (Response. Three.) Second? (Response. Two.) Third? (Response - only one left.) If we are interested in the number of ordered sequences of A, B, and C, we multiply these and get six. But let me explain this in a different way that makes more sense; where the six comes from. We have, A, B, and C again, and we are interested in ordered sequences. We want to choose a letter or an event to come after A where we have a choice of B here, C here; same way B here, C here; A here, B here. OK? Coming out with this now we only have one choice which is like this. ( ) OK. Now each one of these is an ordered sequence, and if we count up the number of ordered sequences we obviously have three, six rather. Now each one of these ordered sequences I call a permutation of the events. The events are all individually identifiable, I can tell A from B from C. But I'm interested in how many ways can I arrange them, and I get six. And the number six I found (I make up this way) going into generalities. Let's say I have n events -- all distinguishable, (if that's how you spell distinguishable), I found out that what I did was going-back to this for a simple minded procedure -- was first put

**Blackboard Work**

A B C




A B C




3 x 2 x 1 = 6

n events

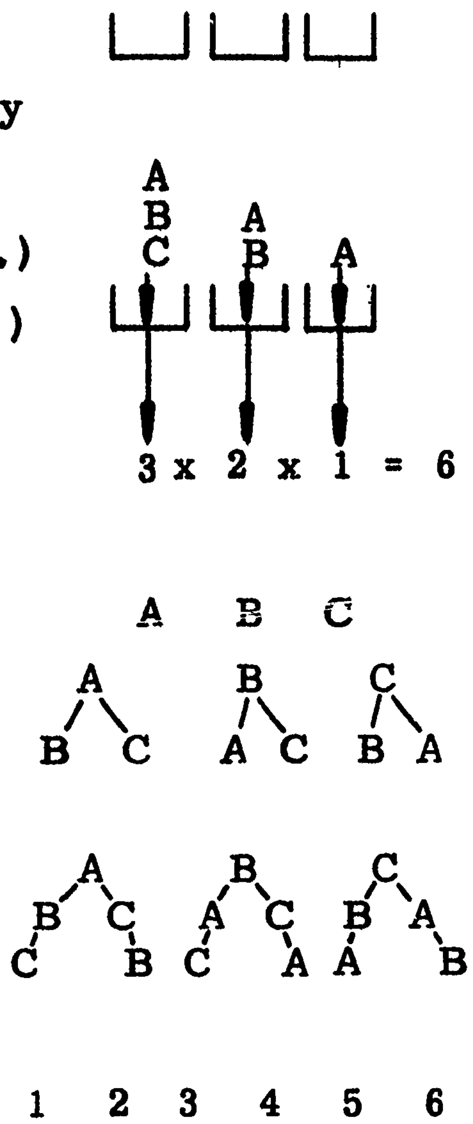
## APPENDIX B

## 5. TRANSCRIPTION FROM PROGRAMMED LECTURE - $T_1$

Let's say we have three events, A B C, three things, it does not matter, just A B C. We can handle it because we are engineers with high mathematical knowledge. We have A, B, and C and we are interested in how many ordered sequences of A, B and C we can get. Let's say we have three bins and we are making choices for what goes into our bins. How many choices do we have if we are throwing these things in. How many choices do we have for the first bin? (Response. Three.) Second? (Response. Two.) Third? (Response - only one left.) If we are interested in the number of ordered sequences of A, B, and C, we multiply these and get six. But let me explain this in a different way that makes more sense; where the six comes from. We have, A, B, and C again, and we are interested in ordered sequences. We want to choose a letter or an event to come after A where we have a choice of B here, C here; same way B here, C here; A here, B here. OK? Coming out with this now we only have one choice which is like this. ( ) OK. Now each one of these is an ordered sequence, and if we count up the number of ordered sequences we obviously have three, six rather. Now each one of these ordered sequences I call a permutation of the events. The events are all individually identifiable, I can tell A from B from C. But I'm interested in how many ways can I arrange them, and I get six. And the number six I found (I make up this way) going into generalities. Let's say I have n events -- all distinguishable, (if that's how you spell distinguishable), I found out that what I did was going-back to this for a simple minded procedure -- was first put

**Blackboard Work**

A B C




3 x 2 x 1 = 6

n events

down n, the number of ways I can fill the first block. The next number I put down was n - 1, number of ways I could fill the second block. And then put down n - 2, and so on, I would have gone on had I more. And, putting in dots for what I am leaving out, I finally would have gotten down to 1. I then would have multiplied all these things out together and I would have gotten the number of permutations. We have a shorthand for this and we say that this sequence of operations is equivalent to writing n with an exclamation point over it which means n factorial. This notation is familiar? unfamiliar? If it's unfamiliar I'm happy because you have learned something. So n factorial we associate with the number of permutations of distinguishable things. Let's say we have the first five numbers in the Arabic number system: How many ways can we arrange the first five numbers? By factorial computation: five times 4 and so on. How many? (Response - one hundred and twenty.) OK. That's not so great. Actually as you go up in number, this number starts getting real big. This is a type of a problem that you have in assigning license plates. Let's say you only wanted to assign numbers on license plates, how many numbers would you have to assign so that everyone in the state could have a license number? Well you go to letters in big states like California because you have more choices of ways to fill the first block. Right? But you don't use all twenty six letters and this we will get to later. Anyway, the permutations, this is all the permutations, all the ordered combinations we can make-out of five events. Another example, let's say we have a rat facing a maze and we have three doors (this is door 1, door 2, and door 3) and he can go through two tunnels (tunnel 1 and tunnel 3) that he can get in the apparatus and three exits (exit 1, exit 2, exit 3) that he can leave through. What's the estimate of the number of

$n$

$n(n-1)$

$n(n-1)(n-2)\ldots$

$n(n-1)(n-2)\ldots 1$

$n!$

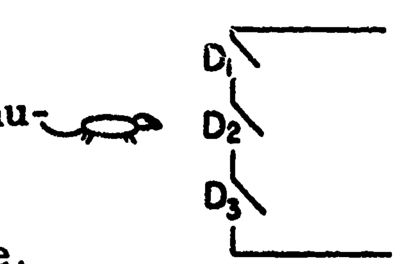
$n! \equiv$ n factorial

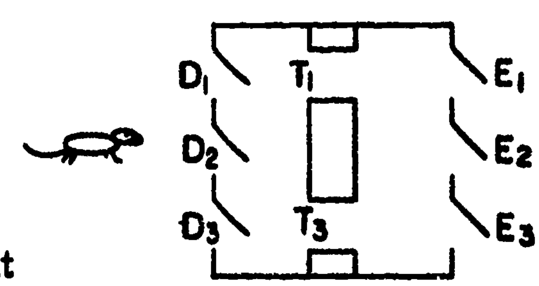
1 2 3 4 5

$(5)(4)(3)\ldots =$ ____

$= \underline{120}$

$5!$



paths he has through this maze? (Response - Eighteen.) OK. How do we get it? Three doors -- think of our little tree that comes out -- now from each of these three doors. We can go through any one of the two tunnels. He has gone this far, he has had six choices. He can leave through any one of these three exits, which multiplies this by three, with a grand total of eighteen paths through the maze. Just like considering the ordered sequence of events -- how many ways can you fill the first one, times how many ways can you fill the second one; times how many ways can you fill the third one. OK. How many permutations of the alphabet are there? Quick, just a number. (Response - twenty-six factorial) That answers it. Nobody in their right mind would expect you to multiply it out. You use the shorthand for something like this. ( ). On to the next problem. Let's say that permutations then of n distinguishable things equal what? (Response - n!) OK. The question now is what if we have n things but they are broken up into groups so that we can't distinguish some of them.

18

$D_1$ $D_2$ $D_3$

$D_1$: $T_1$ $T_2$; $D_2$: $T_1$ $T_2$; $D_3$: $T_1$ $T_2$

$D_1$: $T_1$ $T_2$; $T_1$: $E_1$ $E_2$ $E_3$ = 18

26!

permutations of
n distinguishable things
= n!

APPENDIX B

## 6. TRANSCRIPTION FROM PROGRAMMED LECTURE - $T_2$

The difference between a permutation and a combination is that in the permutation the order of the arrangement of what we are looking at is important. In a combination we don't care about the order. Let me give you an example, supposing I have the three letters A, B, C and I want to know all the different ordered arrangements that you can make with this. Well you could write A, B, C; A, C, B or you could write B, A, C; B, C, A; C, A, B, or C, B, A. Each one of these is a separate permutation of the three letters A, B, C. But there is only one combination of the letters A, B, C. To clarify this, suppose you have the letters A, B, C, D and I wanted to take three of them at a time. I could write A, B, C; A, B, D, or B, C, D and A, C, D. They are four combinations now. How many permutations of the three letters? Well, quite a few. You see there is a problem in calculating these things. Well, let's go about calculating some of these things, to illustrate the difference between a permutation and a combination. I said that in permutations the order is important and let's take an example of how we might develop a formula for permutations. Supposing I had three cells here and I have three balls. This is the same as those three letters we were looking at before. In how many ways can I fill cell one? (Response - Three). In other words I could either put an A there, a B there, or a C. If I filled it with an A then only B and C would remain. Right? How many ways would I be able to fill the second cell? (Response - Two). Supposing I filled it with a B; A and C would remain. How many ways could I fill it? (Response - Two). Still two, so it doesn't make any difference which one you choose first. How many

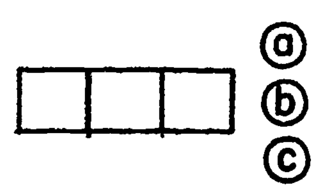
**Blackboard Work**

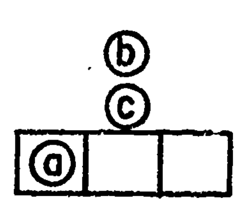
a b c

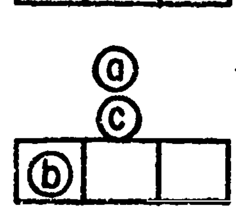
abc
acb
bac
bca
cab
cba

a b c d

abc;abd;bcd;acd







ways would remain then after filling the first and second cells for filling the third cell? One way. So 3 x 2 x 1 = 6, and we recall that those were the number of permutations for the letters A, B, C. If I had four cells and four things to put into it I would have 4 x 3 x 2 x 1 and we would have had 24, and so on. This suggests then a way of writing permutations. Suppose we have n things, we could say the permutation of n things is equal to (n)(n - 1)(n - 2)..... on down the line till the last one would be a 1. That's pretty simple. Supposing I had eight things; eight letters of the alphabet; eight different letters of the alphabet. Don't forget n has to be different things to distinguish one from the other. Supposing I have eight letters of the alphabet, or better yet, eight boys in a room and I want to find out how many ways I could arrange these eight boys in these eight chairs in the front row. How many different ways would there be? Response - (8) (7) (6) (5) (4) (3) (2) (1). OK, somebody with a slide rule figure it out, we're not interested. This is a little bit long to write and we have a sign for abbreviating it called n factorial. There is nothing magic about the word factorial. In multiplication each one of these numbers in the parentheses is a factor, and the whole thing of them is called n factorial. I mentioned a minute ago though that if some of them were indistinguishable then this formula might not hold up. For example, supposing we have the letters A, A, B, C. Well, we can't distinguish between one A and the other A.

$3 \times 2 \times 1 = 6$

$4 \times 3 \times 2 \times 1 = 24$

$(n)(n-1)(n-2)\ldots(1)$

$(8)(7)(6)(5)(4)(3)(2)(1)$

$n!$

$(n)(n-1)(n-2)\ldots(1)=n!$

## APPENDIX B

### 7. TRANSCRIPTION FROM STANDARD LECTURE - $T_3$

Now we should move into the next area of permutations. We have discussed in the past combinations. Now we discuss permutations. Now permutations are merely arrangements, rather than just total groups. The number of arrangements in a set are called its permutations. Now if I've got three people up here and I want to take their picture. Do I want George, Henry, and Bill, or do I want Bill, Henry, and George or do I want Henry, Bill and George? How many different arrangements can I make with these three people? Let's take this simple example, I'm not satisfied, one's a little taller than the other, and I don't know whether I want one head here, and one here, and one here, or this way, or that way. I don't know how I want these people so what I've decided to do, I'm going to take all possible combinations of these, Bill, Henry, and George and now how many pictures I'm going to have to take? (Response - Six) How did we get six., Three people. Right. So that the number of permutations: Unfortunately it is the same letter but I have, just for convenience, used a capital B instead of a script be, but it is a different word. The number of permutations here is n - factorial, and you have all used factorials in the past. The expression n-factorial is just (n)(n - 1)(n - 2)(n - 3).... and so on (2)(1) etc. So six factorial would be (6)(5)(4)(3)(2)(1). One factorial? (Response - One). Zero factorial? (Response - One) Watch this, you get in trouble if you don't. This will save us. You told me that factorial three equals three times two times one, and that equals six. Anyhow we will still be in trouble. Now the number of arrangements of a set are called its permutations. Is that right? Since we've got a few equations here, to think about, we'll just write B equals n factorial. Now let's carry

**Blackboard Work**

| G H B |
|---|

| B H G |
|---|

N = 6

n!

n(n-1)(n-2).(..)

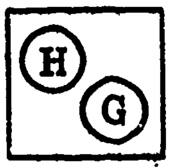
1! =

0! =

(3) (2) (1) = 6

b = n!

it one step further, what are the permutations of n objects; given number of objects, but we are only going to take a few of them at a time? We've got six objects, I've got six cards, well, let's not use that example. Let's go back to the three people we were taking pictures of. I want to take two of them at a time. The number of arrangements of pictures of two of these three people.



## APPENDIX B

### 8. CRITERION TEST

Instructions:

Use formulas as you learned them today, even though you may know other ways to express the same concept.

Fill in the missing answers for the completion-type questions. Example: Honey is ___sweet___.

The possible answers for multiple-choice-type questions are given inside brackets. Circle the correct answer. Example: Honey is (bitter: old: sweet).

1. The degree of certainty one has is usually related to the amount of relevant ____________________ one has accumulated concerning the problem under consideration.

2. The degree of certainty one has concerning the occurrence of events can be used in (interpreting the problem: forming a probability scale: determining the accuracy of the measurements: ascertaining the number of trials needed for a given event: choosing the correct odds in a bet).

3. If all the elements of a problem can be stated with accuracy and certainty, the problem is called ____________________, and we would have no uncertainty about the solution.

4. If a three volume set of books is placed on a shelf by a blind man, what is the probability that they will be in the correct order, i.e., Vol I - Vol II - Vol III? (1/3: 1/6: 1/9: 1/2: 2/3).

5. The denominator in problem four represents the number of (permutations: additive ways: trials: combinations: probabilities).

6. An urn contains three white balls and two black ones. If two balls are drawn without replacement, what is the probability that both will be white:
   (a) Write the formula
   (b) Show the calculations

7. If you are given the five digits 2, 3, 4, 7, 8, how many different three-digit numbers could you form:
   (a) Write the formula
   (b) Show the calculations

8. How many different three-man committees can be chosen from nine men?
   (a) Write the formula
   (b) Show the calculations

9. The probability of an adult winning a certain contest is 0.05 and the probability of a child winning the same contest is 0.01. If both a father and son enter the same contest, what is the probability that some one in the family will win the only prize?

10. A box contains 7 red beads and 3 white beads. How many different necklace patterns could be made with these beads? (45: 90: 120: 35: 210).

11. If you simultaneously flipped a coin and rolled a die, what is the probability of getting either a head on the coin or a ⊡ on the die, but not necessarily both?
    (a) Give the formula
    (b) Show the calculations

12. What is the probability of seeing either an ace or a king in one draw from a deck of 52 cards? (1/26: 2/13: 400/2704: 16/2704: 1/52)

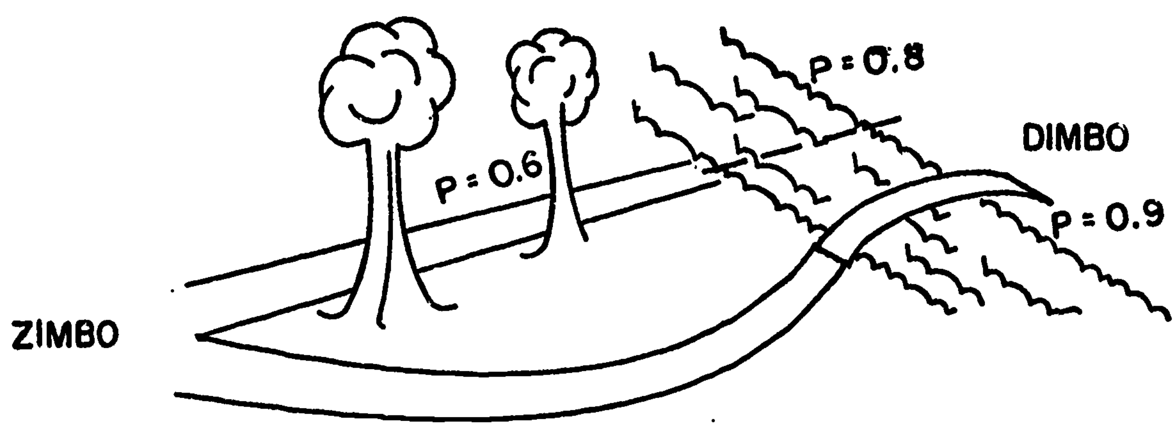
13. In an 8-team league, every team plays each other team 10 times. How many games are played? Show your calculations.

14. A marksman has shot at a target twice on each of 4 days. On the first shot he hit the target once in four days. On the second shot he hit the target twice in four days. The next day out, what is the probability that he will hit the target at least once on either the first or second shot, assuming that his aim has not improved?

15. If on a menu there are six main courses to choose from, and four desserts to choose from, but the choice of a dessert will be influenced by what is chosen for a main course, we say the choices are not (mutually exclusive: exclusive: independent: deterministic: probabilistic).

16. Six dice are tossed. What is the probability that a different number will show up on each die?

17. A military commander wants to relay a message from Zimbo to Dimbo.




There are two routes and he decides to send a messenger via each route. One route leads through a forest and a river ford. There is only 6/10 chance that a messenger could survive passing through the forest and only 8/10 chance he could survive the river ford. The other route leads through a plain and across a bridge. There is only a 1/2 chance that a messenger could survive crossing the plain and a 9/10 chance that he survives crossing the bridge. What is the probability that the message will get through? Show calculations.

18. If you are given a penny, a nickel, a dime, a quarter, a half dollar, and a silver dollar, to find how many different sums of money could be formed from these six coins, you would (calculate the permutations: add the various permutations: add the various combinations: multiply the various permutations: multiply the various combinations).

19. A satellite radio transmitter will operate on any one of two tubes hooked into the transmitter circuit. Let event A be failure of one tube, and event B be the failure of the other tube. There are two identical transmitters in the satellite, each with two tubes. Show the formula you would use to calculate the probability that a message would be transmitted.

20. If the first stage of a three stage missile has a .8 probability of functioning properly, and the second stage has a .9 probability of functioning properly, and the third stage has two rockets, each with a .6 probability of functioning properly, but either one of which can push the third stage into orbit, what is the probability that the missile will orbit successfully?

Instructions: When you finish answering these questions please call the instructor.

## APPENDIX B

### 9. SUBJECTIVE QUESTIONNAIRE ON AUTOMATED METHOD

DEPARTMENT OF ENGINEERING
UNIVERSITY OF CALIFORNIA
LOS ANGELES

Directions to students:

This form will allow you to evaluate the instruction which you have just had. Please check (✓) at the point on each scale where you think the instruction belongs. Do not sign your name to this form.

| | | | |
|---|---|---|---|
| 1. | Were the purposes of the instruction clearly recognizable? | ☐☐☐☐☐ unclear … clear | |
| 2. | How satisfactory was the organization of the subject matter? | ☐☐☐☐☐ well organized … poorly organized | |
| 3. | Were explanations clearly presented? | ☐☐☐☐☐ always … never | |
| 4. | Were there an adequate number of explanations? | ☐☐☐☐☐ plenty … too few | |
| 5. | How difficult was the subject matter? | ☐☐☐☐☐ too hard … too easy | |
| 6. | Do you feel confident that you know the material covered? | ☐☐☐☐☐ confident … not confident | |
| 7. | How did you like this method of instruction as compared to a lecture? | ☐☐☐☐☐ dislike … like very much | |
| 8. | How much do you feel you learned as compared to a lecture? | ☐☐☐☐☐ much more … much less | |
| 9. | How well did you understand the subject matter as compared to a lecture? | ☐☐☐☐☐ poorly … better | |
| 10. | Did you like or dislike the environment in which you were receiving the instruction? | ☐☐☐☐☐ like … dislike | |
| 11. | Do you prefer working at your own pace as you did here? | ________________(yes or no) | |

12. Please add any additional comments you have regarding the instruction.

## APPENDIX B

## 10. SUBJECTIVE QUESTIONNAIRE ON LECTURE METHOD

DEPARTMENT OF ENGINEERING
UNIVERSITY OF CALIFORNIA
LOS ANGELES

Directions to students:

This form will allow you to evaluate the instruction which you have just had. Please check (✓) at the point on each scale where you think the instruction belongs. Do not sign your name to this form.

| | | | |
|---|---|---|---|
| 1. | Were the purposes of the instruction clearly recognizable? | unclear | clear |
| 2. | How satisfactory was the organization of the subject matter? | well organized | poorly organized |
| 3. | Were explanations clearly presented? | always | never |
| 4. | Were there an adequate number of explanations? | plenty | too few |
| 5. | How difficult was the subject matter? | too hard | too easy |
| 6. | Do you feel confident that you know the material covered? | confident | not confident |
| 7. | How extensive is the instructor's knowledge of the subject? | inadequate | extensive |
| 8. | What is your general estimation of this instructor as a teacher? | superior | inferior |

9. Please add any additional comments you have regarding the instruction.

# APPENDIX C

## 1. DATA SHEET

Students' names have been deleted from this report.

| Name | LDEE | Learning Time | Learning Error Score | Criterion Test Time | Criterion Test Score | Teaching Method | Liking Rating |
|---|---|---|---|---|---|---|---|
| | $Q_1$ 101 | 228 | - | 30 | 2* | FRMB | - |
| | 103 | 112 | 34 | 40 | 4 | PTR | 0 |
| | 122 | 221 | - | 18 | 11 | FRMB | 4 |
| | 123 | 188 | 8 | 52 | 13 | PTR | 4 |
| | 123 | 114 | - | 49 | 16 | PTNR | 1 |
| | 123 | 48 | - | 83 | 8 | $T_3$ | - |
| | 127 | 72 | - | 90 | 10 | $T_2$ | - |
| | 128 | 164 | - | 3* | 0* | FRMC | 3 |
| | 129 | 88 | - | 52 | 10 | $T_1$ | - |
| | 130 | 86 | 15 | 76 | 14 | MCM | 4 |
| | 130 | 168 | 24 | 38 | 5 | PTR | 2 |
| | 132 | 172 | - | 20 | 5 | FRMC | 0 |
| | 132 | 148 | - | 54 | 9 | FRMC | 3 |
| | 133 | [illegible] | - | 49 | 11 | $T_3$ | - |
| | 134 | 161 | - | 25 | 4 | FRMB | 0 |
| | 134 | 177 | - | 35 | 8 | FRMB | 4 |
| | 134 | 122 | 48 | 54 | 13 | MCM | 3 |
| | 134 | 93 | - | 54 | 12 | PTNR | 2 |
| | 136 | 88 | - | 39 | 11 | $T_1$ | - |
| | 137 | 88 | - | 50 | 17 | $T_1$ | - |
| | 137 | 170 | 28 | 17 | 9 | MCM | 1 |
| | 138 | 88 | - | 63 | 10 | $T_1$ | - |
| | 139 | 111 | - | 43 | 9 | PTNR | 4 |
| | 139 | 48 | - | 57 | 8 | $T_3$ | - |
| | 140 | 48 | - | 49 | 13 | $T_3$ | - |
| | 142 | 114 | - | 43 | 4 | PTNR | 3 |
| | 143 | 72 | - | 71 | 13 | $T_2$ | - |
| | 145 | 48 | - | 52 | 9 | $T_3$ | - |
| | 145 | 139 | - | 47 | 12 | FRMC | 3 |
| | 145 | 88 | - | 41 | 13 | $T_1$ | - |
| | 146 | 145 | - | 33 | 14 | FRMC | 4 |
| | 146 | 107 | - | 57 | 13 | PTNR | 4 |
| | 147 | 140 | - | 49 | 15 | FRMC | 2 |
| | 147 | 123 | 49 | 40 | 16 | PTR | 4 |
| | 147 | 72 | - | 47 | 16 | $T_2$ | - |
| | 147 | 106 | - | 52 | 14 | PTNR | 4 |
| | 148 | 150 | - | 50 | 12 | FRMC | 4 |
| | 148 | 154 | 9 | 11* | 3* | PTR | 3 |
| | 148 | 197 | - | 13* | 2* | FRMC | 0 |
| | 148 | 83 | - | 50 | 15 | PTNR | 2 |
| | 149 | 154 | - | 13* | 5* | FRMC | 2 |
| | 149 | 168 | - | 31 | 8 | FRMC | 3 |
| | 149 | 72 | - | 60 | 6 | $T_2$ | - |
| | 149 | 107 | 15 | 43 | 15 | PTR | 0 |
| | 149 | 118 | 9 | 56 | 18 | MCM | 4 |
| | $Q_2$ 149 | 142 | - | 97 | 14 | FRMC | 2 |
| | 149 | 48 | - | 48 | 8 | $T_3$ | - |
| | 150 | 72 | - | 95 | 13 | $T_2$ | - |
| | 150 | 72 | - | 58 | 11 | $T_2$ | - |
| | 150 | 131 | 9 | 40 | 7 | PTR | 2 |
| | 151 | 88 | - | 52 | 11 | $T_1$ | - |
| | 151 | 176 | - | -** | - | FRMC | - |
| | 152 | 105 | - | 55 | 14 | PTNR | 3 |
| | 152 | 48 | - | 56 | 6 | $T_3$ | - |
| | 152 | 178 | - | 67 | 19 | FRMC | 2 |
| | 152 | 108 | 17 | 48 | 16 | PTR | 4 |
| | 152 | 183 | - | -** | - | FRMC | - |
| | 152 | 48 | - | 36 | 9 | $T_3$ | - |
| | 153 | 112 | - | 49 | 16 | PTR | 4 |
| | 153 | 48 | - | 42 | 13 | $T_3$ | - |
| | 153 | 115 | 18 | 41 | 17 | PTR | 2 |
| | 154 | 48 | - | 50 | 10 | $T_3$ | - |
| | 154 | 115 | - | 67 | 10 | PTNR | 3 |
| | 154 | 104 | - | 56 | 14 | PTNR | 1 |
| | 154 | 116 | [illegible] | 50 | 6 | MCM | 1 |
| | 154 | 112 | 16 | 49 | 7 | MCM | 4 |
| | 155 | 103 | - | 58 | 11 | PTNR | 4 |
| | 155 | 110 | - | 31 | 13 | FRMC | 2 |
| | 155 | 72 | - | 66 | 9 | $T_2$ | - |
| | 155 | 88 | - | 62 | 14 | $T_1$ | - |

# APPENDIX C

## 1. DATA SHEET (CONT'D)

| Name | LDEE | Learning Time | Learning Error Score | Criterion Test Time | Criterion Test Score | Teaching Method | Liking Rating |
|---|---|---|---|---|---|---|---|
| | 155 | 88 | - | 57 | 16 | $T_1$ | - |
| | 156 | 122 | 24 | 38 | 9 | MCM | 1 |
| | 156 | 99 | - | 51 | 15 | PTNR | 2 |
| | 156 | 72 | - | 63 | 13 | $T_2$ | - |
| | 157 | 154 | - | 28 | 11 | FRMB | 3 |
| | 157 | 114 | 15 | 43 | 8 | PTR | 0 |
| | 157 | 130 | - | 25 | 9 | FRMB | 0 |
| | 157 | 143 | - | 30 | 18 | FRMC | 3 |
| | 157 | 88 | - | 50 | 10 | $T_1$ | - |
| | 158 | 148 | 19 | 15* | 6* | PTR | 4 |
| | 159 | 107 | 13 | 47 | 14 | PTR | 4 |
| | 159 | 149 | - | 23* | 6* | FRMB | 4 |
| | 159 | 149 | 28 | 57 | 12 | MCM | 1 |
| | 159 | 72 | - | 53 | 13 | $T_2$ | - |
| | 159 | 165 | - | 40 | 18 | FRMB | 1 |
| | 160 | 113 | 14 | 47 | 9 | PTR | 1 |
| | 160 | 79 | - | 52 | 16 | PTNR | 4 |
| | 160 | 87 | - | 56 | 14 | PTNR | 3 |
| | 161 | 195 | - | 32 | 14 | FRMC | 4 |
| | 161 | 171 | - | 64 | 19 | FRMC | 3 |
| $Q_3$ | 161 | 140 | - | 25 | 10 | FRMC | 1 |
| | 161 | 100 | - | 51 | 14 | PTNR | 4 |
| | 161 | 88 | - | 42 | 17 | $T_1$ | - |
| | 162 | 103 | 28 | 37 | 16 | PTR | 3 |
| | 163 | 72 | - | 89 | 14 | $T_2$ | - |
| | 163 | 200 | - | 49 | 11 | FRMB | 4 |
| | 163 | 88 | - | 49 | 16 | $T_1$ | - |
| | 164 | 126 | - | 31 | 17 | FRMB | 4 |
| | 164 | 126 | 11 | 30 | 11 | PTR | 3 |
| | 164 | 132 | 20 | 30 | 19 | PTR | 4 |
| | 164 | 81 | - | 63 | 14 | PTNR | 4 |
| | 164 | 48 | - | 43 | 10 | $T_3$ | - |
| | 165 | 109 | - | 63 | 17 | FRMB | 2 |
| | 165 | 99 | 12 | 44 | 17 | PTR | 4 |
| | 165 | 125 | 43 | 67 | 10 | MCM | 4 |
| | 165 | 187 | - | 38 | 17 | FRMC | 4 |
| | 165 | 48 | - | 82 | 11 | $T_3$ | - |
| | 165 | 48 | - | 42 | 7 | $T_3$ | - |
| | 166 | 130 | 16 | 53 | 14 | MCM | 4 |
| | 166 | 72 | - | 52 | 18 | $T_2$ | - |
| | 166 | 167 | - | 31 | 14 | FRMC | 4 |
| | 167 | 80 | - | 72 | 15 | PTNR | 3 |
| | 167 | 112 | 11 | 35 | 11 | PTR | 1 |
| | 167 | 48 | - | 44 | 10 | $T_3$ | - |
| | 167 | 72 | - | 41 | 7 | PTNR | 4 |
| | 168 | 88 | - | 51 | 16 | $T_1$ | - |
| | 168 | 108 | 11 | 55 | 14 | PTR | 4 |
| | 168 | 92 | 23 | 69 | 12 | MCM | 4 |
| | 169 | 75 | - | 37 | 14 | PTNR | 3 |
| | 170 | 175 | - | 30 | 12 | FRMB | 2 |
| | 170 | 152 | - | 39 | 13 | FRMB | 3 |
| | 170 | 159 | - | 73 | 15 | FRMC | 2 |
| | 170 | 97 | - | 43 | 10 | PTNR | 1 |
| | 170 | 165 | - | 42 | 9 | FRMC | 3 |
| | 171 | 115 | - | 41 | 11 | FRMC | 4 |
| | 171 | 80 | - | 41 | 17 | PTNR | 4 |
| | 171 | 48 | - | 41 | 13 | $T_3$ | - |
| | 171 | 72 | - | 67 | 17 | $T_2$ | - |
| | 172 | 116 | - | 43 | 7 | PTNR | 3 |
| | 172 | 88 | - | 43 | 19 | $T_1$ | - |
| | 172 | 125 | - | 34 | 21 | FRMC | 2 |
| | 172 | 141 | - | 34 | 8 | FRMB | 3 |
| | 173 | 88 | - | 56 | 13 | $T_1$ | - |
| | 173 | 104 | 16 | 40 | 14 | PTR | 3 |
| | 173 | 111 | - | 64 | 15 | PTNR | 3 |
| | 174 | 72 | - | 84 | 10 | $T_2$ | - |
| $Q_4$ | 175 | 138 | - | 27 | 9 | FRMC | 4 |
| | 176 | 148 | - | 22 | 5 | FRMC | 0 |
| | 177 | 88 | - | 36 | 21 | $T_1$ | - |
| | 177 | 88 | - | 65 | 20 | $T_1$ | - |
| | 177 | 125 | - | 37 | 16 | FRMB | 1 |

Students' names have been deleted from this report.

# APPENDIX C

## 1. DATA SHEET (CONT'D)

Students' names have been deleted from this report.

| Name | LDEE | Learning Time | Learning Error Score | Criterion Test Time | Criterion Test Score | Teaching Method | Liking Rating |
|---|---|---|---|---|---|---|---|
| | 177 | 92 | - | 65 | 19 | PTNR | 2 |
| | 177 | 72 | - | 46 | 19 | $T_2$ | - |
| | 178 | 56 | - | 53 | 21 | PTNR | 4 |
| | 178 | 87 | - | 68 | 13 | PTNR | 2 |
| | 179 | 185 | - | 40 | 18 | FRMB | 3 |
| | 180 | 88 | - | 33 | 17 | $T_1$ | - |
| | 180 | 143 | 19 | 44 | 17 | PTR | 3 |
| | 181 | 48 | - | 44 | 12 | $T_3$ | - |
| | 181 | 123 | 29 | 56 | 14 | MCM | 1 |
| | 182 | 143 | - | 72 | 17 | FRMB | 1 |
| | 182 | 102 | 40 | 88 | 21 | MCM | 4 |
| | 182 | 103 | 11 | 40 | 16 | PTR | 4 |
| | 182 | 48 | - | 40 | 11 | $T_3$ | - |
| | 182 | 48 | - | 81 | 16 | $T_3$ | - |
| | 183 | 72 | - | 74 | 14 | $T_2$ | - |
| | 183 | 131 | 12 | 48 | 14 | PTR | 3 |
| | 183 | 88 | - | 54 | 14 | $T_1$ | - |
| | 184 | 132 | 28 | 38 | 12 | MCM | 3 |
| | 184 | 74 | - | 46 | 21 | PTNR | 4 |
| | 184 | 94 | - | 52 | 14 | PTNR | 4 |
| | 185 | 83 | - | 48 | 15 | $T_1$ | - |
| | 185 | 72 | - | 48 | 14 | $T_2$ | - |
| | 185 | 111 | - | 53 | 10 | PTR | 0 |
| | 185 | 112 | 15 | 53 | 10 | PTR | 4 |
| | 186 | 91 | 14 | 44 | 22 | PTR | 1 |
| | 187 | 132 | - | 35 | 13 | FRMC | 3 |
| | 187 | 160 | - | 30 | 19 | FRMC | 4 |
| | 189 | 66 | - | 50 | 11 | PTNR | 3 |
| | 189 | 122 | - | 37 | 22 | FRMB | 4 |
| | 190 | 105 | - | 46 | 16 | FRMC | 2 |
| | 190 | 118 | 34 | 50 | 20 | PTR | 2 |
| | 190 | 100 | 16 | 36 | 17 | MCM | 4 |
| | 193 | 68 | - | 76 | 19 | PTNR | 2 |
| | 193 | 88 | - | 66 | 18 | $T_1$ | - |
| | [illegible]3 | 48 | - | 51 | 17 | $T_3$ | - |
| | 195 | 174 | - | 36 | 13 | FRMC | 1 |
| | 198 | 72 | - | 64 | 15 | $T_2$ | - |
| | 199 | 76 | - | 30 | 11 | PTNR | 4 |
| | 204 | 102 | - | 60 | 20 | PTNR | 2 |
| | 210 | 76 | 10 | 71 | 22 | MCM | 2 |
| | ? † | 93 | - | 59 | 11 | PTNR | 1 |
| | ? † | 99 | 21 | 56 | 21 | PTR | 1 |
| | ? † | 133 | 41 | 31 | 11 | PTR | 3 |
| | 154 | 166* | - | - | - | FRMB | - |
| | 143 | 235* | - | - | - | FRMB | - |

* Student did not finish task.

† Discarded samples.

**Student did not take criterion test.

# APPENDIX C

## 2. CRITERION TEST SCORES (x) AND LEARNING TIME (y) BY TEACHING METHOD AND APTITUDE QUARTERS

| Quarters by LDEE | Multiple Choice Machine (MCM) | | Free Response Machine Classroom (FRMC) | | Free Response Machine Booths (FRMB) | | Programmed Text, with Responses (PTR) | | Programmed Text, no overt Responses (PTNR) | | Programmed Lecturer ($T_1$) | | Programmed Lecturer ($T_2$) | | Standard Lecturer ($T_3$) | | Column Row Means *Standard Deviations | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | y | x | y | x | y | x | y | x | y | x | y | x | y | x | y | x | y(1) | x |
| | 86 | 14 | 164 | - | 228 | - | 112 | 4 | 114 | 16 | 88 | 10 | 72 | 10 | 48 | 8 | | |
| | 122 | 13 | 172 | 5 | 221 | 11 | 188 | 13 | 93 | 12 | 88 | 11 | 72 | 13 | 48 | 11 | | |
| | 170 | 9 | 148 | 9 | 161 | 4 | 168 | 5 | 111 | 9 | 88 | 17 | 72 | 16 | 48 | 8 | 143 | 11.1 |
| | 118 | 18 | 129 | 12 | 177 | 8 | 123 | 16 | 114 | 4 | 88 | 10 | 72 | 6 | 48 | 13 | | |
| $Q_1$ | | | 145 | 14 | | | 154 | - | 107 | 13 | 88 | 13 | | | 48 | 9 | | |
| | | | 140 | 15 | | | 107 | 15 | 106 | 14 | | | | | | | 37* | 3.7* |
| | | | 150 | 12 | | | | | 83 | 15 | | | | | | | | |
| | | | 197 | - | | | | | | | | | | | | | | |
| | | | 154 | - | | | | | | | | | | | | | | |
| | | | 168 | 8 | | | | | | | | | | | | | | |
| | 116 | 6 | 142 | 14 | 154 | 11 | 131 | 7 | 105 | 14 | 88 | 11 | 72 | 13 | 48 | 8 | | |
| | 112 | 7 | 176 | - | 130 | 9 | 108 | 16 | 115 | 10 | 88 | 14 | 72 | 11 | 48 | 6 | | |
| | 122 | 9 | 178 | 19 | 149 | - | 112 | 16 | 104 | 14 | 88 | 16 | 72 | 9 | 48 | 9 | | |
| | 149 | 12 | 183 | - | 165 | 18 | 115 | 17 | 103 | 11 | 88 | 10 | 72 | 13 | 48 | 13 | 130 | 12.3 |
| $Q_2$ | | | 110 | 13 | | | 114 | 8 | 99 | 15 | | | 72 | 13 | 48 | 10 | | |
| | | | 143 | 18 | | | 148 | - | 79 | 16 | | | | | | | 34* | 3.8* |
| | | | 195 | 14 | | | 107 | 14 | 87 | 14 | | | | | | | | |
| | | | 171 | 19 | | | 113 | 9 | | | | | | | | | | |
| | 125 | 10 | 140 | 10 | 200 | 11 | 103 | 16 | 100 | 14 | 88 | 17 | 72 | 14 | 48 | 10 | | |
| | 130 | 14 | 187 | 17 | 126 | 17 | 126 | 11 | 81 | 14 | 88 | 16 | 72 | 18 | 48 | 11 | | |
| | 92 | 12 | 167 | 14 | 109 | 17 | 132 | 19 | 80 | 15 | 88 | 16 | 72 | 17 | 48 | 7 | | |
| | | | 156 | 15 | 175 | 12 | 99 | 17 | 72 | 7 | 88 | 19 | 72 | 10 | 48 | 10 | 122 | 13.4 |
| $Q_3$ | | | 165 | 9 | 152 | 13 | 112 | 11 | 75 | 14 | 88 | 13 | | | 48 | 13 | | |
| | | | 115 | 11 | 141 | 8 | 108 | 14 | 97 | 10 | | | | | | | 33* | 3.5* |
| | | | 125 | 21 | | | 104 | 14 | 80 | 17 | | | | | | | | |
| | | | | | | | | | 116 | 7 | | | | | | | | |
| | | | | | | | | | 111 | 15 | | | | | | | | |
| | 123 | 14 | 138 | 9 | 125 | 16 | 143 | 17 | 92 | 19 | 88 | 21 | 72 | 19 | 48 | 12 | | |
| | 102 | 21 | 148 | 5 | 185 | 18 | 103 | 16 | 56 | 21 | 88 | 20 | 72 | 14 | 48 | 11 | | |
| | 132 | 12 | 132 | 13 | 143 | 17 | 131 | 14 | 87 | 13 | 88 | 17 | 72 | 14 | 48 | 16 | | |
| | 100 | 17 | 160 | 19 | 12[illegible] | 22 | 111 | 10 | 74 | 21 | 88 | 14 | 72 | 15 | 48 | 17 | 113 | 15.9 |
| $Q_4$ | 76 | 22 | 105 | 16 | | | 112 | 10 | 94 | 14 | 88 | 15 | | | | | | |
| | | | 174 | 13 | | | 91 | 22 | 86 | 11 | 88 | 18 | | | | | 21* | 3.2* |
| | | | | | | | 118 | 20 | 68 | 19 | | | | | | | | |
| | | | | | | | | | 76 | 11 | | | | | | | | |
| | | | | | | | | | 102 | 20 | | | | | | | | |
| Column Means | 117 | 13.1 | 154 | 13.2 | 160 | 12.7 | 121 | 13.5 | 93 | 13.7 | 88 | 15.0 | 72 | 13.2 | 48 | 10.6 | 127 | 13.2 |
| Standard Deviations | 23 | 4.6 | 24 | 4.2 | 31 | 4.9 | 24 | 4.5 | 15 | 4.0 | 0 | 3.8 | 0 | [illegible] | [illegible] | 3.1 | 34 | 4.1 |

(1) The row means and standard deviations for learning time do not include the non-variant student learning time with $T_1$, $T_2$, $T_3$.

Learning time is in minutes.
Maximum possible criterion test score: 23.

## APPENDIX C

### 3. RESULTS OF TEST OF HYPOTHESES

A. Hypotheses that the mean performances of students (as measured by criterion test scores) are equal if the students are taught by the following methods:

| | F | D.F. | | Significance at | at $\alpha = 0.05$ |
|---|---|---|---|---|---|
| 1. MCM vs. FRMC vs. FRMB vs. PTR vs. PTNR vs. $T_1$ vs. $T_2$ vs. $T_3$. | 1.80 | 7 | 140 | ~ 0.10 | NS |
| 2. FRMC vs. FRMB | 0.11 | 1 | 34 | ~ 0.75 | NS |
| 3. MCM vs. (FRMC & FRMB) | 0.16 | 1 | 50 | ~ 0.70 | NS |
| 4. PTR vs. PTNR | 0.08 | 1 | 50 | ~ 0.80 | NS |
| 5. (MCM & FRMC & FRMB) vs. (PTR & PTNR) | 0.15 | 1 | 108 | ~ 0.70 | NS |
| 6. $T_1$ vs. $T_2$ | 1.98 | 1 | 29 | ~ 0.18 | NS |
| 7. (MCM & FRMC & FRMB & PTR & PTNR) vs. ( $T_1$ & $T_2$) | 1.14 | 1 | 145 | ~ 0.25 | NS |
| 8. ($T_1$ & $T_2$) vs. $T_3$ | 18.43 | 1 | 48 | < 0.0005 | S |
| 9. (MCM & FRMC & FRMB & PTR & PTNR) vs. $T_3$ | 6.89 | 1 | 127 | 0.01 | S |

B. Hypotheses that the mean performances of students (as measured by criterion test scores) are equal if compared according to the following aptitude quarters:

| | | | | | |
|---|---|---|---|---|---|
| 1. $Q_1$ vs. $Q_2$ vs. $Q_3$ vs. $Q_4$ | 14.08 | 3 | 140 | < 0.0005 | S |
| 2. $Q_1$ vs. $Q_2$ | 2.13 | 1 | 65 | ~ 0.18 | NS |
| 3. $Q_2$ vs. $Q_3$ | 3.17 | 1 | 71 | ~ 0.08 | NS |
| 4. $Q_3$ vs. $Q_4$ | 9.80 | 1 | 75 | ~ 0.003 | S |

C. Hypotheses that the mean performances of students (as measured by criterion test scores) are equal if compared according to teaching methods and aptitudes (interactions) as follows:

| | | | | | |
|---|---|---|---|---|---|
| 1. All teaching methods and four quarters | 1.43 | 21 | 140 | ~ 0.10 | NS |
| 2. Machines vs. Programmed textbooks and four quarters | 0.03 | 3 | 108 | ~ 0.99 | NS |

| | F | D.F. | | Significance at | at $\alpha$=0.05 |
|---|---|---|---|---|---|
| 3. Auto-instruction vs. Programmed lectures and four quarters | 0.73 | 3 | 145 | ~ 0.98 | NS |
| 4. Programmed lectures vs. Standard lectures and four quarters | 0.95 | 3 | 48 | ~ 0.40 | NS |
| 5. Auto-instruction vs. Standard lectures and four quarters | 0.36 | 3 | 127 | ~ 0.85 | NS |

D. Hypotheses that the mean learning times of students are equal if the students are taught by the following methods:

| | | | | | |
|---|---|---|---|---|---|
| 1. MCM vs. FRMC vs. FRMB vs. PTR vs. PTNR vs. $T_1$ vs. $T_2$ vs. $T_3$. | 40.47 | 4 | 105 | < 0.0005 | S |
| 2. FRMC vs. FRMB | 3.38 | 3 | 41 | 0.025 | S |
| 3. PTR vs. PTNR | 41.11 | 1 | 52 | < 0.0005 | S |
| 4. MCM vs. FRMC | 21.83 | 1 | 39 | < 0.0005 | S |
| 5. MCM vs. PTR | 0.39 | 1 | 36 | < 0.60 | NS |

E. Hypotheses that the mean learning times of students are equal if compared according to the following aptitude quarters:

| | | | | | |
|---|---|---|---|---|---|
| 1. $Q_1$ vs. $Q_2$ vs. $Q_3$ vs. $Q_4$ | 7.77 | 3 | 105 | < 0.0005 | S |
| 2. $Q_1$ vs. $Q_2$ | 2.30 | 1 | 52 | ~ 0.15 | NS |
| 3. $Q_2$ vs. $Q_3$ | 0.02 | 1 | 53 | ~ 0.93 | NS |
| 4. $Q_3$ vs. $Q_4$ | 0.12 | 1 | 53 | ~ 0.91 | NS |

F. Hypothesis that the mean learning times of students are equal if compared according to teaching methods and aptitudes (interactions):

| | | | | | |
|---|---|---|---|---|---|
| 1. All teaching methods and four quarters | 1.01 | 12 | 105 | ~ 0.50 | NS |

## APPENDIX C

### 4. LINEAR RELATIONSHIPS OF VARIABLES

Correlation Coefficients, 2 Variables:

| | | r | at $\alpha$=.01 |
|---|---|---|---|
| 1. | LDEE and Criterion Test Time, All teaching Methods | .026 | n.s. |
| 2. | LDEE and Criterion Test Time, All machines & texts | .114 | n.s. |
| 3. | LDEE and Criterion Test Score, All teaching Methods | .468 | sig. |
| 4. | LDEE and Criterion Test Score, All machines & texts | .454 | sig. |
| 5. | LDEE and Learning Time, All machines & texts | -.290 | sig. |
| 6. | Learning Time and Criterion Test Time, All machines and texts | -.389 | sig. |
| 7. | Learning Time and Criterion Test Score, All machines and texts | -.250 | sig. |
| 8. | Criterion Test Time and Criterion Test Score, All teaching Methods | .168 | n.s. |
| 9. | Criterion Test Time and Criterion Test Score, All machines & texts | .314 | sig. |

Multiple Correlation Coefficients, 4 Variables:

| | | R |
|---|---|---|
| 1. | Criterion Test Scores on LDEE, Learning Times and Criterion Test Times | .526 |
| 2. | Learning Time on LDEE, Criterion Test Time and Criterion Test Score | .462 |
| 3. | Criterion Test Time on LDEE, Learning Time and Criterion Test Score | .460 |
| 4. | LDEE on Learning Time, Test Time, and Criterion Test Score | .499 |

Multiple Correlation Coefficients, 3 Variables:

| | | R |
|---|---|---|
| 1. | Criterion Test Score on LDEE & Criterion Test Time, All Methods | .493 |
| 2. | Criterion Test Score on LDEE & Criterion Test Time, All Machines and texts | .526 |
| 3. | LDEE on Criterion Test Time, Criterion Test Score, All Methods | .471 |

| | R |
|---|---|
| 4. LDEE on Criterion Test Time & Criterion Test Score, All Machines and Texts | .455 |
| 5. Criterion Test Time on LDEE and Learning Time, All Machines and Texts | .389 |
| 6. Criterion Test Score on LDEE and Learning Time, All Machines and Texts | .471 |
| 7. Learning Time on LDEE and Criterion Test Time, All Machines and Texts | .461 |
| 8. LDEE on Learning Time and Criterion Test Score, All Machines and Texts | .489 |
| 9. Criterion Test Time on Learning Time and Criterion Test Score, All Machines and Texts | .449 |
| 10. LDEE on Learning Time and Criterion Test Time, All Machines and Texts | .290 |
| 11. Criterion Test Score on Learning Time and Criterion Test Time, All Machines and Texts | .344 |
| 12. Learning Time on LDEE and Criterion Test Score, All Machines and Texts | .319 |
| 13. Criterion Test Time on LDEE and Criterion Test Score, All Methods | .178 |
| 14. Criterion Test Time on LDEE and Criterion Test Score, All Machines and Texts | .316 |
| 15. Learning Time on Criterion Test Time and Criterion Test Score, All Machines and Texts | .412 |

Liking vs. Criterion Test Scores

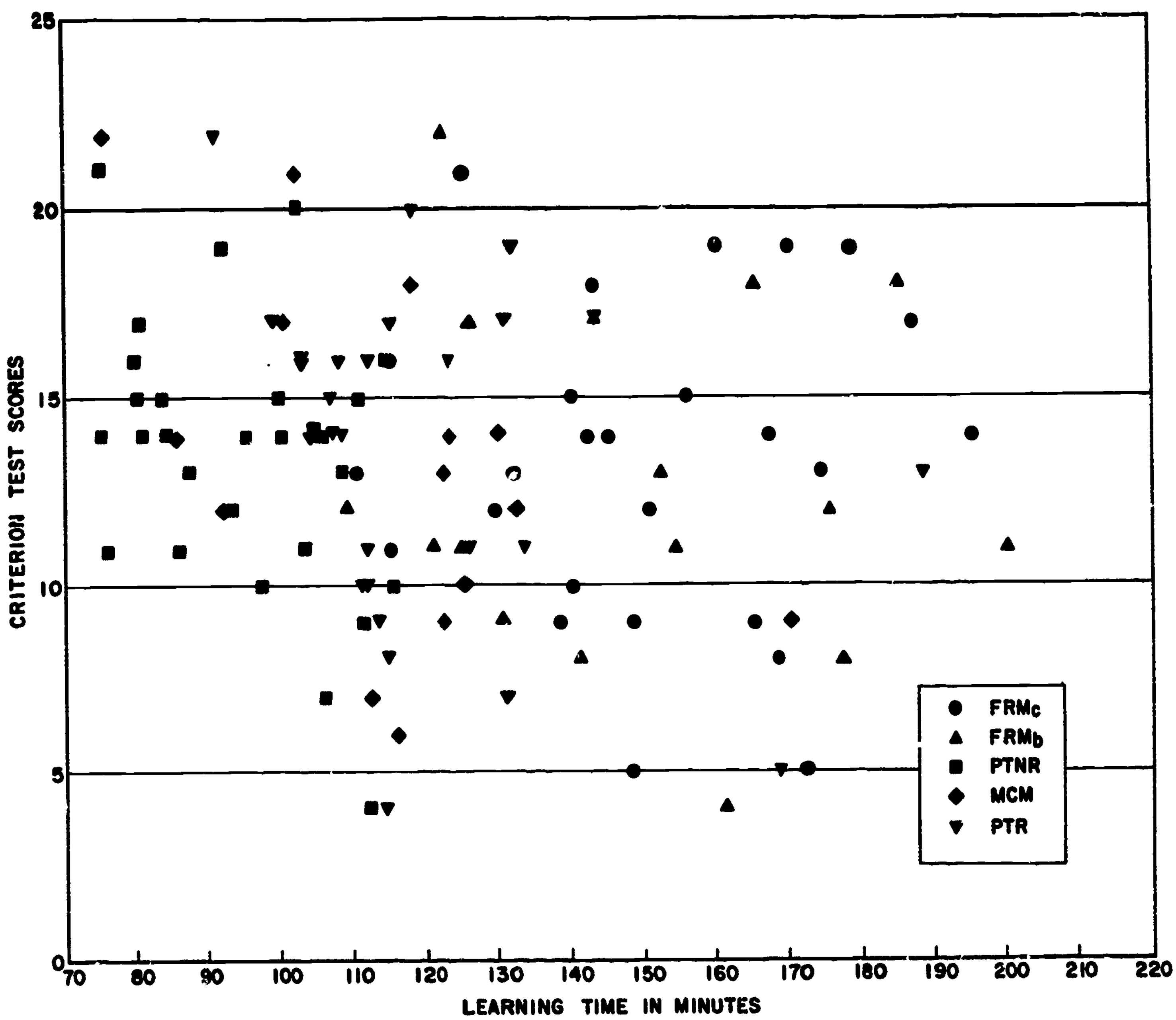
A study of liking ratings and criterion test scores failed to show a significant linear relationship between these two measurements for all machine and text methods together, as well as for each method separately. For all methods there were relatively few students who gave 0 or 1 liking ratings. How a student felt towards a particular method did not seem to be related to how well he did on the criterion test.

Liking vs. LDEE

Similarly, analyses of liking ratings and LDEE did not show any relationship either for the individual methods or for all machine and text methods taken together. There was a wide variability in the liking rating for any given LDEE score. Apparently the liking or disliking of any particular method is not influenced by the ability of the student, as measured by LDEE.

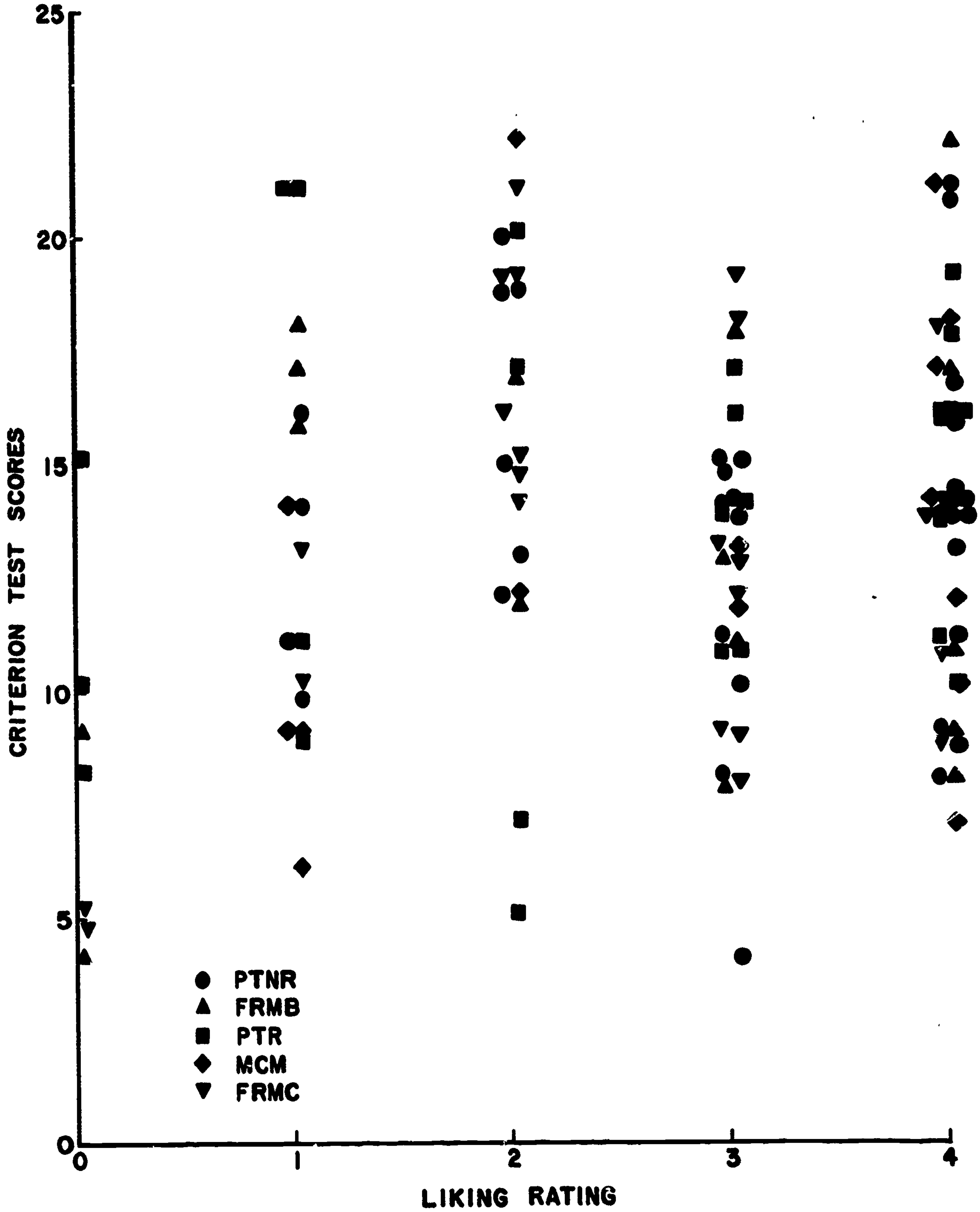
APPENDIX D

1. LEARNING TIME VS. CRITERION TEST SCORES



APPENDIX D

2. LIKING VS. CRITERION TEST SCORES



## APPENDIX E

## OBSERVER'S COMMENTS

### Classroom With Machines

Observer A: In general, the students showed serious attitude toward the task. During the first fifteen minutes they were easily distracted by noises in the room, but after this short period most of them settled down. Boredom was evident in a few students within one hour after starting to work. Some students were frustrated by small difficulties in operating machines. I was amazed at the ability of these freshmen students to concentrate on the task.

Observer B: A student on the multiple-choice machines said that he found the machine itself more "fun" than the lesson presented by the machine.

Students who used the free-response machines wriggled and fidgeted more than students who used multiple-choice machines. One student using a free-response machine claimed it was "too boring to turn that crank". I suggest that students be permitted to get up and stretch, smoke, and go for a drink whenever they like.

Observer C: Many students asked how many more items there were on the program (no indication given to students on how long the lesson would be). One student who had only 4 hours of sleep the previous night, had difficulty keeping awake and turning the handle on the free-response machine.

Observer D: Whenever one student made an error on the multiple-choice machine, all the students would hear the "error indicator sound" and look up at the other students and smile.

Some signs of muscular fatigue, yawning, stretching, particularly on the free-response machines after two hours on the machines.

Questions about how long the program was, since some students had later classes.

Classroom With Programmed Textbooks

Observer E: Students using PTNR seemed more serene than students who used PTR. Many scowls among later group, some of whom looked ahead in the text and also back, apparently to review previous items. Also, some of the students using PTR looked ahead at the answers before writing their response, and some erased their responses after checking with the correct answer.

Observer F: Many students were fidgety or sleepy (work started at 8:00 AM). Also, it was not clear to some of the students that there was no time limit for using the teaching material. Some students were also curious about how their criterion test scores would affect their course grades.

## APPENDIX F

### STUDENT'S COMMENTS

#### MCM

1. This type of instruction demands the attention of the student.

2. I prefer my algebra text, as I can do only as many samples as I need. This method of instruction requires more attention than a lecture, therefore the learning process is faster.

3. I have personally found it to be confusing. There was a multitude of formulas and instructions, and consequently little information was retained toward the latter half. I also believe that two hours is an extremely long period for this machine.

4. I think a red light signal would be more appropriate than a noise in signaling a wrong answer.

5. Educational for a while. A break was needed so that thoughts could be organized. Interest began to lag from time element.

6. Too long a session with no breaks. Try to absorb too much material at once.

7. I felt that I learned much more than in a lecture.

8. Prefer time to look over and study notes. Too vast an area was covered.

9. I feel that this is a little more clear than a lecture. I would have liked more time.

#### FRMC

1. After the 150th item and a little before, time seemed to drag.

2. Extremely logical, excellent in scope and coverage.

3. Would have liked to re-read certain parts before proceeding.

4. I feel that the quantity of information was too much to be assimilated at one sitting. I think that the material would be grasped better if

1/2 - 2/3 of the material was presented.

5. When a question is asked, or intended, please make it clear.

6. The test itself was too long -- it contained too many problems.

7. Very excellent instruction.

8. It was so long that you become frustrated. Too much at once causes confusion later on.

9. Unique way of learning. Should be used more widely.

FRMB

1. Too slow.

2. Loss of interest occurs rapidly.

3. Seemed slightly exaggerated. Had trouble holding my interest. Many busy work questions.

4. Good general idea, but the test was too long to effectively hold my interest. I feel length could be cut without loss of material.

5. Since there was no opportunity to review items, I had to furnish my own explanations. At times I grew tired of working.

6. I feel that one should be able to read over the material more than once.

7. Too many questions. Waste of time.

8. The idea is very good, but there should be someone available to whom questions could be asked.

PTR

1. I, personally, didn't have time to thoroughly absorb the material presented well enough to work these problems correctly. I also feel that this method of education is too impersonal.

2. Much of the material was overly repetitious. I would have liked to have skipped over many pages. (Note: high scoring student)

3. I didn't read the preliminary instructions, and I went through the whole book reading from top to bottom. (Note: student still scored high!)

4. More time needed.

5. I feel that this method is excellent as a refresher course, but it cannot replace the slower, systematic lecture method for first time learning. As a refresher it is better than a lecture.

6. I would like to have the teaching pamphlet handed back.

7. There was too much material covered in too short a time.

8. I didn't feel as if I was working at my own pace. Knowing that there is a quiz to follow, I had to hurry to be sure of doing the quiz.

9. Although I did not especially care for this media of learning, a student might be able to obtain some value from it if he knows the purpose and usefulness before the session begins.

10. I like this method because you can figure it out for yourself.

PTNR

1. I'd like lectures more than this type of instruction. I am a foreign student and I get the lecture much faster.

2. Pace was too fast at end and slow at first. I had trouble in reading the material because I wanted to read down the page instead of at the same point on consecutive pages.

3. Very fine idea.

4. Perhaps the best advantage to this system is that the person using it can refer back to previous material without missing anything in the time spent doing so.

5. Discussion should follow the written lesson.

6. I think this type of instruction should be widely used. The use of only one sentence to a page, the repeating of facts, and the reference to a

preceding subject while on a different one made things very clear.

7. Instruction moved very slowly in places and fast in others.

8. I believe this booklet should first be read as it was, then there should be a discussion period to correct any misinterpretations and to help those who could not grasp the material covered.

9. I think it worked good as long as you give good explanations and examples so the student wouldn't have any questions about it. Also, building up to difficult problems.

10. Is this a psychology test? It's a great idea and all, except that after a couple of hours of reading the same thing, I get a wee bit bored, especially after flipping pages back and forth.

11. I like the idea of reading a small bit of information on each page and then going on to the next page quickly.

12. The one drawback I find is that if one forgets some part of the instruction as he progresses well past it, he will find it hard to look up the information which he forgot.

13. The lecture led into the material very well. In a very few spots, not enough explanation and examples.

14. This would be a good method to prepare for a lecture or review a lecture.

15. The only thing I dislike is that the freedom to ask questions is removed.

16. I could have learned the material better if I had more time.

$\underline{T_1}$

1. Well prepared lecture covering dull topics made interesting by well-timed jokes and comments. I thought the instructor did an excellent job in organizing and presenting topics.

2. The lecture was prepared fine but there was too much material presented at once. This confused me very much.

3. Holds attention of class very well! Pleasant to listen to!

4. The instruction was very clear and presented in a short time what would have taken weeks to learn otherwise.

5. With a night of study, the material presented could be easily assimilated.

$T_2$

1. Very well presented and interesting.

2. Too much subject matter all at once.

3. I can't memorize formulas that quickly.

4. The instruction was slow and many examples were given.

$T_3$

1. Instructor didn't seem too clear on some of the poi[illegible]s asked by students. I don't believe the entire test could be taken with the information given in the lecture.

2. I feel you could have had better picked examples of each question. You made subject seem simpler than it really was.

3. The instructor was willing to explain anything unclear, but could have pushed the subject to insure understanding.

4. No time to study notes!