REPORT RESUMES

ED 012 106 EA 000 591

TOWARDS BETTER CURRICULA THROUGH COMPUTER SELECTED SEQUENCING OF SUBJECT MATTER.

BY- TAFT, MARTIN I. REISMAN, ARNOLD

EDRS PRICE MF-$0.09 HC-$1.08 27P.

DESCRIPTORS- *CURRICULUM PLANNING, *MATHEMATICAL MODELS, STUDENTS, SCHEDULING, *COMPUTER ORIENTED PROGRAMS, *LEARNING THEORIES, REINFORCEMENT, *SEQUENTIAL LEARNING, SIMULATION, ALGORITHMS,

A MATHEMATICAL MODEL OF ESTABLISHED AND INDUSTRIALLY VALIDATED LEARNING AND FORGETTING THEORIES IS OUTLINED, AND A COMPUTER-EXECUTED HEURISTIC ALGORITHM FOR SELECTING THE BEST SCHEDULE FOR SUBJECT PRESENTATION IS GIVEN. FUNDAMENTAL PARAMETERS OF THE MODEL INCLUDE EDUCATION POTENTIAL, TYPE OF SUBJECT MATTER, TYPE OF LEARNER, TEACHING METHODS, AND NUMBER OF TIMES A GIVEN SUBJECT HAS BEEN TAUGHT OR REINFORCED. THE SIMULATION MODEL (1) OFFERS A UNIFIED APPROACH TO CURRICULUM PLANNING, (2) ALLOWS THE LEARNER TO BE MADE AN INTEGRAL INPUT TO CURRICULUM PLANNING, (3) FOCUSES ATTENTION ON MAJOR VARIABLES CONNECTED WITH CURRICULUM RESEARCH AND OFFERS A PARTICULAR FUNCTIONAL RELATIONSHIP BETWEEN THESE VARIABLES, AND (4) REPRESENTS A DETAILED PLAN OF ACTION. THE MODEL'S GREATEST SIGNIFICANCE LIES IN ITS PRESENTATION OF AN EXPLICIT CONCEPTUAL FRAMEWORK WHICH CAN BE TESTED, VERIFIED, IMPROVED, OR REJECTED. THE COMPUTER PROGRAM IS WRITTEN IN FORTRAN IV. (HM)

"Towards Better Curricula Through Computer Selected Sequencing of Subject Matter"

by

Martin Israel Taft[1] & Arnold Reisman[2]

[1] Associate Professor of Engineering
California State College at Los Angeles

[2] Visiting Professor of Engineering and of Commerce
University of Wisconsin, Milwaukee

ABSTRACT

It is generally recognized that reinforcement, over an extended period of time of a given subject matter taught enhances the student's mastery and subsequent retention of knowledge and/or skills. Recent major studies of curricula have concentrated on the content and method of presentation but have not made any significant strides towards the systematic exploitation of the potential contribution to the learning process of reinforcement through proper sequencing of subject matter presentation. This paper outlines a mathematical model of the established and industrially validated learning and forgetting theories and presents a computer executed heuristic algorithm for the selection of the best schedule for subject presentation. Applications of this methodology can be made at all levels of our educational system; from the elementary grades through graduate school, in highly academic as well as vocational training programs.

INTRODUCTION

Since the launching of Sputnick I various phases of the American educational system have gone through a critical self-examination. Thus, the mathematics and science curricula at the elementary and secondary school levels have been greatly restructured in terms of content as well as method of presentation. Undergraduate university curricula, especially in the professions such as engineering, business administration and education, have tended towards greater emphasis on the principles and on the unification of subject matter. Typically, proposals resulting from curriculum studies have focused on the material covered during the four years of the normal professional preparation program, on methods of presentation to make the material more meaningful and/or on the need to extend such programs to 4 1/2 or 5 years of study. In two cases U. C. L. A. [1] and Dartmouth [2] the contents of traditional courses have been broken down into more elementary units, i.e. the underlying; concepts, precepts, laws, tools, applications and so forth. A procedure was then developed which allows each of these elemental items to compete, in·as objective a manner as has yet been devised, for its share of the total curriculum time. It may therefore be presumed that a better allocation of time and therefore emphasis resulted from these studies. Hence a better balanced curriculum for the objectives set forth. This indeed was a radical departure from past practices and certainly a long step forward. However, the studies' attainments fell short of their inherent potential inasmuch as the problem of sequencing of these subject matter units was handled pretty much as in times past. Yet, the reinforcement through proper sequencing and repetition of subject matter plays an important, if not a key, role in the level of retention and of mastery of knowledge and of skills at the end of a course of study.

Learning and forgetting theories of psychology are well developed. The quantitative aspects of these theories have been successfully applied in industry [3] and they can and should be brought to bear in education to enhance the level of mastery of subject matter at graduation and the retention of same thereafter. Systematic sequencing of the subject matter should materially help to accomplish these goals.

It is towards this end that a heuristic algorithm implemented by a large digital computer program has been developed. This paper will briefly describe the algorithm, the computer program and through an example some of the power of its application. Finally, the implications of this methodology for future research and applications will be outlined.

AN OVERVIEW OF THE SEQUENCING MODEL

It is assumed for the purpose of this work that the content of a curriculum has been established and that the total program time has been rationed to the various elemental subject items. We then pose the question what are the major factors influencing the sequence in which the elemental subject units are to be presented?

Let us imagine a student studying differential calculus. Typically, he enters this course at the beginning of his second semester. As he is exposed to more and more class hours of instruction, his educational potential in this subject area increases. What does educational potential mean? In the present context, the educational potential will represent that level of mastery of the subject matter which the student attains as a result of his experiences up to the time in question. Does this mean how well he has memorized this material? Does it mean how well he can use it in new situations? Does it mean that he can see its relationships to other subjects? Does it imply that he has developed new attitudes and skills in this subject area? The answer to these questions is that depending upon the course content, some or all of these criteria will apply. Every person who teaches a course has, implicitly or explicitly, developed a set of criteria with which to evaluate the course. We are constantly giving students tests to determine the level of mastery of the material presented. Our tests may not be very accurate yet we are making decisions based upon our testing. The point being made is that we do have criteria and we do test.

As we teach the student, hour by hour, his level of mastery in the given subject increases; but it does not increase linearly. It has been shown [4] that a considerable body of empirical data from experimental work in psychology already exists and that this data is directly related to the problems of learning. What emerges from this large body of data is that, in general, a person follows a learning curve which looks like a stretched out letter-S. Initially, when a student is introduced to new material, the slope of the curve is very close to zero. This implies that if we plot level of mastery (P) versus time (t) we find that for every unit of time that we expose the student to the subject matter, his level of mastery increases very little. But as the number of hours of learning increases, the slope increases rapidly until mastery is directly and linearly proportional to learning time. Then, as the learning time is increased still further, the curve gradually levels off until it becomes asymptotic to some maximum level of mastery. This maximum level represents the level of mastery which the student would reach if he were to master not only the material presented in the course in question, but also the material in all other courses offered by the school which repeat and reinforce the material in the given course. Thus, any student who was to achieve the maximum level of mastery in a given course would have obtained the largest amount of"overlearning" that is theoretically possible for a given course in a given curriculum. It can be seen that as the top of the curve is approached, each additional unit of learning time produces less and less increase in level of mastery; there is what may be thought of as a point of diminishing returns.

Now we consider what happens when a student has completed a course and is not using the material from it in another course. By analogy to economic problems the completed course can be considered an investment. The moment the student stops learning a given subject and does not use it in any other courses, there is a decay or depreciation in his level of mastery. In other words, if an equivalent final examination for the course were given to the student some time after completion of the course, he would obtain a lower test score than previously. From psychological test data, classroom experiments, and industrial studies over a wide variety of subject matter areas, people, teaching methods, and so forth, it has been found that the decay or forgetting curve may be represented by a negative exponential.

In general, the students' level of mastery decreases with disuse as time goes by. However, as soon as he starts to use the subject matter in question in another course, then his knowledge begins to rise again. It shall be assumed that it rises from the point on the learning curve where he left off last but shifted downwards because of the decay. References [5,6] present precise descriptions of the learning and forgetting curves. At this point, it should be noted that in describing the student's mastery of a given subject we require a function or functions which produce a series of curves which rise through the learning phase, drop through disuse, then rise again through reinforcement, and so forth until graduation day or termenation of the formal program of study.

On the day of graduation or termination of studies a student will have some level of mastery of a given subject. The final level of mastery depends upon how the presentation and utilization of this subject was distributed over the total time of the program. If the total time allotted to this subject was used during the first semester, the student might have approached the top of his learning curve. However, during the remaining seven semesters in school his level of mastery would continuously decay so that on graduation he would remember very little about the course. However we know that the student will problably experience some repetitions of the material in other courses and probably in different contexts. Therefore the curve will rise a little, fall a little, rise a little, and so on until at graduation the student's final level of mastery in this subject will be somewhat higher than if there had been no repetitions at all.

It can and will be shown that there are some distributions of the subject matter that produce higher levels of mastery at graduation than do others. We therefore consider the distribution of every course, topic, or item in the curriculum in such a way that, at graduation, we maximize the student's mastery of the entire curriculum. This means that if we added together the student's levels of mastery in all courses on the last day in school, the total would be a measure of mastery of the entire curriculum. Different schedules or distributions of subject matter will yield different totals. It is a major objective of this work to develop a methodology for finding the schedule or schedules which produce the highest overall mastery.

It is not sufficient merely to maximize mastery on graduation day; it is also important to maximize the students' retention of the material after graduation. It turns out that the rate of forgetting decreases with the increase in the number of repetitions of the subject matter, the teaching methods used, the cumulative amount of time taught, and other factors. It will be shown that fortunately, schedules that are optimal with respect to total mastery are also optimal with respect to retention.

DEVELOPMENT OF A GENERAL LEARNING FUNCTION

It is assumed here that the general trends predicted by the learning theorists are correct with respect to learning and forgetting. In view of the large number of interacting variables connected with learning, and in view of the lack of any general theory of learning which is acceptable to most of the practitioners in the field, the present attempt at a mathematical model will involve the grouping of many of the variables into a small number of lumped parameters. The degree of mastery of a given course, topic, or subject matter item, will be expressed as a function of the lumped parameters and a number of other pertinent variables. As a very gross initial approximation we can state that the degree of mastery (henceforth known as the educational potential,p) is a function of the type of subject matter, S; the type of learner, L; the type of teaching method, M; the cumulative learning time, t_L; the forgetting or decay time, t_D; and the number of repetitions of the subject matter, R. Thus,

$$p=p(S, L, M, t_L, t_D, R)$$

Since these are the fundamental parameters to be used in this model, a more detailed explantion of their meaning is now given.

p The education potential represents that level of mastery that the student has achieved at a given time t, relative to an initial base p. The base p is usually taken to be zero for the purposes of this model unless sufficient empirical data regarding the student's initial knowledge of the subject area in question is available. For a given schedule, the educational potential is directly but nonlinearly porportional to the cumulative learning time. We measure educational potential in the same units as we use for time; namely, weeks or hours. In trying to determine how much a student has learned in a given course we normally say that "he has had four weeks of Algebra". This does not imply that the student has mastered four weeks worth of Algebra. Rather it means that if we know the learning time we can estimate the level of mastery by means of the appropriate learning function which relates p to t.

S The type of subject matter can be broken down into any number of arbitrary categories. For instance, the Engineering Science Curriculum at Dartmouth College [2] has been broken down into the following categories: analytical technique, concept, definition, engineering device, experimental technique, factual data, instrument, law, precept, principle, and special illustration. Another method of categorization breaks the subject matter into various levels of complexity; from extremely simple, concrete, illustrations to highly abstract and generalized material.

From a curriculum synthesis viewpoint, the subject matter can be characterized by the importance that the faculty places upon it. The percentage of time in the entire curriculum devoted to a given item by the faculty is an explicit measure of a number of implicit factors. It includes a faculty concensus regarding the total time that should be allocated to this subject matter commensurate with the educational objectives of the school, the available resourses, and the time that students are available in the classroom. It also includes the faculty's estimate of the direct amount of time required to teach the subject under average conditions and the indirect time to be devoted to the repetition of the subject matter in other courses or school activities. Thus, the type of subject matter, S, is a direct function of the total time devoted to it by the faculty. This total amount of time shall henceforth be designated by the letter, H.

L The type of learner can initially be categorized into three groups; a high learner, an average learner, and a low learner. Students may be placed into these general categories by using a composite score derived from such data as I.Q. tests, College Entrance Examinations (SAT), cumulative grade point averages, general ability profiles, counsellors' recommendations, and so forth. For the purpose of this model a standard learner is defined as that student whose composite score is equal to the average composite score of all of the students in the educational institution. In this model the value assigned to a standard learner is given by L=1. All other values of L are assigned relative to this value.

M The methods of teaching can be characterized in many different ways. Arnold Roe has stated [7] that the corpus of knowledge on teaching methods can be viewed in three dimensions: [A] Relation to the structure of the specified course content; [B] Relation of the structuring to the students and teachers; [C] Relation to the behavioral aspects of the students. In private discussions with Stephen Abrahamson it was concluded that a fourth dimension may be added; namely, the behavioral aspects of the teacher. Theoretically interactions between elements in one dimension with elements in the other dimensions should lead to the filling of each cell with a number representing a utility for the particular intersection of elements. Utility numbers are, in general, difficult to ascertain. In the experimental literature on teaching methodology statements are usually made regarding the elements in one of the dimensions only. Dimension [C] which is related to the behavioral aspects of the students has been summarized by McKeachie [8] and Tyler [9]. The other dimensions have been discussed by Roe in the reference cited earlier.

For the purpose of this model the teaching parameter, M, will be defined operationally in terms of its effect upon the level of mastery of the subject matter at a given time relative to the level that would be achieved under standard conditions. Standard conditions are defined as those conditions that prevail at the time that this model is implemented in the school. In this sense, M represents an index which is equal to one (1) under standard conditions and is greater or less than one depending upon whether the teaching methods in general are better or worse than those considered under standard conditions. This approach is not as unprecise as it may seem at the outset. Although absolute values to describe teaching methods cannot be obtained at the present time, relative values can be estimated and verifications of these estimates can be made with a minimum expenditure of time and resources. For the purpose of distinguishing between different schedules or sequences of subject matter it is sufficient to use values of M like 0.8, 1.0, and 1.25. These numbers could represent substandard, standard, and superior teaching methods respectively.

t_L The variable t_L represents the cumulative amount of time that a given subject has been studied in the classroom. It includes the estimated time that the subject matter has been reinforced or used in other courses or subject areas. In keeping within the precision obtainable from this model and the precision of the available data, time shall be measured in weeks, rather than in hours or some shorter time unit of measurement.

R The variable R represents the total number of times that a given subject has been taught or reinforced up till the time under consideration. The total number of times includes the initial time that the course was introduced and each succeeding time that the course was used in other courses. In order to be considered a repetition a course may be taught or used for less than one week.

t_D The decay (or forgetting) time occurs when the given subject matter is not being taught nor used. It is assumed that no forgetting occurs while the material is being taught or used; forgetting occurs at all other times.

A general function which satisfies all of the conditions given in [4] and which is dependent upon the parameters stated above is now presented.

$$p=MH(1-S^{-L(t_L)^2})S^{-At_D} \quad \text{where: } A = \frac{H-Bt_L}{MLR}$$

B = an empirically derived constant related to initial forgetting

$t_D = 0$ during learning or relearning

$t_D > 0$ during forgetting.

Ambiguities with regard to the independent variable t can be eliminated by writing one equation for learning and another for forgetting:

$$p_L = MH(1-S^{-Lt^2}) \qquad \text{and} \qquad p_D = p_L S^{-At}$$

The t used in the learning equation is the same as t_L; while the t used in the decay equation is the same as t_D. These equations satisfy the conditions of learning stated in [4] and others.

The composite equation for the education potential presented thus far represents an "additive model". This implies that the parameters M, L, and S are independent of each other. It is however, more reasonable to expect that in a process as complex as learning these parameters are functionally dependent upon each other. We would expect some mutual interactions. A simple example will be used to illustrate the problem.

Let S, the type of subject matter have two categories: S_1 and S_2

L, the type of learner, have: L_H, L_M, and L_L

M, the type of teaching method, have: M_I, M_T, and M_L

If the educational potentials of the students were to be actually measured at the end of a course of study, the experimental data due to mutual interactions might result in graphs similar to those shown in Figure 1.

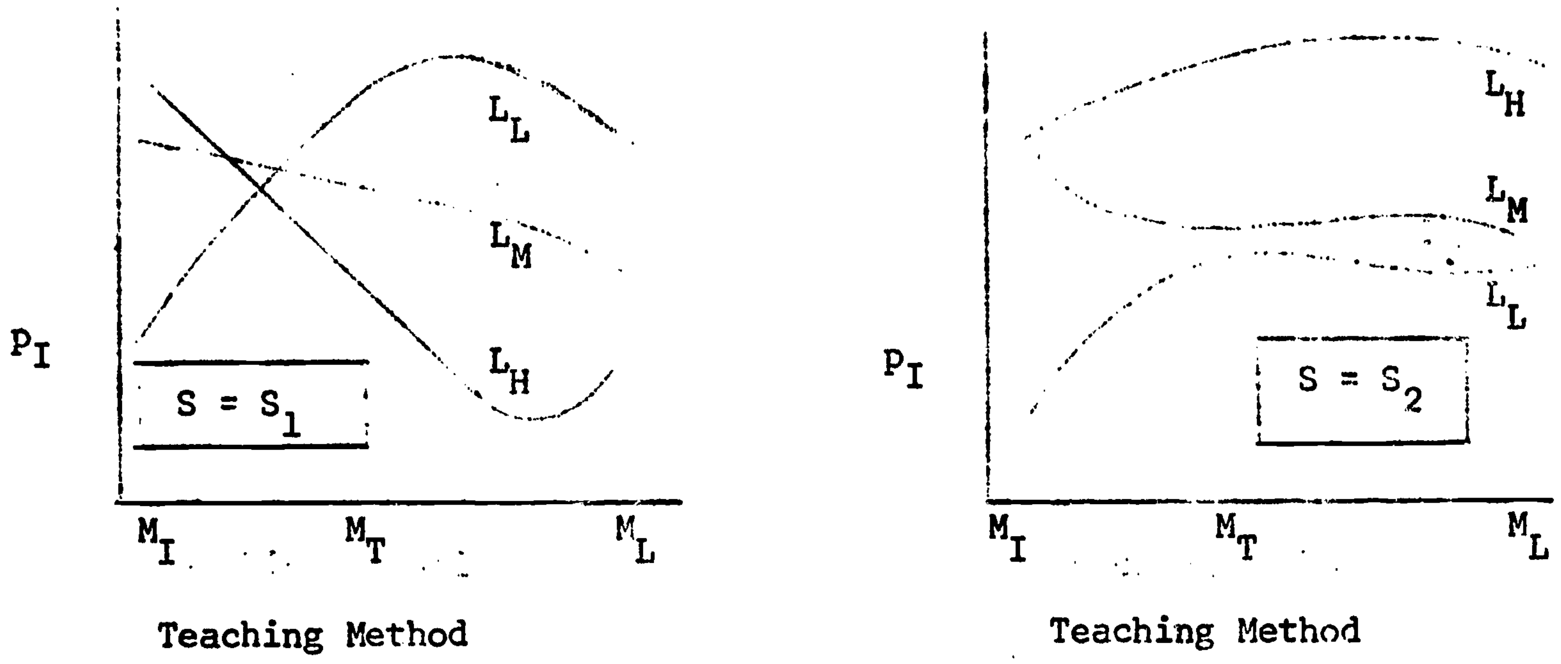


Figure 1. --Interactions between parameters S, M, L.

For subject matter S_1, a low learner L_L, taught by the method of teaching machines M_T, might yield a high educational potential p and much lower p's for the method of independent study M_I or a lecture method M_L. On the other hand, an entirely different graph might be obtained for a high learner L_H.

In order to compensate for the effects of interactions for which we do not as yet have an acceptable theory or explanation, we shall multiply the equation of our model by an interaction factor, I.

In a manner entirely analogous to that used in engineering to define efficiencies, flow coefficients, friction and safety factors, we define the interaction factor as the ratio of the empirically-determined p and the p which is calculated from the model.

$$I = I(M, L, S) = \text{Interaction Factor} = \frac{p(\text{actual})}{p(\text{model})}$$

$$I = \frac{\text{Educational potential from experimental data with interactions}}{\text{Educational potential from the model without interactions}}$$

The composite equation for the educational potential for one particular course now becomes:

$$p = IMH(1 - S^{-Lt_L^2})S^{-At_D}$$

The model can be generalized for m courses in the j-th schedule.

$$P_j = \sum_{i=1}^{m} P_i = \sum_{i=1}^{m} I_i M_i H_i (1 - S_i^{-L_i t_L}) S_i^{-A_i t_D}$$

If there are n possible schedules, the next task is to find the schedule with the highest P. Thus, we must maximize P over schedules $j -1$ through $j = n$. We turn our attention to this problem in the next section.

A HEURISTIC METHOD FOR SCHEDULING

The combinatorial problem.

The problem of developing optimum or suboptimum patterns of courses (which we call schedules) hinges upon the fact that for a relatively small number of courses, there are an extraordinary number of possible arrangements. For n courses there are $_nC_r = \frac{n!}{n(n-r)!r!}$ combinations of courses taken r at a time. Thus, if there were only forty courses, there would be 658,008 possible schedules. However, not all of these schedules are really different from each other and many others are not acceptable because they do not satisfy constraints such as those for prerequisites and maximum hours of classes per week allowable. Even if symmetry and the constraints were to reduce the number of schedules by a factor of 100, the problem would not be appreciably simplified because the total number of schedules to be investigated would still be "large".

It is not possible even with the most rapid data-processing equipment available to investigate and compare all the allowable schedules that are possible and to find the one which maximizes the objective function, namely, the educational potential, P. What is needed is a technique which can generate and evaluate a relatively large number of possible schedules without a tremendous expenditure of time and money. Thus a suitable heuristic algorithm is required.

In 1962, Gordon Armour [10] presented a methodology for determining better relative location patterns for physical facilities, the "Computerized Relative Allocation of Facilities Technique" (CRAFT).

The CRAFT algorithm produces good solutions (but which are not to be assumed to be best) to the plant layout problem by successively exchanging each department in location with every other department, evaluating the incremental transportation costs resulting from each exchange, and retaining only those layouts that incur lower incremental costs. A solution is reached when further exchanges of departments do not result in any reduction in the incremental costs. This heuristic algorithm which is implemented by means of a large computer program produces layouts that are far superior to those produced by other methods, even though they are not necessarily optimal.

A heuristic algorithm.

The central idea of the solution to the scheduling problem considered here is taken from CRAFT. By exchanging course locations rather than department locations, it is possible to generate a progression of different schedules and to systematically converge on one of a number of good solutions. These solutions are far better than those currently available and solutions which cannot easily be improved upon. The algorithm that will be used in this model follows:

a. Compute the educational potential, P_j, for the first allowable schedule, j. (This is usually a schedule recommended in the school catalogue.)

b. Calculate the value of p_j obtained by exchanging the location in the schedule of each course with every other course in a non-redundant manner. Compute p_j values only for those schedules that satisfy all of the school constraints. After each exchange, compare the value of p_j obtained with the previous one. Retain the larger value. If there are n courses and they are exchanged r at a time, there will be

$$_nC_r = \frac{n!}{r!(n-r)!} = \frac{n(n-1)\ (n-2)\ldots(n-r+1)}{r!} \quad \text{exchanges.}$$

c. After all exchanges have been completed, print out the schedule having the highest p_j (namely, the last schedule retained) and associated data. Compare the latest value, p_j with the initial value, p_1. If p_j is higher than p_1, go back to step b and begin the next iteration. If p_j is equal to p_1, (there has been no increase in p_j) continue with step d.

d. Compute an ideal value of p_j for schedule j and an efficiency based upon the best schedule.

e. Print the final schedule and associated data.

f. Stop. A suboptimum schedule has been reached.

The computer program.

The heuristic algorithm has been formalized in a computer program which is briefly presented here. The program contains eighteen subroutines and over 700 cards in the source deck. The program is written in Fortran IV and has been run on the Honeywell 800 computer. At the present time the program is capable of scheduling over 100 different courses and handling more than 220 time increments. The smallest time increment is usually taken as a week. This implies that the program can be used to schedule courses during every single week of a four-year curriculum.

The essential logic of the program is shown in broad outline in the

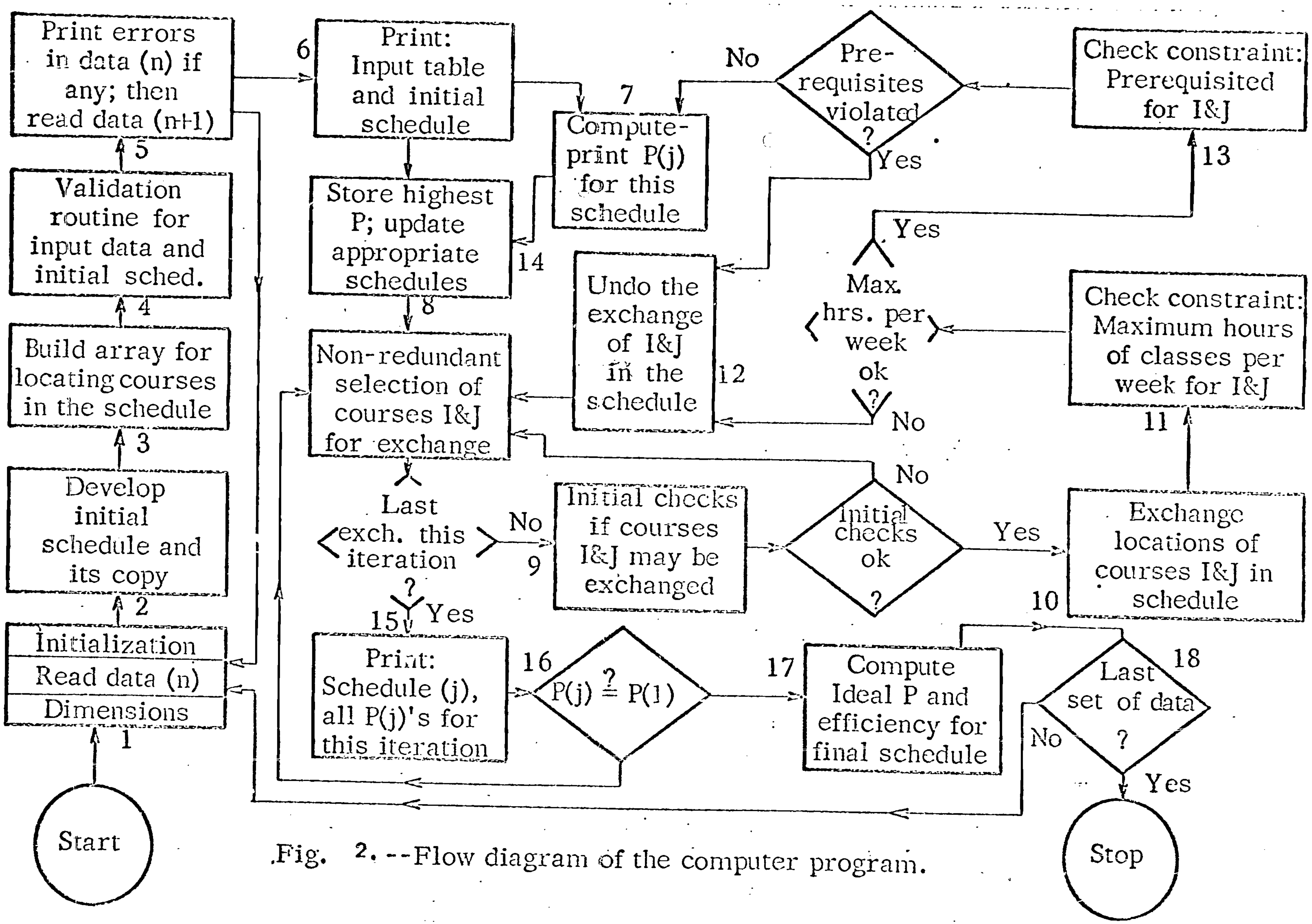


Fig. 2.--Flow diagram of the computer program.

flow diagram, Figure 2. A brief description of each of the subroutines that are numbered in the flow diagram will aid in interpreting the entire computer program.

1. The entire input to the program is read from individual sets of data cards which can be stacked one after the other following the source deck. The input cards contain data regarding the type of format to be used in printing the schedules; the names, starting times, durations, and hours per week of all the courses; estimated reinforcing hours for each course; data regarding which courses shall remain in a fixed location; course parameters; prerequisite and corequisite information.
2. The program will then utilize the starting time and duration of each course to develop an initial schedule which will be printed out.
3. For the purpose of keeping track of each of the courses in the schedule and to reduce the computing time, a subroutine has been developed which locates each course by its row and column in the schedule.
4. The initial input data and first schedule is inspected to determine whether there are any major discrepancies in the input. This routine will determine whether the prerequisites for each course in the initial schedule are satisfied. It also determines whether the maximum number of hours per week allowable have been exceeded during any time interval in the initial schedule.
5. If any discrepancies in the initial schedule or input data is found, the exact error is printed out and the program returns to the beginning and reads the next set of data.
6. If there were no discrepancies in the original data set then a table of the initial input and a copy of the initial schedule is printed.
7. This subroutine computes a total P or educational potential for the given schedule by:
    a. Dividing the schedule into small time increments such as one, two, or four weeks.

b. During each time increment an increment in p is calculated for each course in existence within this interval of time. The sum of all the p increments for each course is obtained by adding the increment in p to the previous total p at the end of each time interval. During those time intervals when forgetting occurs, the increments in p are negative numbers and are subtracted from the current total p for the course under consideration.

c. The total P for the initial schedule is compared with the previous total P which at this point is zero. The higher value is stored by subroutine 14 and the program then proceeds to item 8.

8. This subroutine contains a triangular matrix which provides for the non-redundant selection of two courses to be exchanged in location in the given schedule. Since there are n courses taken two at a time, it can be seen that by setting r equal to 2 in the previously given formula, the total number of possible exchanges for one iteration is n(n-1)/2. Thus for twenty courses there would be 20(20-1)/2 or 190 individual exchanges. If the exchange under consideration is not the last one of the iteration, the program proceeds to item 9.

9. In this subroutine preliminary checks are made to see whether an actual exchange is advisable. Two courses may not be exchanged if their starting times are equal or if their durations are unequal. If these two conditions are not satisfied, then the program returns to item 8 and two new courses are selected for possible exchange.

10. If the two courses pass the initial checks then the exchange routine physically exchanges the two courses in location in the schedule and

also exchanges their starting times and locations in the array.

11. If a three-hours-per-week-course is exchanged with a one-hour-per-week-course, it is possible that in its new location the three-hour-per-week-course may cause the maximum allowable number of hours per week to be exceeded. If this occurs, the program goes to subroutine 12.

12. This subroutine reverses the operations that were carried out in subroutine 10; it places the two courses in question back into their previous locations in the schedule and then the program proceeds to subroutine 8 where two new courses are selected.

13. If the maximum-hours-per-week constraint is not violated, the program continues to subroutine 13 where the prerequisites for the two courses in question are scrutinized. If there have been no violations of the prerequisites or corequisites or either of the two courses exchanged, then the program goes to subroutine 7 where a P for this schedule is calculated. However if the prerequisites are violated the program proceeds to 12 and ultimately to 8 where new courses are selected for exchange.

14. After a total P has been calculated for a given schedule it is compared with the previous total P and the higher value is stored. In this routine appropriate tables and schedules are updated depending upon which P must be remembered.

15. If the last exchange of this iteration has been completed, the program goes to subroutine 15. The latest schedule is printed together with all of the P's for this iteration.

16. The last P calculated is compared with the first one of this iteration and if there has been no improvement, namely they are both equal, the program proceeds to item 18. If on the other hand there has been a

change in P, the program returns to subroutine 8 and the triangular matrix is initiated from the beginning. The program will then carry out another entire iteration and continue in this way until there is no improvement in P during an entire iteration.

17. In this routine an ideal educational potential is computed for the final schedule. If the reinforcements for a given course could be scheduled at any time, we would attempt to schedule them as soon as possible after the given course has been completed. This would mean that the student would learn all of the course material continuously without any intervening periods of forgetting. Under these conditions, when all of the reinforcements have been completed, the rate of forgetting will be the minimum possible rate due to the fact that we have scheduled the maximum number of reinforcements (repetitions), and forgetting occurs only after there has been the greatest possible amount of overlearning. This calculation leads to a possible but highly improbable total educational potential which we classify as the ideal. This routine also carries out the calculation of an efficiency which is defined as follows:

$$\text{Efficiency} = \frac{P(\text{final}) - P(\text{initial})}{P(\text{ideal}) - P(\text{initial})}$$

This efficiency represents one possible standard by which to judge the relative superiority of the schedule calculated by the model and the schedule taken from a school catalogue.

18. This subroutine inquires whether there are any new data sets that have not as yet been processed. If there are additional sets the program returns to the "read" statements and begins to calculate a new data set. In the event that there are no new data sets left, the program stops. The program will also stop if there are any contradictions in

in the final set of data.

Additional computer program capabilities.

1. By changing a single "dimension" statement in the source deck it is possible to increase the number of scheduled courses from 100 to 200, or to increase the number of time intervals from 220 to 440 without requiring the use of a larger computer.
2. Any number of courses can be kept in fixed locations in the schedule; they would never be exchanged in location with any other courses. This feature is very helpful in those cases where it is decided to give certain courses at particular times.
3. The program can rapidly compute a value for the educational potential for individual schedules that are to be compared. For instance, it might be desirable to know whether a course in Statistics should be taught to engineering students in the freshman year or the junior year. Both types of schedules can be evaluated in less than a minute of computer time.
4. Schedules with courses of different durations can be handled by the program with no special instructions or changes in the source deck.
5. Changes in the function for calculating P, which would result from future research and field testing, can be made in a few minutes by retyping a few cards in the source program deck. Such changes in the objective function will not affect the operation of the rest of the program.

The complete computer program is available at the University of Southern California-Honeywell Computer Center. An example of a typical but hypothetical application of the computerized methodology is presented in the next section.

EXAMPLE

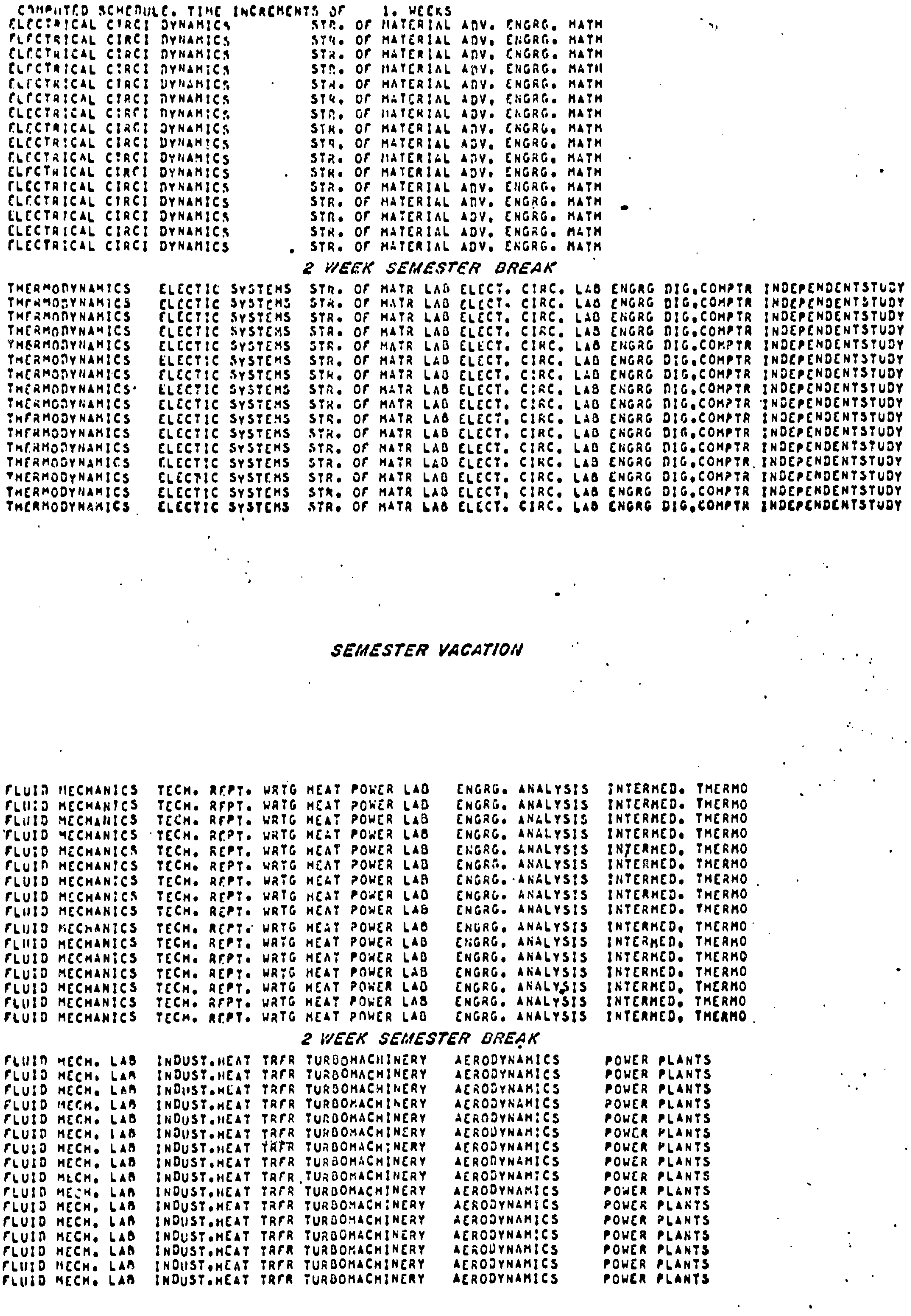
The computerized sequencing model has been applied to the problem of finding improved schedules for the last two years of the engineering curriculum for a mechanical engineering student at the California State College at Los Angeles. A typical schedule which is recommended in the college catalogue was used as the initial schedule in the computer program. This schedule is shown in Figure 3. Every line in the schedule represents the courses studied by the student for a period of one week. Each semester is sixteen weeks long; there are two weeks between semesters; the summer vacation lasts for eighteen weeks; and graduation is assumed to occur two weeks after the last final examination is given.

Since only engineering and mathematics courses were considered for scheduling, it was assumed that a maximum of thirteen hours per week of these technical courses are allowable. In addition, all of the prerequisites given in the 1965 college catalogue were introduced. Finally, an estimate was made of the number of weeks that each course reinforces every other course in the initial schedule. An estimate of this type would normally be made by a consensus of the faculty.

The computer program produced a printout of the level of mastery for each course for every week in the initial schedule (88 weeks total). These values have been plotted for four typical courses in Figure 4. The graphs show among other things, that forgetting occurs between semesters; forgetting decreases with increase in reinforcements and with proximity to total mastery; and that the maximum height of the learning curve varies with the subject matter.

An improved schedule of courses produced by the computer program is shown in Figure 5. It appears that this final schedule is not much different from the initial schedule. Although 650 different schedules were attempted by the computer, only a comparatively small number of these were allowable. This is directly attributable to the large number of scheduling constraints that are

OUTPUT



```
 COMPUTED SCHEDULE. TIME INCREMENTS OF     1. WEEKS
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
ELECTRICAL CIRCI DYNAMICS         STR. OF MATERIAL ADV. ENGRG. MATH
                          2 WEEK SEMESTER BREAK
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY
THERMODYNAMICS    ELECTIC SYSTEMS  STR. OF MATR LAB ELECT. CIRC. LAB ENGRG DIG.COMPTR INDEPENDENTSTUDY



                               SEMESTER VACATION



FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
FLUID MECHANICS   TECH. REPT. WRTG HEAT POWER LAB   ENGRG. ANALYSIS   INTERMED. THERMO
                          2 WEEK SEMESTER BREAK
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS
FLUID MECH. LAB   INDUST.HEAT TRFR TURBOMACHINERY   AERODYNAMICS      POWER PLANTS

FOR ITERATION  2. MAX. NO. OF EXCHANGES=  325    NO. OF ALLOWABLE EXCHANGES=  22.
INITIAL P=  252.38     FINAL P=  259.46    (P(FINAL)-P(INITIAL))=  7.08
```

Fig. 5. --Computer printout of an improved schedule for last two years of mechanical engineering at CSCLA.

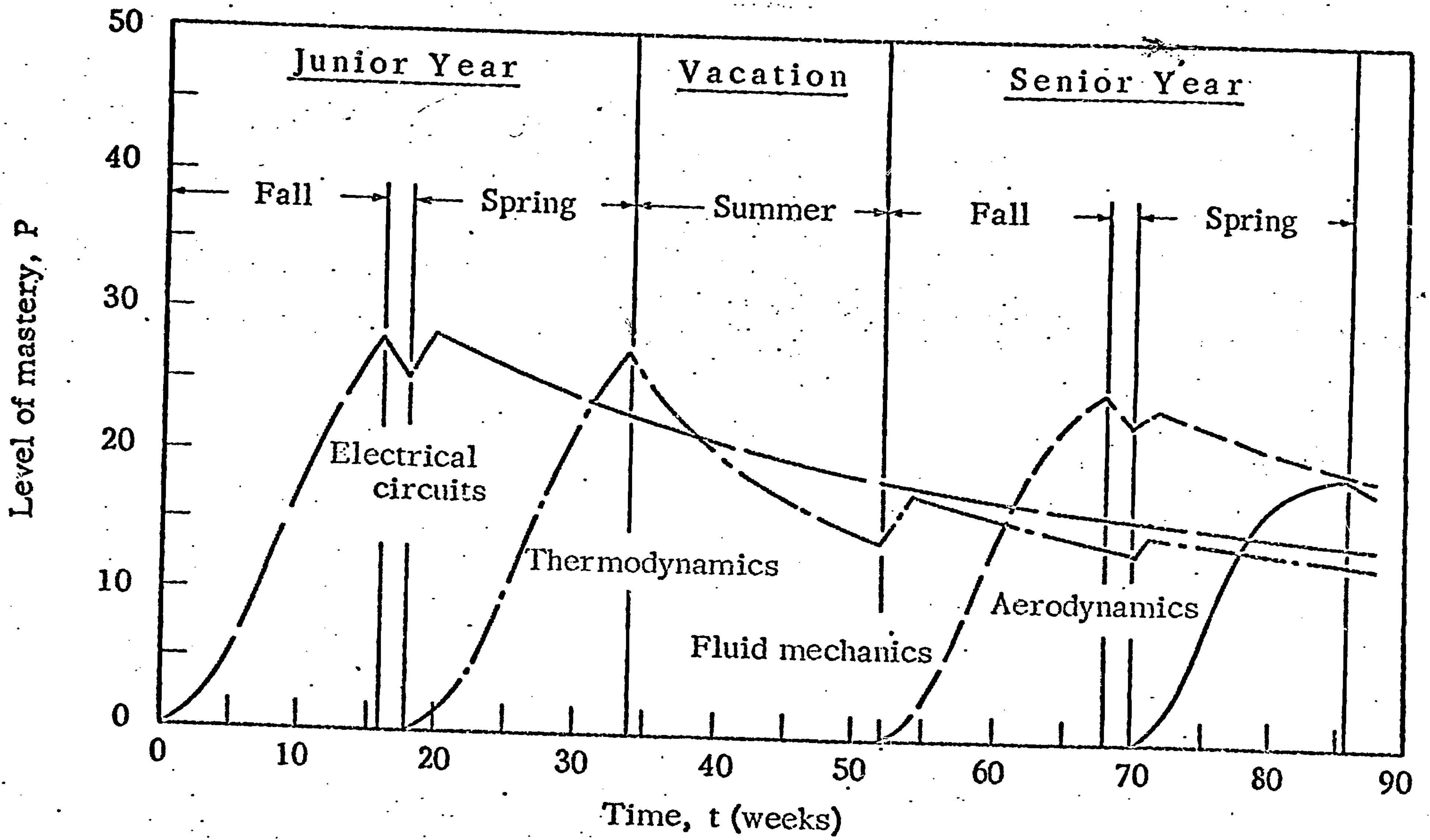
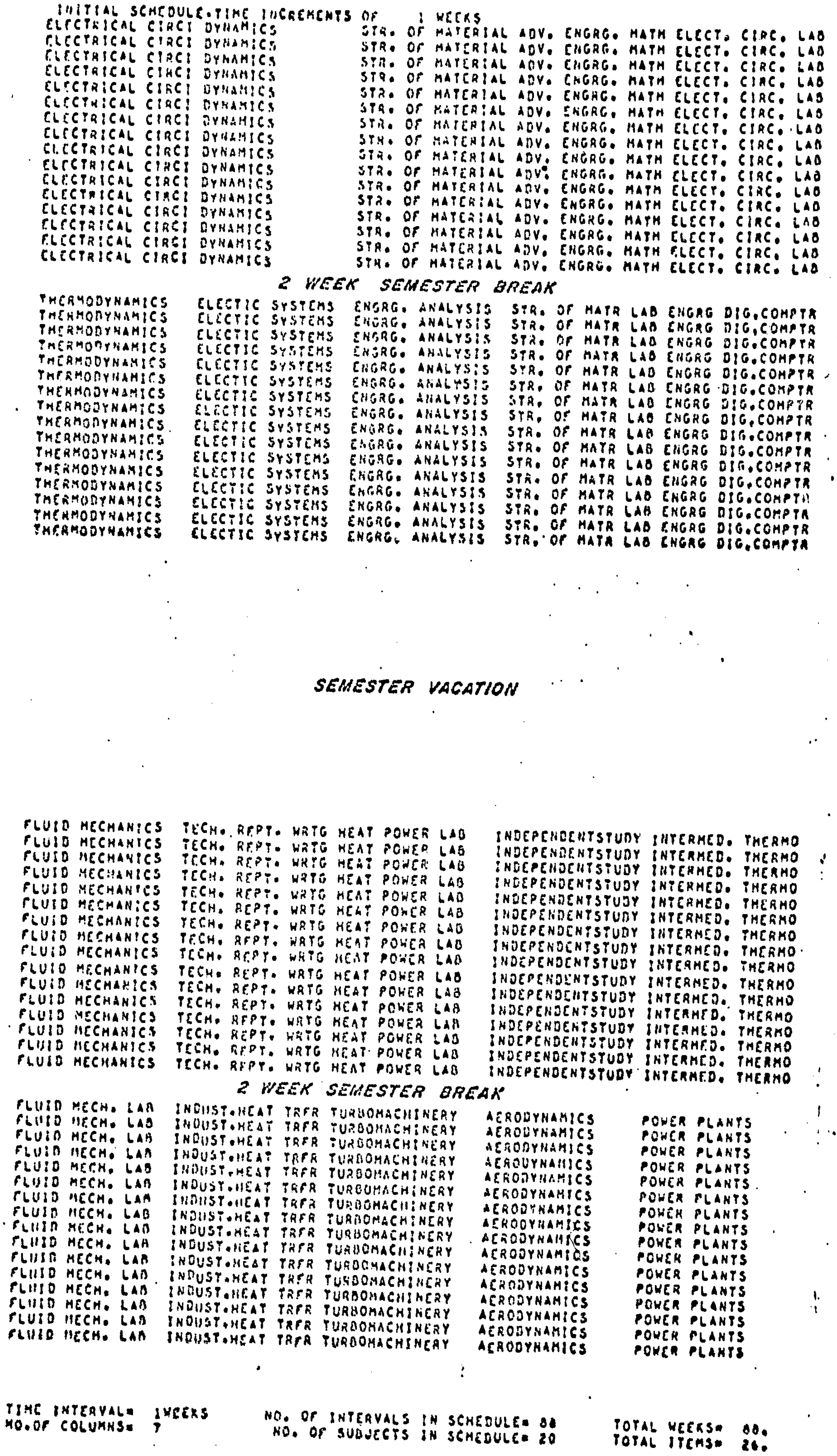


Fig. 4. --Levels of mastery as function of time for four courses in Engineering at California State College at Los Angeles. (Computer computations were based upon typical catalog schedule and current college requirements and constraints.)

INPUT



```
 INITIAL SCHEDULE.TIME INCREMENTS OF    1 WEEKS
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
ELECTRICAL CIRCI DYNAMICS            STR. OF MATERIAL ADV. ENGRG. MATH ELECT. CIRC. LAB
                    2 WEEK  SEMESTER BREAK
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR
THERMODYNAMICS   ELECTIC SYSTEMS  ENGRG. ANALYSIS  STR. OF MATR LAB ENGRG DIG.COMPTR




                         SEMESTER VACATION




FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
FLUID MECHANICS  TECH. REPT. WRTG HEAT POWER LAB     INDEPENDENTSTUDY INTERMED. THERMO
                    2 WEEK  SEMESTER BREAK
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS
FLUID MECH. LAB  INDUST.HEAT TRFR TURBOMACHINERY    AERODYNAMICS     POWER PLANTS


TIME INTERVAL=  1WEEKS        NO. OF INTERVALS IN SCHEDULE= 88       TOTAL WEEKS=  88.
NO.OF COLUMNS=  7              NO. OF SUBJECTS IN SCHEDULE= 20       TOTAL ITEMS=  26.
```

Fig. 3. --Computer printout of initial schedule. Last two years of mechanical engineering at CSCLA.

imposed in this curriculum. Substantially greater improvements could be obtained by reducing the number of prerequisistes, increasing the number of courses by changing over to a "quarter" system or a continuous progress system, and by considering the interactions between the technical and liberal arts courses in the design of new schedules.

A table of parameters used in the calculation of P is printed toward the end of the computer program output and is reproduced in Figure 6. The table also includes an ideal P and a final P for each of the twenty courses considered in the schedule.

A series of sensitivity studies were carried out to determine the effects of small changes in the learner, teaching method, and the starting schedule used in the program. It was found that relatively small changes in these parameters yielded the same best schedule. This result indicates the relative stability of the solutions resulting from the use of the heuristic algorithm and this computer program in particular. Large changes in M and L resulted in significant changes in the suboptimum schedule.

Although the sensitivity studies produced one schedule, it also yielded a different value of total level of mastery (P) for every combination of M, L, and schedule Sc. It is of considerable importance to know whether these values of P are statistically significant, i. e. whether the variations in P are due to chance or due to specific interactions between the parameters. To accomplish this, level of mastery scores were generated by computer simulation for two levels of teaching methods, three levels of learner ability, and two levels of scheduling (catalog and derived) and a statistical analysis was made [4].

The statistical analysis of the aforementioned simulation data showed that interactions do occur and they are significant. These results could not have been predicted by considering the factors individually or by visual analysis of the model. The use of the analysis of variance in conjunction with the model's simulation data has made it possible not only to predict interactions that seem consistent with empirical findings in educational research, but also to estimate which kinds of interactions are significant and the expected relative degree of significance between factors. This finding is very encouraging.

CONCLUDING REMARKS

1. The model presented offers a unified approach to curriculum planning; it integrates the usual logical and time constraints on the curriculum content with our broad existing knowledge about educational psychology.
2. The model allows us to make the learner (student) an integral input to curriculum planning.
3. It focuses attention on the major variables connected with curriculum research and offers a particular functional relationship, between these variables. The model's greatest significance lies, perhaps, in the fact that it presents an explicit conceptual framework which can be tested, verified, improved or rejected.
4. The framework represents a rather detailed blueprint for action. It encourages the use of simulation, heuristic, and statistical techniques to deepen and integrate our knowledge in such specialized areas as learning theory, curriculum synthesis, student counselling and testing.

```
                    TABLE OF PARAMETERS USED IN THE CALCULATION OF P

COURSE      S          I        M        H        L        D     P(IDEAL)  P(FINAL)

   1     1.00589     1.00     1.00    28.00     1.20     .85     20.79     11.68
   2     1.01156     1.00     1.00    20.00     1.20     .85      8.36      5.20
   3     1.00664     1.00     1.00    26.00     1.20     .85     16.59     11.61
   4     1.00956     1.00     1.00    22.00     1.20     .85     17.64     15.08
   5     1.00664     1.00     1.00    26.00     1.20     .85     18.83      9.50
   6     1.00356     1.00     1.00    36.00     1.20     .85     13.76      9.49
   7     1.00356     1.00     1.00    36.00     1.20     .85     26.97     25.47
   8     1.00956     1.00     1.00    22.00     1.20     .85     13.68     12.49
   9     1.00664     1.00     1.00    26.00     1.20     .85     15.97      8.86
  10     1.00803     1.00     1.00    24.00     1.20     .85      8.13      8.13
  11     1.00803     1.00     1.00    24.00     1.20     .85      8.13      8.13
  12     1.00874     1.00     1.00    23.00     1.20     .85     18.79     18.79
  13     1.00803     1.00     1.00    24.00     1.20     .85     21.94     18.09
  14     1.00451     1.00     1.00    32.00     1.20     .85      8.88      8.88
  15     1.00956     1.00     1.00    22.00     1.20     .85     15.70     14.26
  16     1.01606     1.00     1.00    17.00     1.20     .85     15.47     15.47
  17     1.01156     1.00     1.00    20.00     1.20     .85     17.26     17.26
  18     1.01815     1.00     1.00    16.00     1.20     .85     14.88     14.86
  19     1.00451     1.00     1.00    32.00     1.20     .85     13.23      9.91
  20     1.01431     1.00     1.00    18.00     1.20     .85     16.98     16.08
                                               TOTAL IDEAL P=PIDTOT= 311.06
TOTAL IDEAL P= 311.1   FIRST TOTAL P= 255.4   LAST TOTAL P= 259.5   MAX. EXCHANGES= 325   EFFICIENCY= 7 PER CENT
```

Fig. 6. --Computer printout of parameters used in the calculation of P.

References:

(1) Rosenthal, D., Rosenstein, A. B., and Wiseman, G. *Curricular Synthesis.* Educational Development Program Report No. 3-63, prepared by the University of California, Department of Engineering, Los Angeles, May, 1964.

(2) Trent, Horace M., and Trent, Eva Mae. "The Engineering Science Program at Dartmouth College Contents of the Core Curriculum." Thayer School of Engineering, Dartmouth College, 1962-63. (Mimeographed.)

(3) Thue, H. J., Maynard, B. I., and Shappell, N. H. "Time Reduction Curves." Proceedings 5th Annual Industrial Engineering Institute, University of California, January 30-31, 1953, 27-34.

(4) Taft, Martin I. "Toward a Systems Analysis Approach to Engineering Education; A Heuristic Model for the Scheduling of Subject Matter." Unpublished Ph.D. dissertation, School of Engineering, University of Southern California, 1966.

(5) Hilgard, E. R. *Theories of Learning*. New York: Appleton-Century Crofts, 1956.

(6) Seagoe, M. V. *A Teacher's Guide to the Learning Process*. Iowa: William C. Brown, Second Edition, 1961.

(7) Roe, Arnold. "Preliminary Draft for the Panel on Teaching Methods." Appendix VII, Report on the Conference on Honors Programs in Engineering, Boulder Colorado: University of Colorado (June 10-14, 1963), 163.

(8) McKeachie, W. J. "Understanding the Learning Process," *Journal of Engineering Education*, L (1960), 863-865.

(9) Tyler, R. W. "The Evaluation of Teaching," *Journal of Engineering Education*, L(1960), 863-865.

(10) Buffa, E. S., Armour, G. C., and Vollman, T. E. "Allocating Facilities with CRAFT," *Harvard Business Review*, XLII, No. 2 (March-April, 1964), 136-147.