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BASIC PROPERTIES OF AN AUTOMATED TEACHING SYSTEM. FINAL REPORT.

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THE OBJECTIVES OF THE "TEACHING SYSTEMS PROJECT" WERE (1) TO PROVIDE A COMPREHENSIVE MODEL OF THE GENERALIZED AUTOMATED TEACHING SYSTEM, (2) TO EXPRESS THIS MODEL IN MATHEMATICAL TERMS AND DETERMINE THE MAGNITUDE OF THE CONSTRAINTS, AND (3) TO EXPLORE THE COMPUTER FUNCTIONS IN AN AUTOMATED TEACHING SYSTEM. EXPERIMENTS USING VARIOUS KINDS OF PROGRAMING METHODS ARE DESCRIBED. THE CONCLUSIONS FROM THESE EXPERIMENTS LED TO THE DEVELOPMENT OF A RATIONALE FOR A STUDY OF THE ADAPTIVE ABILITY OF COMPUTERS TO MEET THE LEARNING NEEDS OF INDIVIDUAL STUDENTS. THE CONCLUSIONS WERE--(1) THE TIMES REQUIRED FOR LEARNING FROM VARIOUS METHODS OF PROGRAMED INSTRUCTION WERE SIGNIFICANTLY DIFFERENT, (2) THE METHODS OF PRESENTING PROGRAMED SELF-INSTRUCTIONAL ITEMS WERE NOT AS IMPORTANT AS THE SEQUENCING OF THE ITEMS, AND (3) BOTH LINEAR AND BRANCHING PROGRAMS COULD PRODUCE JUST AS MUCH LEARNING AT LESS COST BY USING A CARD FILE AS BY USING A COMPUTER. FURTHER INVESTIGATION WAS DEVOTED TO THE PROBLEM OF ESTABLISHING THE RATIONALE FOR INVESTIGATING THE CAPABILITY OF A COMPUTER TO CONTINUOUSLY ALTER ITS LOGIC PROGRAM OR STRATEGY DURING THE PROCESS OF STUDENT LEARNING. (AL)

JUNE 1964

DEPARTMENT OF ENGINEERING

basic properties of an automated teaching system

FINAL REPORT

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BASIC PROPERTIES OF AN AUTOMATED TEACHING SYSTEM,

Final Report

Teaching Systems Project
(NDEA Grant 7-04-138.01)

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FOREWORD

The research described in this report, "Basic Properties of an Automated Teaching System", by H. W. Case and A. Roe, was conducted under the sponsorship of the United States Office of Education, Department of Health, Education and Welfare under Title VII of the National Defense Education Act.

This is the final report for the Teaching Systems Project under Grant 7-04-138.01.

The objectives of the Teaching Systems Project were:

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

b. To express this model in mathematical terms and determine the magnitude of the constraints.

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

In the early stages of the investigation, a number of experiments and studies were conducted, primarily to acquaint the project personnel with the salient features of programmed instruction.

The first experiment(10)* examined the effect of presenting to 186 freshman engineering students course material on elementary probability via multiple-choice teaching machines, free-response teaching machines, programmed texts requiring overt responses, programmed texts requiring no overt responses, programmed lecturers, and standard lecturer. Though the time required for learning under the various methods was significantly different, there was no significant difference in the criterion test performance of the students using the various programmed methods of instruction, and the students using programmed methods did significantly better than those who had the standard lecture. Six months later there was no significant difference between the performances of the students who had had the different methods of instruction.

One of the inferences drawn from this experiment was that the method of presenting programmed self-instructional items was not as important as the careful sequencing of these items. To determine whether this was indeed a valid assumption, 36 freshman psychology students were matched according to their prior mathematical ability as shown by quantitative scores on College Entrance Board Examinations and divided into two groups, one of which was given an ordered sequence of 71 items on elementary

*Numbers in parenthesis refer to publications listed in Appendix B.

probability, and the other was given a scrambled sequence of the same items. After the learning session both groups took the same criterion test. There was no significant difference between the groups, either in the learning time, error score during learning, criterion test score, or criterion test time.[8] However, in a subsequent experiment,[11] the sequencing assumption was again examined using a longer and more difficult program. In this case students viewing the scrambled sequence required more time and scored lower than students viewing ordered sequences.

Our early experiments made use of linear programs which required the student to go through every item in the program. Different presentations of the linear programs failed to produce significantly different terminal performances. However, significant differences had been obtained in the amount of time required to complete the learning session. It was therefore decided to give attention to those methods which might speed up the learning process without adversely affecting terminal performance. This meant using some kind of branching program -- but which one?

In preparation for experiments on the effects of different branching procedures, two devices were designed. One was a random-access film projector with a device for recording the items viewed by the students, and the other was a random-access card file. The estimated cost for producing the film projector was in excess of $70 each; the individual card file cost less than one dollar. The card file was designed so that the student would not be aware of the particular type of branching procedure used in his course of instruction. It also provided a record of which items the student saw and his response to each item.[12]

Using the card file, a pilot study was conducted with branching methods during May, 1961, in the freshman engineering laboratory course. In September, 1961, a full-scale experiment[11] was conducted, with the various branching programs given to 189 engineering freshmen as a part of their regular instruction. The group was divided into aptitude thirds on the basis of their engineering entrance examination scores and assigned randomly

to the following seven method groups. The first group (linear) worked through each item. The second group (forward) branched forward if their responses to key items indicated a knowledge of the particular concept being dealt with. The third group (backward) saw each item but at the end of a group of items covering a particular concept, if their responses indicated they had not mastered that concept, branched back to the same sequence of items a second time. The fourth group (backward alternate) followed the same procedure as the third group but instead of branching back to a repetition of the same items, they were branched to alternate items covering the same concept. The fifth group (pre-test forward) differed from the forward-branching group in that they took the criterion test before they had a chance to see the program and then repeated the test at the end of the program. The sixth group (random) worked through the same items as the linear group, but the ordering of items was random rather than sequential. The seventh group (text) was given the forward branching program in the form of a textbook instead of the card file.

In all the branching programs, two key branching items were used in preference to a single one to test the student's mastery of a concept, in order to reduce the possibility of the student's guessing the correct answer and thereby skipping over a sequence of items which he did not really know.

In evaluating the results of the experiment, the first question posed was whether the program resulted in any significant learning at all. There was indeed a very significant increase in the mean test scores from pre-test to post-test (29.3 to 63.8, significant at $< .0005$). Similarly there was a significant reduction in the time required to complete the test items (39.6 to 21.7 minutes, significant at $<.0005$).

The various branching methods were then compared. No significant interactions were observed between aptitude thirds and methods. Hence, results were treated by covariance design to remove the effect of aptitude on learning methods. An overall analysis of variance for methods showed

a significant difference between the groups in test scores (at .01 level) and in learning times (at .0005 level). But no significant difference in test scores was observable between the "backward" and "alternate backward" or between the "linear" and "forward" or between "linear" and "backward" groups in test score.

With regard to learning time, significant differences were observed between the linear and the backward groups (118.1 and 135.4). The difference between the linear and forward groups was not significant (118.1 and 110.2). As expected from the above, the differences between the forward and the backward groups was significant (110.2 and 135.2).

The card file was used during the experiment primarily because we wished to control the browsing behavior of the students and thereby get a valid learning time measurement. In order to find out what effect on learning time and post-test performance was introduced by the card file arrangement, we gave one group of students a forward branching program in the form of a scrambled text which instructed the student to follow a specified item sequence but also gave him the opportunity to browse if he so wished. The results show no significant difference between the two groups in test scores and in test times. But in learning time, the mean difference of 30 minutes was very significant (at <.0005 level) in favor of the text group. It is very likely that the students browsed through the text, which would account for the learning time difference.

Subjective opinions of students about the various branching methods, indicated by their liking ratings, did not correlate either with their aptitudes or with their performances on the criterion tests.

One of the conclusions that emerged from this experiment was that learning time was one of the more important variables, one which could be significantly affected by differences in the teaching procedure. However, we became increasingly aware of the multitude of contingent circumstances which affect the teaching-learning process,[15] and became convinced that

an efficient data handling and logic device would be required.[14] We had observed, however, that digital computers were being used to select items to be presented to students based on the student's responses to previous items and on a preconceived, fixed set of branching rules. Also, the computers were being used to gather and process data on student performance for periodic review by the experimenter or teacher. Our experience with the simple card file indicated that these particular functions could be accomplished in a far less expensive fashion than by using an "on-line" computer in the teaching system. The particular computer function which we were interested in was the adaptive capability of the computer to continuously alter its logic program or strategy during the process of student learning.

The usual approach of specifying a fixed strategy for controlling the teaching stimuli, based on a particular principle of learning, is a non-optimizing approach and is only as good as the choice of the particular principle of learning underlying the strategy, or the skill with which the principle is translated into a strategy (or computer program). Our approach is to attempt to improve student performance by continuously varying and comparing possible strategies. In such a system, students are both learners and "experimental subjects", and the traditional experimental approach of ignoring the effects on subjects who have been exposed to suboptimal regimens cannot be tolerated.

We were further convinced that a prerequisite for the logical design of a teaching system was to have some measure of student performance which reflected a value or "utility" outside of the system. Without such a value on the output of a teaching system it would be difficult to justify allocation of resources in the system.

The "systems" we considered could be roughly divided into four categories.

> Micro-micro systems: Concerned with a transformation of students' behavior by a single, relatively short sequence of learning items.

Micro systems: concerned with a transformation of students' behavior by a longer sequence of learning items, such as are encountered in a semester course.

Macro systems: a collection of micro systems characterized by a curriculum or curricula in a school, university or school district.

Macro-macro systems: related to the transformation of students' behavior by the total learning experience encountered during the students' lives.

Educational systems could be further classified (regardless of size) according to the extent of adaptivity, as follows:

Zero Level Adaptive Behavior: A fixed, preconceived strategy (or pedagogy) is used for presenting to all students a fixed, preconceived set of courses or list of subject matter.

First Level Adaptive Behavior: A fixed strategy which uses an individual student's past history of performance to determine which particular course or list of subject matter from a preconceived set of such courses or subject matter is shown to that individual student.

Second Level Adaptive Behavior: The particular courses or list of subject matter which is shown to a particular student is determined by a fixed strategy which uses an individual student's past history of performance and the history of performance of all students who have previously gone through the system.

Third Level Adaptive Behavior: A set of strategies for presenting students with courses or lists of subject matter is available. The choice of a particular strategy for a particular student depends on the history of performance for each of the strategies.

Our interest centered on providing a rationale for designing an automated teaching system exhibiting third level adaptive behavior. The elements of this rationale would consist of:

a. Provisions for data gathering and processing

b. A criterion function

c. Decision rules

d. A utility function.

Each of these elements are described in Report No. 63-63 in some detail,[17] and only brief mention will be made here of a, b, and c.

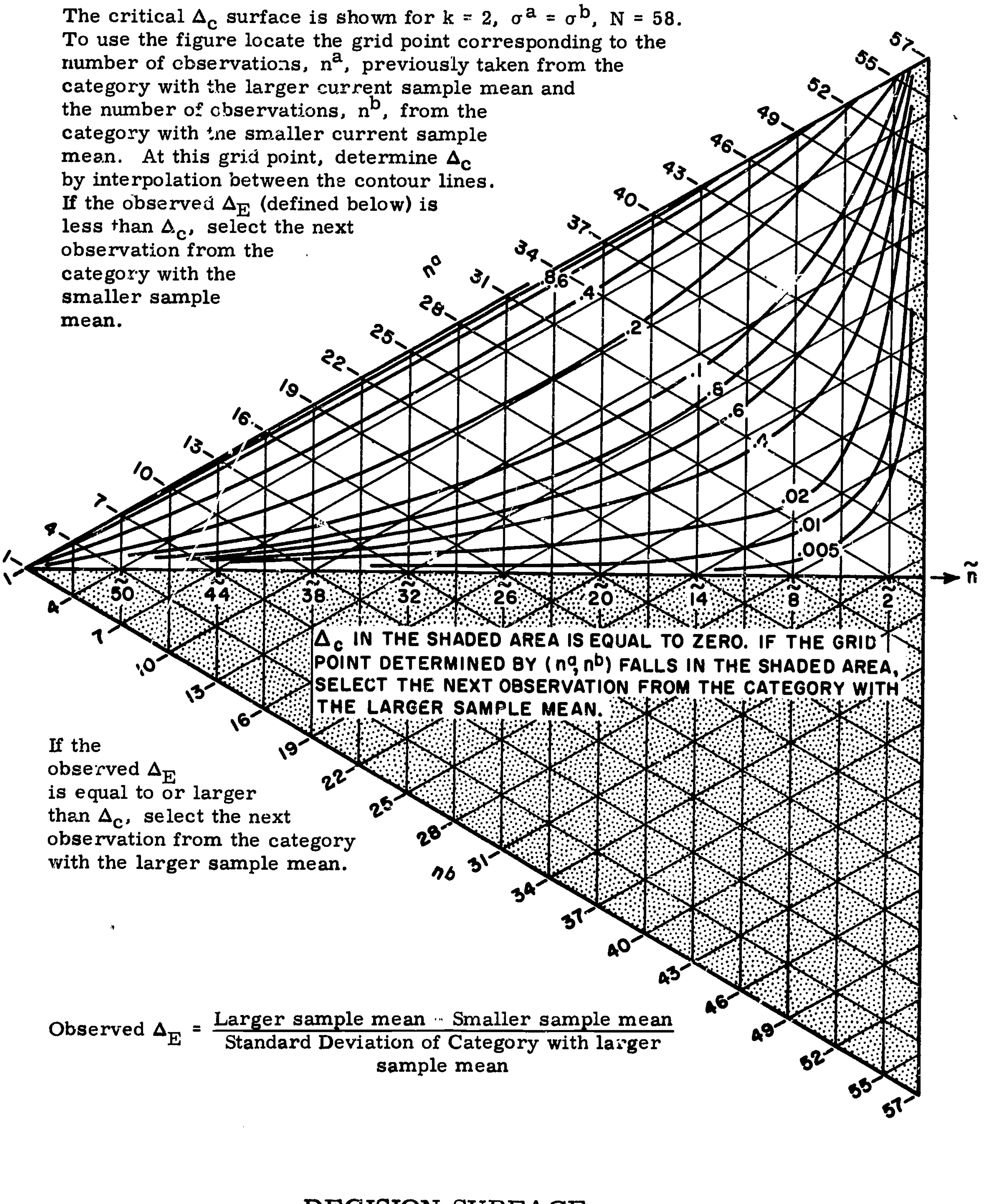
a. Data gathering and processing. The assumption is made that the amount of data that is required for an adaptive automated teaching system is sufficiently voluminous to require the use of modern data processing equipment. Such equipment may or may not be used for presenting course content material directly to students (as in the computer-controlled teaching machines). Another assumption, somewhat contingent on the use of modern data-processing equipment, is that flexible scheduling (for individual students, at any time during the school year) will be employed.

b. A criterion function is developed for an adaptive educational system where two processes are being carried out simultaneously, namely, (1) students are learning subject matter, and (2) the system controllers are learning about the student's learning. Process (2) may include exploratory use of various alternative pedagogical procedures or subject matter, some of which may result in better student performance than others. In such a situation there is a trade-off between processes (1) and (2). The suggested criterion function is the sum of the net utility of all students' outputs, and obviously this function should be maximized.

c. The decision rule which will tend to maximize the criterion function will depend somewhat upon the available a priori knowledge of probability distribution of the net utility of students' outputs. Report No. 63-63 contains decision rules for a few probability distributions, the most important being for normal distributions. The problem of how to sequentially assign individual students to available learning situations so as to maximize the sum of their net outputs is akin to the mathematician's "multi-armed bandit" problem, and a solution for normally distributed populations with

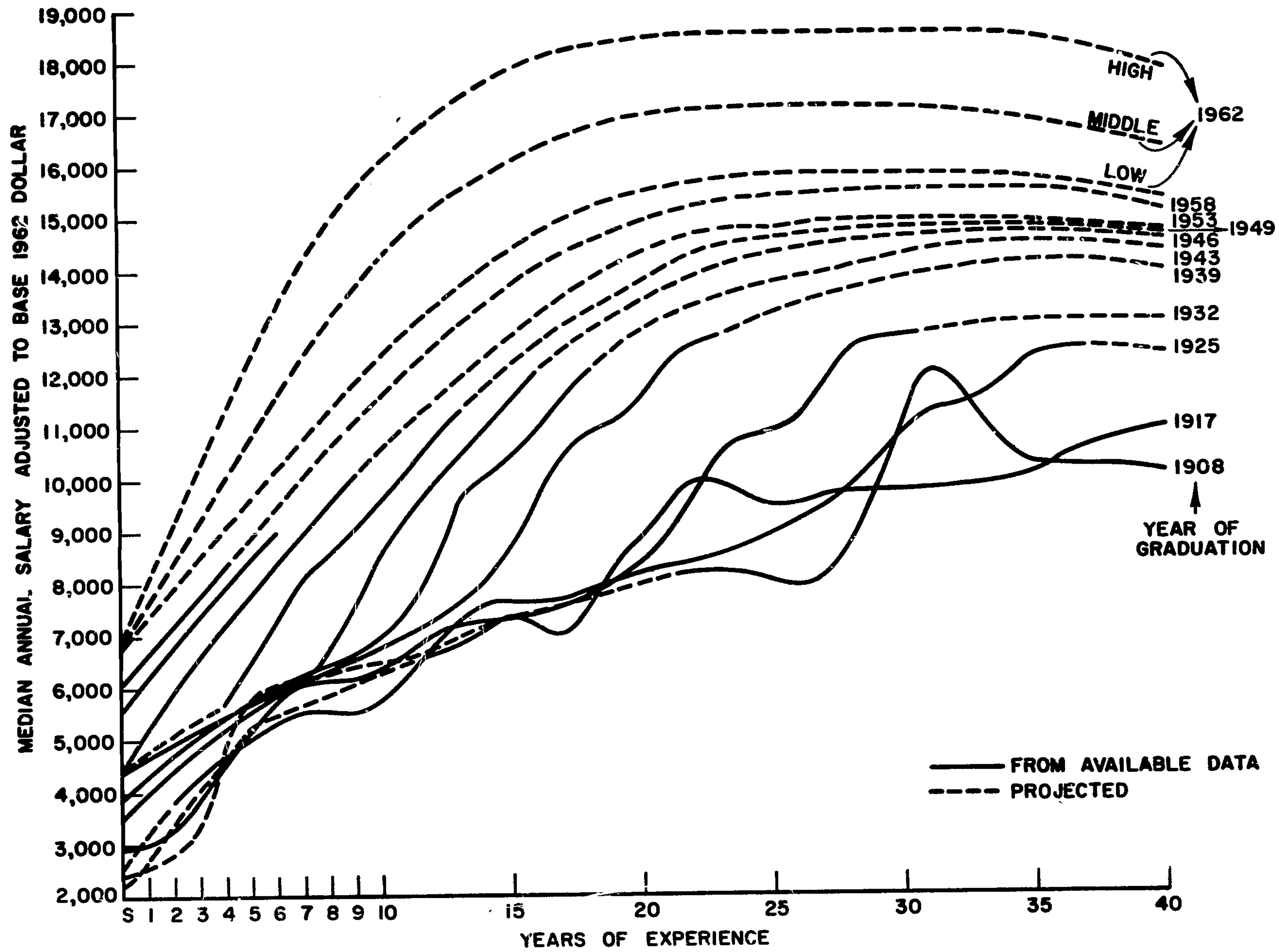
unknown means had not been previously found. Report No. 63-63 presents a computational backwards-induction solution to this problem, and one which is of particular interest to computer-mediated teaching systems, since the proper action to take for each possible contingency can be determined before the system goes into operation, and stored in memory. An example of the solution for assigning students to one of two learning situations is illustrated in Figure 1.

d. The utility function is used to provide a measure of student performance, or output. It converts such available measures as student grades, student learning time, teacher inputs, school capital and maintenance costs, etc., into a net value of the transformation effected by the system. To obtain the utility, one first projects the future expected life cycle earnings of the average student going through a particular educational experience from the history of life earnings of students who have previously gone through a nominally similar educational experience. (See Figure 2 for example of such a projection for the engineering student graduating in 1962.) In order to use this average expected life cycle earnings for a specific student, some adjustment must be made for individual differences. The most widely available measures of individual student differences are class standing and scholastic grades. Interestingly enough, many studies on the relationship between school performance and subsequent earnings fail to indicate a correlation. This apparently is true for the first ten years after a student leaves school (and many of the studies which report no correlation do not trace a student's career beyond the 10 year mark). However, for technically trained people at least, earnings tend to diverge ten years after graduation. D.S. Bridgman, in "Success in College and Business", Personnel Journal, Vol. 9, 1930, pp. 1-19, quotes Gifford's 1928 study of Bell Telephone System college graduate employees, where higher salaries were associated with higher class standing and vice versa (see Figure 3). Somewhat similar findings were obtained in a more recent (1962) study of over 10,000 Bell Telephone System college graduates, and in an analysis made by our group on data obtained on engineering graduates from tl. University of California.



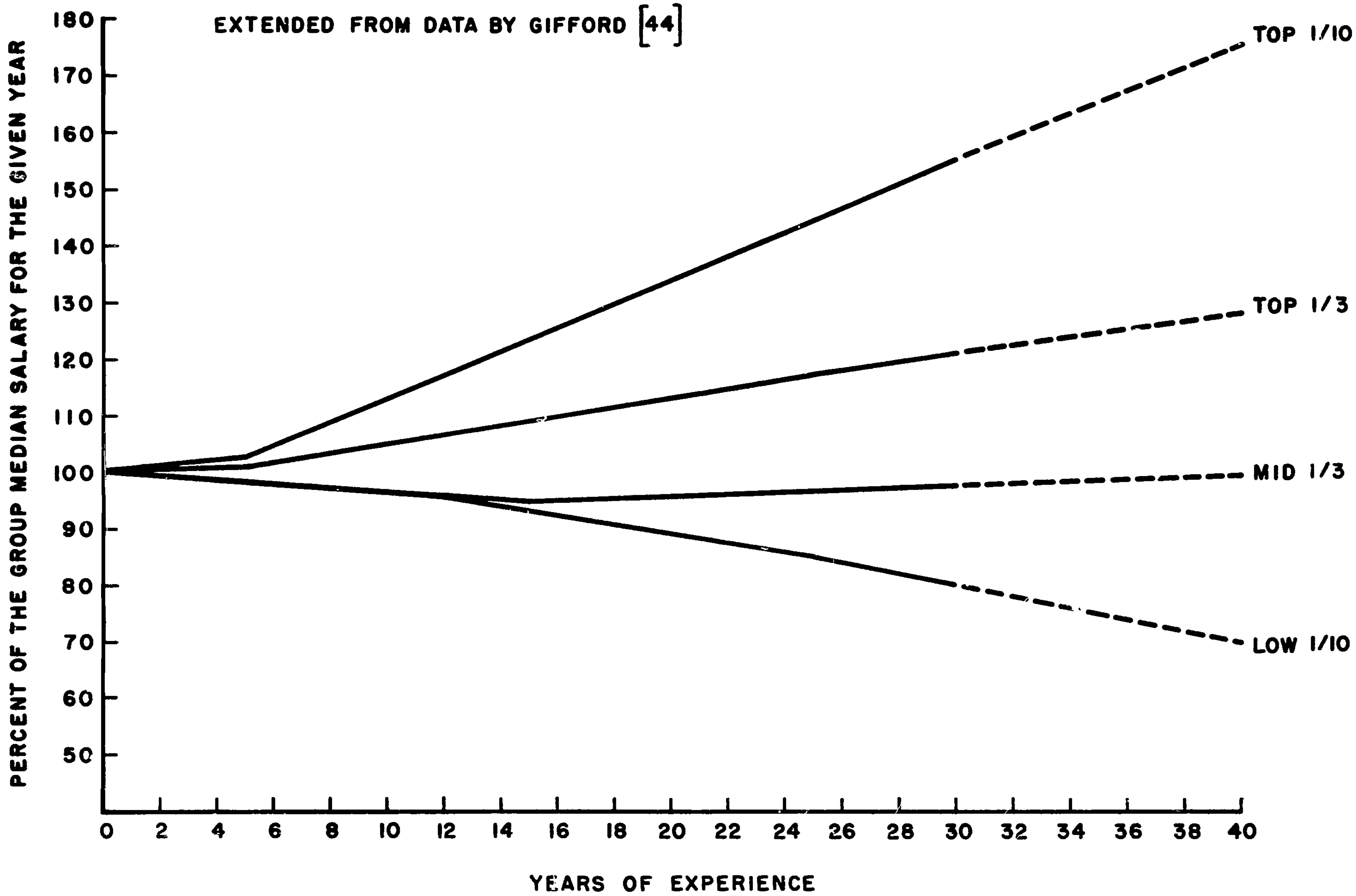
DECISION SURFACE

FIGURE 1



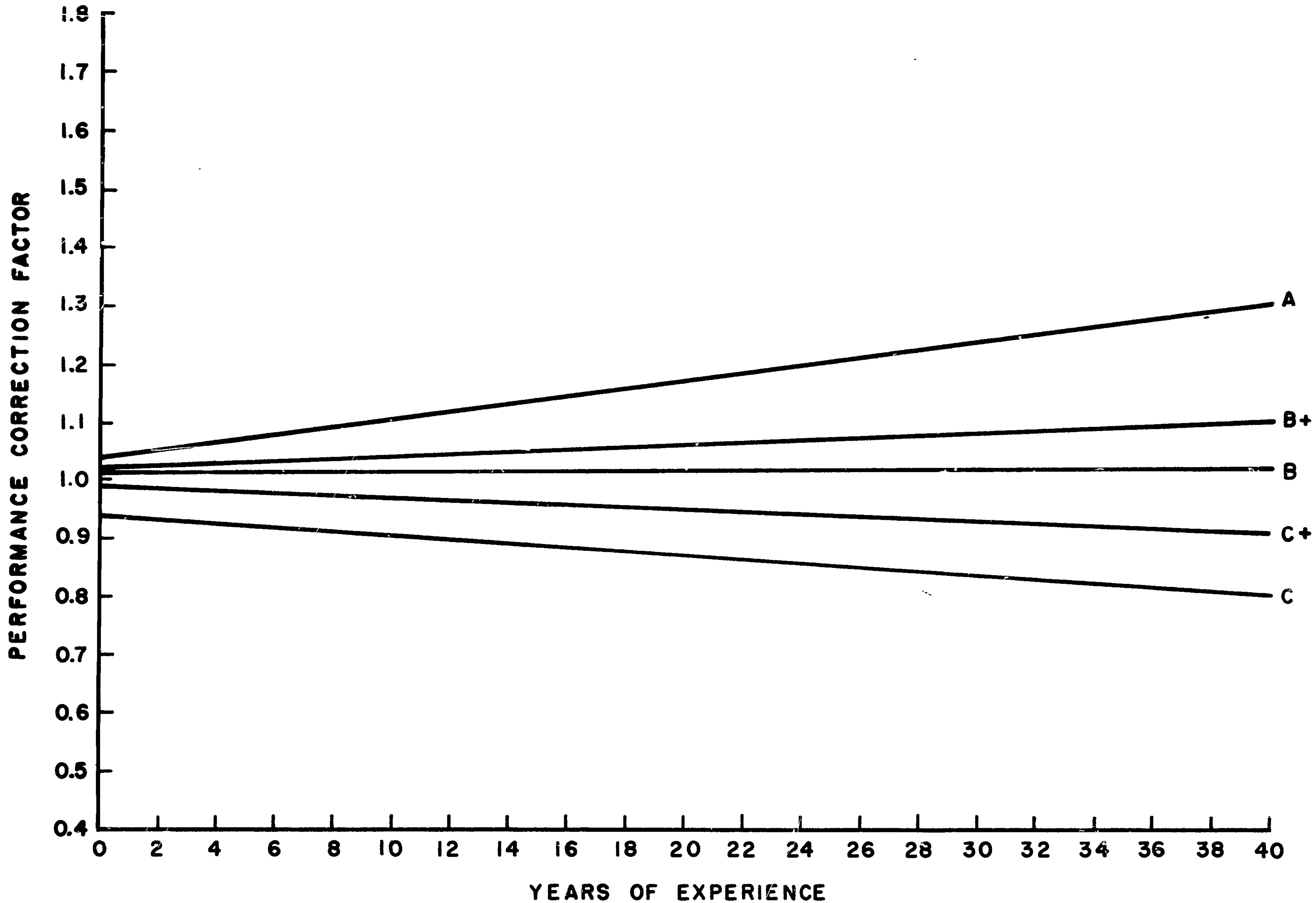
ADJUSTED LIFE-CYCLE EARNINGS FOR ENGINEERS

FIGURE 2



COLLEGE CLASS STANDING AND SUBSEQUENT RELATIVE EARNINGS; FROM GIFFORD (1928)

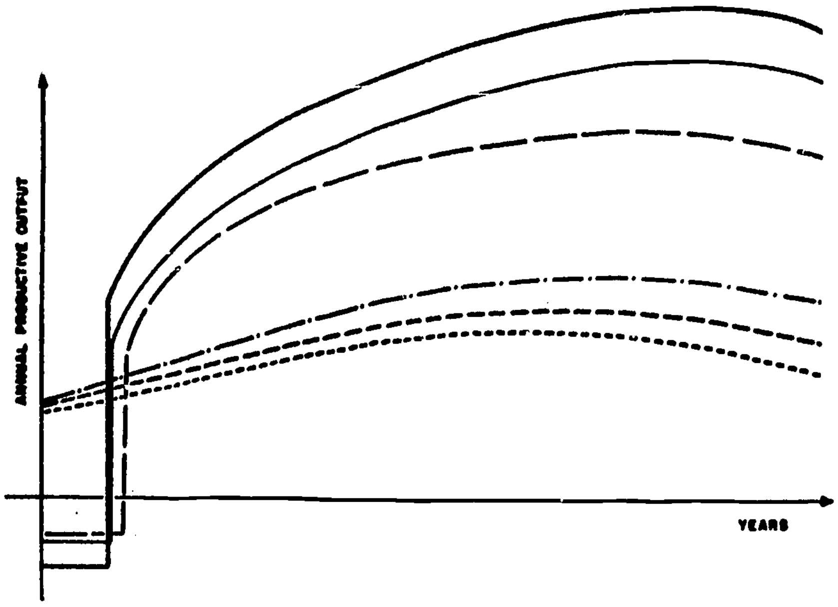
FIGURE 3



PERFORMANCE CORRECTION FACTORS

FIGURE 4

From this recent data, approximate correction factors are obtained as shown in Figure 4. Applying these correction factors to the average expected life cycle earnings, one obtains a set of curves similar to the upper lines on Figure 5. The lower lines represent the expected life cycle earnings or persons who have not gone through the specified educational experience.



EFFECT ON PRODUCTIVE OUTPUT FROM INDIVIDUAL AND EDUCATIONAL DIFFERENCES

FIGURE 5

The next step is to select a discount rate and find the present worth of the expected life cycle earnings of the individual student. From this is subtracted the present worth of the expected life cycle earnings of matched individuals who have not gone through the educational experience. The result is the "utility" or net output associated with a given educational experience.

Discounting future earnings, aside from being a common economics practice, has two important features. First, it reduces the error in the estimate of the utility by giving less weight (e.g., discounting over a longer period) to earnings occurring later in the life cycle. Secondly, it solves the problem of how to evaluate the trade-off between the increment in student performance and the increment of time necessary to obtain such an increment of performance. An example borrowed from Report No. 63-63[17] will illustrate this point. If the average engineering student could complete

his college studies in three years instead of the customary four years, the increment in the present worth of his expected life cycle earnings would be $12,600. Report No. 63-63 goes on to indicate that such an engineering student could theoretically afford to spend up to $6,800 for each of the three years in an accelerated program, as compared to approximately $1,800 for each of the years in the normal four-year program.

Another variation of this problem is to calculate the additional amount of resources one would be willing to commit to education if these additional expenditures resulted in a student getting an M.S. instead of a B.S. degree in four years.

Somewhat more speculative, since it introduces the additional uncertainties of the relationship between school performance and subsequent professional performance, is the problem of calculating the additional amount of resources one would be willing to commit to education if these expenditures resulted in a student getting, say, an A average instead of a B average.

It is relatively easy to specify a utility for those macro systems where sufficient historical data exist for making projections. The problem is more difficult for micro and micro-micro systems, and the present approach, pending the accumulation of further data, is to make a number of simplifying assumptions. Many of these assumptions are discussed in detail in Report No. 63-63.

APPENDIX A

PERSONNEL ASSOCIATED WITH THE TEACHING SYSTEMS PROJECT

Dr. Harry W. Case, principal investigator, 1961-1964
Dr. Arnold Roe, co-principal investigator, project director, 1961-1964
Dr. Mildred Massey, statistician, 1961
Dr. Henry Kramer, mathematician, 1962-1963
Dr. Yasuko Filby, research psychologist, 1961
K.M. Srinivas, research psychologist, 1961-1963
William Kirk, Jr., research psychologist, 1962
Richard Nazro, computer and instructional programmer, 1961
Steven Crocker, computer programmer, 1961
Jane Osuga, computer programmer, 1962
Glen Johnson, computer programmer, 1963-1964
Richard Pierce, research engineer, 1961
Arieh Lewin, research engineer, 1961
Stephen Jensen, research engineer, 1962
Paul Englund, research engineer, 1963-1964
Dora Stein, technical writer and office administrator, 1961-1962
Phyllis Brunner, clerk-typist, 1961-1962
Nancy Goldin, clerk-typist, 1963-1964
Penelope Mitchell, clerk-typist, 1963-1964
Jeanette Griver, student, 1961
Mark Sink, student, 1961
Rollie Winters, student, 1961
Vassiliki Vlachouli, student, 1961
Ronald Baldwin, student, 1961
Carl Pignoli, student, 1962

APPENDIX B

PUBLICATIONS AND REPORTS OF THE TEACHING SYSTEMS PROJECT

1. The automated learning research program in the Department of Engineering. Arnold Roe, UCLA Alumni Mag., 1961, 35, No. 5, p. 14-16.

2. Branching programs in automated instruction: a simplified format. Arnold Roe, University of California, Los Angeles, Department of Engineering, Report No. 61-72, August 1961.

3. A dynamic statistical approach to the control of human behavior. Arnold Roe and John Lyman, Paper presented at APA, New York, September, 1961.

4. An evaluation of auto-instructional techniques. Harry W. Case and Arnold Roe, Paper presented at APA, New York, September 1961.

5. The use of linear and branching programs in freshman engineering courses. Harry W. Case and Arnold Roe, Paper presented at Pacific SW Section, ASEE, Las Vegas, December 1961.

6. Learning to operate a small computer by auto-instructional text. Arie Lewin, Arnold Roe and Thomas J. Woodson, Paper presented at Pacific SW Section, ASEE, Las Vegas, December 1961.

7. Research on teaching machines and programmed learning. Arnold Roe, J. Engr. Ed., 1962, 52, pp. 439-446.

8. Scrambled versus ordered sequence in auto-instructional programs. K. Vlachouli Roe, Harry W. Case and Arnold Roe, J. Ed. Psychol., 1962, 53, No. 2, pp. 101-104.

9. Programmed learning experiments in engineering at UCLA. Arnold Roe and Harry W. Case, Paper DP 62-640 presented at AIEE meeting, St. Louis, April-May 1962.

10. Automated teaching methods using linear programs. Arnold Roe, J. Appl. Psychol., 1962, 46, No. 3, pp. 198-201.

11. A comparison of branching methods for programmed learning. Arnold Roe, J. Ed. Res., 1962, 55, pp. 407-416.

12. Format for branching programs in automated instruction. Arnold Roe, IRE Trans. on Ed., 1962, E-5, pp. 131-135.

13. A report on programmed instruction. <u>J. Engr. Ed.</u>, 1962, <u>53</u>, pp. 117-123.

14. The dynamics of an automated teaching system. Arnold Roe, John Lyman and Harold Moon. In <u>Applied programmed instruction</u>, Stuart Margulies and Lewis D. Eigen, eds., John Wiley, New York, 1962.

15. Research in programmed learning. Arnold Roe, In <u>Programmed learning and computer-based instruction</u>, John E. Coulson, ed., John Wiley, New York, 1962.

16. Programmed learning in freshman engineering classes. Arnold Roe, Mildred Massey, Gershon Weltman and David Leeds. In <u>New media in higher education</u>, James W. Brown and James W. Thornton, Jr., eds. Assoc. for Higher Educ. and NEA, Washington, D.C., 1963.

17. An adaptive decision structure for educational systems. Arnold Roe, <u>University of California, Los Angeles, Department of Engineering, Report No. 63-63</u>, December 1963.

18. Preliminary draft for the panel on teaching methods. Arnold Roe, In <u>Honors programs in engineering</u>, Frank Kreith and Jeremiah M. Allen, eds., Allyn and Bacon, Boston, 1964.