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A model of the educational process and a derived procedure series for implementing an individualized instruction system are presented. The application of computer technology to individualized instruction requires an operational definition of the educational process in terms of school practices. A process model involving three major sets of variables, educational goals, individual capabilities and instructional means, with means a function of goals and capabilities, is outlined. Following upon this conceptual model, an instructional model and the functional basis of an individually prescribed instruction (IPI) system are developed as a sequence of operations. As instruction proceeds, performance is monitored and assessed, and necessary adaptations occur at subgoal decision points. The system is also evolutionary; it is able to compare interim student behavior and final outcomes with predictions of original operational functions and provide the basis for modification when appropriate. Experience obtained in introducing computer assistance into a currently operational IPI system is described at length, and system research abilities, including a cumulative data bank for basic learning and measurement studies, are discussed. (SS)

AN INFORMATION AND MANAGEMENT SYSTEM FOR INDIVIDUALLY PRESCRIBED INSTRUCTION[1]

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One of the most important potential uses of computers in schools is to individualize the educational process. However, as the history of attempts at individualization indicates, little can be accomplished unless the educational process is operationally defined and translated into specific school practices. The basic requirement for this is the presentation of an instructional model which underlies and generates (a) the operations and procedures (materials, school environment, and teaching practices) that need to be carried out and (b) the data and research information required to perform the educational functions in an effective way, according to the expressed aspirations.

Therefore, before any fruitful discussion can begin on how the computer might facilitate such education, it is necessary to make explicit just how individualization is to be accomplished. The instructional model can serve as the beginning of a system which can then be improved by information obtained from its application. If the model is absent or ambiguous, it is difficult to structure operations and essentially impossible to make continuous improvements in the total educational system. It is in this light and as a starting base for discussing the individualized school and the computer that we present a model of educational practice which can underlie individualized instruction.

Stated simply, individualized education is defined as adapting instructional practices to individual requirements. Three major facets are involved, each of which defines a set of variables in the system: (1) educational goals, (2) individual capabilities, and (3) instructional means. Goals are defined to suit the individual, as when individuals choose different courses of instruction for different vocational aspirations. Individual capabilities refer to the competencies which the individual brings to a particular instructional situation; these capabilities are influenced by prior background and schooling. Instructional means, which include what is taught and how it is taught, are dictated by both the nature of the individual's capabilities and the nature of educational goals. These three aspects may change in the course of one's education or one's life, but in any particular span of time, during a specific teaching act, it is assumed that certain values of these major kinds of variables are present: we assume that particular capabilities of the individual are present; we assume that a particular educational goal or level of competence is to be attained; and we assume a set of available instructional means and conditions relevant to assessed capabilities and criteria of competence.

Thinking about the educational process in this way suggests the following general instructional model which is presented as a sequence of operations (Glaser, 1969).

1. The goals of learning are specified in terms of observable student behavior and the conditions under which this behavior is to be exercised.

2. Diagnosis is made of the initial capabilities with which the learner begins a particular course of instruction. The capabilities that are assessed are those relevant to the forthcoming instruction.

3. Educational alternatives adaptive to the initial profile of the student are presented to him. The student selects or is assigned one of these alternatives.

4. Student performance is monitored and continuously assessed as the student proceeds to learn.

5. Instruction proceeds as a function of the relationship between measures of student performance, available instructional alternatives, and criteria of competence.

6. As instruction proceeds, data are generated for monitoring and improving the instructional system.

The implementation of these operations requires both research and application. The model can be implemented along a continuum of various degrees of automation. It is possible to begin without automation at all. Teachers and teacher aides, with a redesigned school organization and appropriate tests and materials, can carry out individualized instruction in a particular school. Individually Prescribed Instruction (IPI) during its early years at the Oakleaf School (Glaser, 1968; Lindvall and Bolvin, 1967) has been such a non-automated version. There is no necessary correlation between the effectiveness of individualized education and the degree of automation involved. Only if the required operations are carried out in a manner adaptive to the individual, can the system be effective. Automation can implement a good system as well as a bad one. However, it seems possible that automation canbe a significant aid to the conduct of an individualized system and to the collection of research data so that the system can be improved.

Automation can be introduced in individualized education as a means of assisting the teacher in carrying out and managing the process. Here the computer can service classroom terminals which assist the teacher in diagnosing and prescribing a course of instruction for the student. When automation is used in this way in an individualized setting, it has been referred to as "computer-managed instruction" (CMI).[2] In CMI, the primary function of the computer is to assist the teacher and student in planning instructional sequences, where the actual instruction may be self-instruction packages (automated or not), or more conventioanl instruction. On the other had, when the computer is used by the student as a <u>means</u> of instruction, the term commonly employed is "computer-assisted instruction" (CAI). Both CMI and CAI carry out educational functions, and the relationship between them is an inclusive one: CMI can occur without CAI, but if CAI is used, the information necessary for CMI is usually present. Between these two there are shadings, as when the computer is used for such adjunct purposes as testing, special laboratory exercises, data analyses, etc.

The general model of instruction presented can be carried out in three modes: non-automated, CMI, or CAI. It is highly probable that increasing levels of automation can improve individualized education, but only if more is learned about adapting education to individual requirements. A CMI system can obtain such information in addition to its uses for operational implementation. The non-automated version, the early years of the Oakleaf School, represents a first application of the general instructional model. After a period of pilot work, CMI is being introduced to speed up the collection and analyses of the data required for the redesign of an improved system.

Instructional Decision Making

All teaching involves decisions about how instruction should proceed. Particularly characteristic of individualized instruction is the necessity for instructional decisions relevant to each student. The differential decision-making function in individualized instruction is a central issue. These decisions require a great variety of information about the individual student, such as: (a) What criteria of competence should be applied? These have been traditionally stored in terms of test grades, teacher judgments of quality, etc. (b) What is the background of the student? This has been stored in the student's written record in terms of intelligence test and aptitude test scores. (c) How does a student proceed in his learning? This is usually the teacher's impression of the student as slow or fast, or attentive or distractable, and rarely takes the form of documented information. (d) What instructional means are available for teaching certain lessons? This has been catalogued in the teacher's head or on a resources list. In the model of individualized instruction envisioned here, a sizable amount of information is needed for each student on a daily basis. It is obvious that some form of assistance is necessary to help the teacher store and act in terms of such data.

A computer management system has as its objectives the collecting and processing of information on each student and supplying this information to the teacher in a summarized form so that it is directly applicable to human decision making. It is possible that at each decision point, data can be summarized for the teacher at his request or supplied to him on a regular basis. It also seems possible that such information, in a form different from that supplied to the teacher, can be supplied to the student and used by him in choosing or discussing with the teacher his next instructional sequences. With this approach, the teacher's valuable time can be reserved for the most subtle and difficult educational decisions. The computer can be programmed to suggest decisions to the teacher based upon analysis of the learning process and past experience with similar students. The teacher can then make a judgment whether to accept, revise, or reject this recommendation.

It needs to be emphasized that the primary function of the computer in a CMI system is to make possible more complicated decision processes than would be possible without the computer and to do this on a continuous basis. The computer cannot be justified if it is simply used to keep records. Clerks are cheaper record keepers than computers. In an individualized system, the teacher continuously needs information and assistance in making instructional decisions. Through providing decision tables in the computer, help can be provided to the teacher on a continuous basis. The computer itself is not making the instructional decisions. The computer is the means by which the psychologist and teacher can work together on a day-to-day basis to provide a continuously improving system of instructional decision making.

Implementation of a System for Individualized Instruction

It is appropriate to examine the procedures that would be carried out in an indiviudalized school proceeding according to the model previously mentioned. The system is oriented around the instructional decisions required for adapting the educational environment to each student. The procedures involved supply information about the student to both the teacher and the student; information is further supplied about the effectiveness of the instructional alternatives (procedures and materials) that are used in the school.

1. Specification of goals, subgoals, and decision nodes. Educational goal-setting is a complex problem that cannot be ignored; in fact, goals are inevitably involved, whether explicitly or implicitly, whenever instruction takes place, The educational technologist does not set the goals for American education. Instead, his task is to identify goals which are espoused in his society and then to develop the procedures for achieving those goals. When he has finished his task he can say to educators, parents and students: If you have goal A, then consider doing X, Y, and Z. The eventual result is a variety of goals from which the learner is then free to select and for which instructional means are defined and made available.

Schools must provide not only the means toward a variety of goals, but also the mechanism whereby goals can be identified or selected for each student. Although selecting goals is often seen as a guidance function differentiated from subject-matter teaching, the two functions are not separable. The guidance technology required to institute a system of goal setting on an individualized basis must be defined and implemented if an individualized school is to function with alternative goals and alternative paths toward these goals. No one will argue that all students should have the same educational goals nor that goals must remain constant for a given student, although it is probably true that the goals of elementary school, directed toward teaching fundamental skills and knowledge, permits less freedom for goal setting than later schooling. Up to a point in the individualized elementary school, choice is more among instructional means than among more ultimate goals.[3]

The specified goals for a given student imply a series of subgoals. The arrangement of these subgoals is a function of the structure of the subject-matter goals which have been selected, the approach of the course designer to the subject matter, and also the way in which the student elects, or his performance advises, that instruction should proceed. Different students may follow different paths through these subgoals so that for any particular individual the subgoals may be omitted, added to, recombined or rearranged. These changes take place as a function of the instructional steps described later in this paper. A major point at this time, however, is that the subgoals provide nodes at which instructional decisions are made by the teacher with the aid of the psychologist via the computer. Experience and research data collected can serve to "validate" subgoal hierarchies, permissible paths, etc. Specifying subgoals essentially involves describing student behavior and ways of measuring it. Data obtained serve to establish the effectiveness with which this is done.

2. Measurement and diagnosis of the initial state or behavior with which the student enters an instructional situation. Initial diagnosis requires two kinds of information: long-term history and short-term history. Long-term history refers to information on student background characteristics such as intelligence, aptitudes, etc. Short-term history refers to the student's performance during recent instruction in relevant subject matter. In a CMI system, a teacher would have access to a profile of test information (both long-term and short-term) from a computer terminal

and would be able to ask specific questions about the characteristics of each student. One step further in CMI, the computer could be used to give subject-matter placement tests specific to the course of instruction, and the results put in the student's record. The teacher could examine the data and make decisions about student placement. As a further step, suggested placement decisions could be displayed for the teacher, and he could accept, reject, or amend these suggestions on the basis of a perusal of the record.

The necessary research for developing this aspect of an individualized system would be study of the reliability of the placement tests and their relationship to instructional decisions in terms of maximizing the success, learning efficiency and motivation of the student. As such information is obtained, placement decisions could become increasingly useful.

3. The assignment of instructional alternatives. On the basis of the information obtained from the diagnosis in the previous step, a student is assigned, guided to, or allowed to select means of instruction. In CMI, the range of instructional alternatives could be displayed on the classroom terminals either for the student or teacher to choose from. Various allocations of teaching resources could be suggested to the teacher by indicating which students might be available to tutor other students and which students might be grouped together for a discussion of teacher presentation.

A basic question in the design of instruction is what instructional alternatives are made available and how are they decided upon. On what basis do alternative instructional experiences differ so as to be adaptive to individual requirements? Adaptation can take place on the basis of the different content relevant to different subgoals; adaptation can also take place on the basis of instructional procedure. The student's placement profile can indicate the student's present level of accomplishment and his mastery of prerequisites. General intelligence measures may suggest whether or not the student requires more or less closely sequenced instruction and whether or not the student can effectively manage his own progress. However, these relationships are far from clear. Aptitude measures of the kind used in typical present-day aptitude batteries may be somewhat predictive of long-term academic and vocational success and, as a result, assist the student in the selection of vocational goals. Such aptitude measures, however, appear to be less relevant to predicting immediate instructional requirements. For example, there is little information about whether spatial or mechanical aptitude is related to particular ways in which the student learns. In contrast, measures of student behavior obtained in the course of instruction, as performance is continuously assessed, should provide better information about the kinds of instructional alternatives that should be made available to the student.

4. Continuous monitoring and assessment. As the student proceeds along the course of instruction, his performance is monitored and continuously assessed in terms of the established decision points. Measures are obtained similar to those used to assess initial placement, but in addition, new measures are obtained which are specifically related to the student's learning characteristics: For example, how much practice does he require? What kind of instructional alternatives does he enjoy? Is he slow and steady or impulsive? How well does he retain what he has learned? etc. Information of this kind, updated as the student progresses

should provide the primary information for the decision making required to guide student learning. This information would incorporate and supersede initial long-term aptitude measures and placement information.

Implicit in the proposed model of individualized instruction is the assumption that most or all of the students can master, to a defined criterion of competence, the goals and subgoals along the path of learning. The basic task in adapting instruction to individual differences is to determine the methods and materials that will enable most students to attain mastery. It is no longer assumed, as it is in conventional instruction, that student attainment will follow a normal distribution of grades--some failing, some excelling, and some falling in between. What eventually distinguishes students is their degree of understanding of a subject matter and this is a function of how much they learn, and the extent to which they are taught to use their knowledge to learn new things, to generalize to new situations and solve problems, and to be creative.

For the above assumptions underlying individualized instruction, it is necessary to employ techniques for measuring student achievement which are different from generally used measurement practices. In the context of the instructional model, a student's performance can be measured with reference to the behavior described in each subgoal. The measure of achievement indicates the degree to which the student has attained or surpassed the described level of competence. The measure gives information about the nature of the student performance and in addition, gives the relative standing of the student in a group of his peers. Most standardized and generally used measures of achievement assume a distribution of attainment and provide only information about a student's performance in relation to others: for example, grade placement scores or percentile scores. These measures provide information about relative performance but do not provide information about student performance in terms of criterion levels of achievement. In the model for individualized instruction, achievement measures are criterion-referenced rather than only norm-referenced in order to assess the outcomes of learning at each selected decision point.

In a non-automated individualized situation, providing this information for daily activities requires a great amount of record keeping and clerical summarization. With CMI help, record keeping is still necessary but procedures and forms can be devised for placing this information in the computer and printing it out in a format useful to the teacher. The teacher might be presented with a summary statement on the basis of which he could make decisions, and certain decisions might be suggested to him. Accomplishing this may be less complicated than it sounds since decisions by the teacher and/or the student may be relatively simple to make, once performance information and instructional alternatives are presented to them.

5. Adaptation and optimization. As the student learns, information is obtained about the characteristics of his learning; instructional assignments take place; and assessment is made of performance at the subgoal decisions points. This three-way relationship between learning measure, instructional alternatives, and criterion measures becomes a continuing operation throughout the course of instruction. What is obviously very important in this context is the nature of the measures of the criterion behavior of the subgoals. Since the measures of learning history and instructional alternatives are evaluated in terms of subgoal performance, the particular

measures of mastery that are optimized become critical. Depending upon the measures used, some gains will be maximized and others minimized; some kinds of student performance may be minimized inadvertantly unless they are expressed and explicitly assessed. It is for this reason that the model requires criterion-referenced measures of the desired outcomes of education. The continuous pattern of assessment and instructional prescription is a multi-stage decision process which is directed toward establishing the most effective sequence of instruction, as judged by the student and the teacher, for attaining selected educational goals.

In practice, an underlying conception of how learning proceeds influences the interaction between outcome measures, instructional variables and individual learning characteristics. Different measures and different instructional alternatives can provide a very large number of possible learning paths; however, many of these paths are ruled out if constraints are supplied about how learning occurs. In a non-automated individualized system, the teacher's conception of how learning occurs influences the decisions he makes, and the information with which he is supplied also provides such constraints. In CMI, the displays to the teacher and any more detailed suggestions to him presuppose conceptions about the nature of learning; and since both teacher and computer are involved, the conception built into the system and the teacher's conceptions interact.

6. Evolutionary operation. A primary property of the instructional system described here is that it accumulates information which is used to improve its own functioning. Improvement takes place in two ways: (a) The system uses procedures and materials in keeping with the state of knowledge, and data obtained during the operation of the system allow

these procedures and materials to be made more efficient; and (b) new knowledge about the learning process and about the conduct of individualized instruction can be obtained. Since the learning of each individual is carefully monitored, the system makes it possible to explore a variety of research questions. In fact, in its early use, the system should be over-monitored for this purpose; as it becomes more operational, less information needs to be provided.

A plan for research and development in individualized instruction at the Learning Research and Development Center (LRDC) at the University of Pittsburgh includes the transition from a non-automated individualized procedure to a CMI system which eventually will include CAI as one available instructional means. Non-automated IPI serves the purpose of forcing redesign of the organization of the school. It also calls to the attention of the teacher the necessity for detailed individual student information. This has facilitated the introduction of teacher inquiry terminals to be used for CMI. Following this familiarization with the potential of computers, various computer-based components in various areas can be introduced. The general instructional model described above should permit the incorporation of each of these as appropriate knowledge and technology become available.

IPI as an Implementation of the Model

In Individually Prescribed Instruction, the entire curriculum in each subject area (mathematics, reading, and science) has been broken down into instruction units for subgoals of achievement. For example, the math curriculum has identified 430 specific instructional objectives. These objectives are grouped into 88 units. Each unit comprises an instructional entity which the student works through at any one time; on the average there are five objectives per unit, with a range of 1 to 14. A set of units covering different subject areas in mathematics comprises a level; levels can be thought of as roughly comparable to a school grade level. On entering the school, the student takes a placement test which places him in a particular unit. If his profile is scattered, he begins work on the lowest numbered unit. A unit has associated with it a pretest and a posttest, and each objective (or skill, as it is called in the subsequent printouts) within the unit has attached to it one or more curriculum-embedded tests. Following placement to a unit, the student takes the unit pretest which attempts to diagnose the student's profile within the unit. For example, he may have mastered objectives 1, 2, 4 and 5, but not 3, 6, 7 and 8; at this point, the teacher prescribes for him work related to the objectives he has not mastered. As a student works through a lesson, he takes, at the teacher's discretion, the curriculum-embedded test which assesses whether mastery has been attained on the objective and also to what extent some competence has been attained on the next objective. When all objectives have been mastered, the unit posttest is taken. If 85% is attained on this test, the student begins the next unit; if not, he is reassigned to an appropriate objective in the unit until he masters it. Various discretionary powers are left to the teacher about whether to keep the student in a unit or to move him ahead.

Computer Assistance for IPI

Designing and implementing a computer system to facilitate the operation and evaluation of IPI was simplified by the fact that the IPI system had already been in operation at the Oakleaf School for three years. The clerical operations which had evolved over that three-year period helped to clarify the nature of the data and the types of questions which tended to be asked of these data. In addition, memoranda were collected from experienced staff members summarizing the types of questions they wanted to ask of the IPI data base. All of this helped define the content and the organization of the data files. An analysis of the types of data generated by the operation of IPI and the types of inquiries which teachers, evaluators and researchers wanted to make of the data determined the design of a first approximation to a computer management system for IPI.

The system design also took into account available computer hardware. This included the University of Pittsburgh IBM 360 model 50, and IBM 1050 terminal with card reader attachment and three IBM 2741 terminals. The central processing unit has extended core which allows up to 32,000 bytes per on-line terminal. A 250 million byte disk and six tape drives were also part of the 360 configuration. The 1050 terminal was located at the school and connected by leased line to the IBM 360 computer on the University compus. The IBM 2741 terminals are located at the LRDC. This CMI system is called IPI/MIS, the IPI Management and Information System.

The major aspects of the IPI/MIS system as it is operating today are summarized in Figure 1. The basic data are recorded on optical scan forms by clerks located throughout the school. These forms are brought together and processed at the IBM 1232 optical scanner. The resulting punched cards are then read by the 1050 terminal at the school and the data edited and added to the current student file on disk at the 360 computer. If errors are detected in the editing, diagnostics are sent back to the school terminal for correction. The student disk file contains test and prescription data on the unit in which the student is currently working and selected background data. When a student completes a unit, the data obtained during that unit are written out on a scratch file on disk. At the end of the day, a program updates the student tape from the scratch file. The student tape contains all the instructional history available for each student. The tape file is organized by student and consists of a variable number of fixed length records for each student, the number depending upon the number of instructional units he has completed. Also included are background data collected at the beginning of each school year such as standardized test results, home background data, sex, homeroom, etc.

There are four major functions which the MIS can provide in an individualized school: (1) collect data; (2) monitor student progress; (3) provide prescription information; (4) diagnose student difficulty. These functions have two primary objectives: to increase the effectiveness of the model for individualizing instruction and to maximize the productivity of the teacher operating the IPI system.

During the fourth year of IPI operation, school personnel included one principal, twelve teachers, and twelve teacher aides. The primary function of the aides was to score tests and record test results. They also tabulated data for inquiries by the principal, teacher, and LRDC research and curriculum design staff. The three main functions of the teachers have bee writing prescriptions, diagnosing student difficulties, and tutoring individuals and small groups of students. The clerical and teacher load can be reduced by having data entered directly by teachers and students at classroom terminals. The teacher load can be reduced by having the computer assume some of the prescription and diagnosing functions, thus freeing more time for instruction.

A description of three possible reports which are now available from the 1050 terminal at the school should help clarify how the system is facilitating school operations. The most frequently used report is illustrated in Printout 1, which is a unit summary for a particular student. (Last names have been deleted for these illustrations.) This printout is most frequently requested following the failure of a posttest so that the student's work in that unit can be reviewed and appropriate prescriptions made. As seen in Printout 1 the top of the table summarizes his pretest and posttest scores for each skill in the unit. It also indicates the date (as day of school year) upon which each of these tests had been taken. Prescriptions and curriculum-embedded test (CET) scores follow, again by date and skill. For this unit, for example, it is possible to trace what this student did in math from the fourth day of school to the 27th day of school; not only what he did but how well he did.

The computer report illustrated in Printout 2 summarizes all of the work being done by the students in a particular homeroom. This summary of where each student is in the curriculum and how long he has been there is used in the teachers' group-planning sessions, together with Printout 3, to help decide which student seems to have gotten "bogged down" in his progress and which students might be used to help in tutoring. Also, Printout 3 provides information as to which students might be brought together for group work in a unit.

One shortcoming of the present system is that the school has only one terminal and it is in the data room and not the classroom. The teacher who is making prescriptions on a continuous basis does not have time to send "down the hall" for the required report, so those needed reports must be anticipated by the teacher and/or the system. Also, it usually takes about a day or two for the scan forms to go through the various processing steps to finally reach the computer's disk storage.

The next apparent step in the development of IPI/MIS is to install a terminal network at the school so that both teachers and students can have convenient access to computer terminals. A single terminal in the school cannot provide the data collecting, the monitoring, the teacher inquiry and diagnosis functions needed. Classroom CRT terminals would allow data to be entered directly into the system quickly and easily.

Terminals in each classroom would also facilitate student diagnosis. Occasionally a student will get "bogged down" in a particular unit and none of the available tests for that unit reveal the nature of the student difficulty. That is, the tests for a given unit measure the unit's objectives and not the prerequisite behaviors. Although the student may have previously "mastered" prerequisite behaviors, he may have moved on to another unit prematurely due to errors of measurement, or he may not have retained the necessary behavioral repertoire for the current unit in which he is having difficulty. Currently, the teacher attempts to diagnose the difficulty through questioning the student in a type of clinical branch testing. It is possible that this can be done much more effectively using a computer-assisted branch testing approach. Given the current unit in which the student is having difficulty and given the prerequisite behaviors for that unit, items can be presented for on-line student response which should facilitiate the identification of the missing knowledges or skills. Prescriptions can then be written for appropriate lesson units.

The first year of developing and implementing IPI/MIS suggested several changes in both the instructional system (IPI) and in the computer support system. However, it is clear that more fundamental advances will come through a systematic program of evaluation and research. The availability of the MIS should facilitate such a program.

IPI Research and Evaluation

The IPI educational system, consisting of units geared to assessable objectives, is very amenable to the type of evaluation called for in the sixth step of the instructional model. The instructional units are used in an environment in which relevant information is readily available on the participating students and teachers. Information regarding the relative effectiveness of different units designed to meet the same objectives can be systematically collected so that decisions can be made regarding which units are more appropriate for what kinds of students at what points in their educational development. Weak units among those offered can be identified and replaced in the system. Objectives for which no adequate units are now available will be discernible and appropriate units developed. This, in turn, will lead to a more potent system of education for each student which more and more closely approximates desired goals.

In addition to the "is it working?" type of evaluation studies, the retrieval and analysis sytem and the IPI data bank provide a vast resource for basic learning and measurement studies. The scientist has quick and convenient access to the data so that if he gets "hot" on a particular question he can interact with the data and his hypotheses at the moment rather than wait for weeks between getting an idea and seeing the first printout. Evaluation and research requirements have been given a high priority in development of the IPI/MIS. The system is now operation l to the extent that learning psychologists and curriculum evaluators can sit at the computer terminal and retrieve data for selected students or units according to search parameters which the researcher types in as verbal requests. He can edit the requested data if necessary, and proceed with an appropriate data analysis of the retrieved, edited data. The student history file, containing all of the data collected on all of the students for one academic year, can be searched in three to five minutes, depending upon the demands being placed on the computer by other terminals at that same time. An example of this search is provided in Printout 4.

In the Printout 4 example, the investigator was interested in examining selected data for all of the students who had taken the pretest in E level subtraction in mathematics (unit e4). Line four (4.) of the search parameters is the primary selection criterion, which is indicated by ending the line with a period. This command directs the search routine to select only those students who had taken the pretest for unit e4. The lines ending with an exclamation mark indicate data to be retrieved for the selected students if it is available; for example, line five (5.) is a request for the prescription information on students who worked on the first objective (skill) in unit e4. This search resulted in a work file (called "e4 stuff" by the terminal user) of 32 students. The file contained the unit performance data for those students plus some background data requested for them, that is, their Otis IQ scores and their Stanford Arithmetic computation percentiles, if available in the file.

Current research applications of the MIS are primarily concerned with three major aspects of IPI and their interrelationships: (1) the diagnostic tests; (2) the prescription behavior of teachers; and (3) the content and sequence of the curriculum materials. The first three years of IPI required a tremendous effort to develop the necessary tests and curriculum materials. Also, teacher retraining was a large task. These developmental activities were primarily and necessarily departmentalized; that is, a group of test specialists developed the test battery, while subject matter experts in the various curriculum areas developed the materials and their sequence. Other staff members worked with the teachers in developing their new mode of teaching. The real challenge now is to investigate the functioning of all of these components and their interactions. The computer information system makes this large task more feasible.

For example, Bolvin (1967) has observed that there is considerable variance in prescriber behavior. Some teachers tend to assign a bare minimum of study and practice and then assign a posttest to see whether the student requires more study and practice for that particular unit; they thus go back and forth between prescription and posttest until mastery is apparently achieved. Other teachers are moderate prescribers and tend to "follow the book" strictly in terms of the pretest scores; no work is prescribed if the pretest skill scores indicate greater than 85% mastery, and if less than 85%, the extent of the assignment is determined by the degree to which the pretest score deviates from that mastery goal. Still a third type of prescriber tends to "over prescribe." That is, students generally are assigned much more work than would seem to be indicated by the pretest scores. A systematic analysis of the data involving prescriber, prescription, and subsequent student performance will help clarify the relative effectiveness of these different prescription behaviors and will suggest whether or not they should vary depending upon the student and type of behavior being taught in that unit. For example, it may be important that certain skills be given extensive practice (computation for example) so that in subsequent, more complex units requiring those skills, achievement is not hampered through lack of retention. Printout 5 is an illustration of data relevant to this area of concern. Note how the number of tasks prescribed varies for the same pretest scores, depending in part upon who did the prescribing.

Another line of current inquiry is concerned with the structure of curriculum sequences. For only ten objectives there are over three million possible sequences. Fortunately, most of these sequences are ruled out by content structure and conceptions of the learning process. Instructional sequences can, however, also be empirically studied. Techniques similar to multiple scalogram analysis (Lingoes, 1963) of available placement and pretest results can assist in determining whether or not the objectives are being taught in the order of their difficulty and ease of successive facilitation of the next learning stage. It is also possible to see whether or not the extent to which objectives are not in order of difficulty affects the time it takes for students to master that particular sequence of objectives and their eventual ability to use what has been learned.

Printout 6 illustrates the results of a multiple scalogram analysis of pretest skill mastery data for a math unit. On the left the seven objectives for this unit are sequenced in their present order. On the right, the computer program puts them in order of difficulty (1,4,7,2,6,3,5) and then assesses the extent to which they "scale." That is, do students who pass (indicated with a 1) skill 5 also tend to pass the other six skills in the set. Similarly, does failing (0) skill 7 imply failing skills 2, 6, 3, and 5, for example. The program indicated that this was a reasonably good scale. Whether or not the resulting new sequence is more effective in facilitating learning can, of course, be empirically examined.

A more fundamental task which MIS can facilitate is the development of alternate forms of instruction that are adaptive to student profiles. Of course, now a student can be assigned to material in which he shows a lack of mastery; and he need not be assigned to lessons for which his mastery is satisfactory. But in addition, lessons may involve different kinds of vocabularies; they may involve more or less closely sequenced instruction; or they may involve instruction which puts more or less of a burden on the student to manage his own progress. Essentially, the problem is to determine different instructional alternatives that are related to different patterns of learning. The goal of the IPI/MIS is to help with empirical work which would determine the measures most efficient for assigning individuals to alternatives and the necessary alternatives that need to be made available.

Toward CAI

The development and adoption of the type of individualized model proposed here seems to be a necessary prerequisite for bringing CAI out of the "backroom" and into the classroom. It seems unlikely that CAI will ever provide all of the instruction for all of the students all of the time. Yet it is virtually impossible to incorporate CAI into traditional schools where the classroom of students is the basis for instructional decisions and scheduling. On the other hand, it is easy to incorporate CAI lessons into IPI/MIS as those lessons become available for solving specific instructional problems. The computer is there, the terminal capability is there, and the flexibility of an individualized school organization is there. Most important, a model for individualization is there. It seems reasonable that the same instructional model which guided the development of IPI and is guiding IPI's "automation," can guide the development and implementation of CAI in an individualized school. Some mix of these aspects seems to be the end toward which we are currently striving.[4]

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Footnotes

1. The preparation of this paper and the research and development described herein were performed pursuant to a contract with the U. S. Office of Education, Department of Health, Education and Welfare. Additional support has been provided by the General Learning Corporation.

2. Although we are not completely happy with all of the connotations of computer-managed instruction, it does seem to be the expression most frequently used by people currently working in this general area of concern. It should be emphasized that the computer here is used as a tool in the management of the information needed by teachers in planning individualized education.

3. See, for example, Cooley (1967) for a more detailed consideration of guidance in the individualized school.

4. The specification of models for individualizing education, the development of IPI, the implementation of CMI, and the eventual incorporation of CAI in individualized schools are major activities at the Learning Research and Development Center. We wish to take this opportunity to thank our many colleagues and students who have contributed to these efforts.

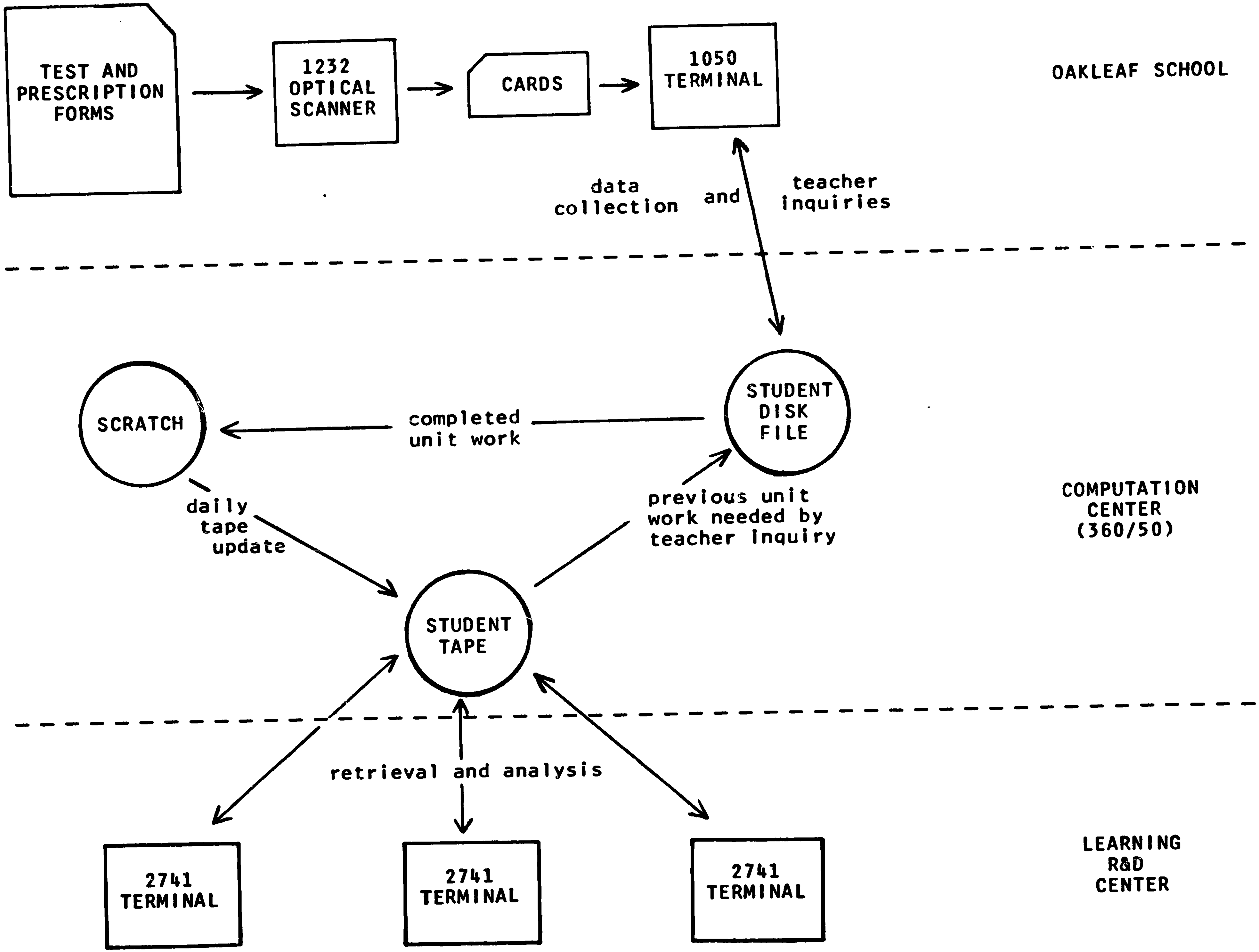

Fig. 1. Major aspects of IPI/MIS

0512 M . . . ,KELLY DATE - 030

CURRENT MATH IS LEVEL F DIVISION

SKILL	PRETEST SCORES	POSTEST SCORES 1ST	2ND	3RD	4TH
1	99	99	50		
2	50	99	99		
3	00	50	50		
4	75	50	50		
5	60	80	40		
6	99	99	67		
7	75	99	99		
8	33	67	33		
DATE	004	018	029		

PRESCRIPTIONS AND CETS

DATE	SKILL	PAGE - SCORE				
010	02	01-90	02-80	03-90	04-90	06-90
		08-90	09-90			
		CET 10	PART 1-99	PART 2-00		
013	03	01-90	02-90	03-90	04-90	07-90
		08-90	09-90	10-90	12-80	13-90
		14-60	15-90			
		CET 16	PART 1-25	PART 2-67		
015	03	CET 22	PART 1-88	PART 2-99		
016	04	CET 10	PART 1-99	PART 2-99		
016	05	CET 10	PART 1-85	PART 2-99		
017	07	CET 10	PART 1-99	PART 2-99		
017	08	CET 07	PART 1-99	PART 2-		
021	03	CET 20	PART 1-75	PART 2-		
021	04	CET 10	PART 1-75	PART 2-99		
023	05	CET 10	PART 1-85	PART 2-99		
023	05	09-90	11-90	12-90		
		CET 13	PART 1-99	PART 2-67		
026	03	CET 16	PART 1-99	PART 2-00		
027	08	CET 07	PART 1-99	PART 2-		
027	05	CET 10	PART 1-99	PART 2-99		

Printout 1. Unit summary for a single student.

GRADE 6 MRS. FAYE MUELLER DATE - 036 MATH

ID	NAME	SKILL	UNIT	DAYS
0306	A . . . , JOHN	04	F COMBINATION OF PROCESSES	8
0317	A . . . , LOUANNE	05	E FRACTIONS	31
0339	B . . . , LINDA	01	F DIVISION	4
0341	B . . . , ROBERTA	05	F MULTIPLICATION	31
0352	B . . . , MARK	04	E MULTIPLICATION	30
0374	D . . . , RICHARD	05	E NUMERATION	5
2052	C . . . , MARLENE	02	D SYSTEM OF MEASUREMENTS	8
2096	H . . . , GILBERT	01	E ADDITION	3
2041	H . . . , ROBERT		E MULTIPLICATION	1
0705	K . . . , PAUL	04	E FRACTIONS	31
0693	Z . . . , JANICE	06	E FRACTIONS	31
0682	W . . . , KIMBERLY		F NUMERATION	5
0671	V . . . , EDGAR	07	E COMBINATION OF PROCESSES	31
0669	T . . . , MICHELE	04	E DIVISION	29
0636	S . . . , MARY ANN	02	E MONEY	5
0614	P . . . , DENISE	08	F DIVISION	31
0603	P . . . , TIMOTHY	02	D SYSTEM OF MEASUREMENTS	
0591	P . . . , ROBERT	11	E MULTIPLICATION	31
0567	M . . . , PEGGY	03	F MULTIPLICATION	28
0545	M . . . , MICHAEL	05	D SYSTEM OF MEASUREMENTS	24
0512	M . . . , KELLY	08	F DIVISION	32
0501	L . . . , LINDA	07	E NUMERATION	33
0498	L . . . , RONALD	04	E MULTIPLICATION	9
0487	L . . . , MICHELE	02	E NUMERATION	5
0443	K . . . , KEVIN	06	E SYSTEM OF MEASUREMENTS	31
0432	K . . . , KAREN	04	G MULTIPLICATION	7
0421	K . . . , MICHELE	03	G NUMERATION	31
0419	J . . . , WILLIAM	01	E MONEY	3

Printout 2. Class list showing how long each student has been working in his current unit.

GRADE 6 MRS. FAYE MUELLER DATE - 036 MATH

Unit	Student No.	Name	SKILL
D SYSTEM OF MEASUREMENTS			
	2052	C . . . , MARLENE	02
	0545	M . . . , MICHAEL	05
	0603	P . . . , TIMOTHY	02
E NUMERATION			
	0374	D . . . , RICHARD	05
	0487	L . . . , MICHELE	02
	0501	L . . . , LINDA	07
E ADDITION			
	2096	H . . . , GILBERT	01
E MULTIPLICATION			
	0352	B . . . , MARK	04
	2041	H . . . , ROBERT	
	0498	L . . . , RONALD	04
	0591	P . . . , ROBERT	11
E DIVISION			
	0669	T . . . , MICHELE	04
E COMBINATION OF PROCESSES			
	0671	V . . . , EDGAR	07
E FRACTIONS			
	0317	A . . . , LOUANNE	05
	0705	K . . . , PAUL	04
	0693	Z . . . , JANICE	06
E MONEY			
	0419	J . . . , WILLIAM	01
	0636	S . . . , MARY ANN	02
E SYSTEM OF MEASUREMENTS			
	0443	K . . . , KEVIN	06
F NUMERATION			
	0682	W . . . , KIMBERLY	
F MULTIPLICATION			
	0341	B . . . , ROBERTA	05
	0567	M . . . , PEGGY	03
F DIVISION			
	0339	B . . . , LINDA	01
	0512	M . . . , KELLY	08
	0614	P . . . , DENISE	08
F COMBINATION OF PROCESSES			
	0306	A . . . , JOHN	04
G NUMERATION			
	0421	K . . . , MICHELE	03
G MULTIPLICATION			
	0432	K . . . , KAREN	04

Printout 3. Class list sorting students by unit.

Search Example:*

```
>$$logon e65wwc.
>$$att d stutape as xx.
>$$load d search.

TYPE THE FILE NAME OF THE STUDENT TAPE.

>xx

THE STUDENT TAPE IS DATED 042068.
LIST YOUR SEARCH PARAMETERS.

1. >id.
2. >otis iq!
3. >st acp%ile!
4. >math pret,e4,=1.
5. >math presc,e4,skill 1(1),cet!
6. >math presc,e4,skill 2(1),cet!
7. >math presc,e4,skill 3(1),cet!
8. >math post,e4,=1!
9. >end.

PARAMETER LIST COMPLETE
DO YOU WANT YOUR OUTPUT ON TAPE OR DISK?
 >disk

SPECIFY DATASET NAME.
 >e4stuff.
COMPILATION BEGINS.

(diagnostics printed here if there were errors in the search parameters)

COMPILATION COMPLETE
OUTPUT FORMAT:

ONE BACKGROUND RECORD OF 09 BYTES PER STUDENT.
ONE OVERALL RECORD OF 91 BYTES PER STUDENT.
SEARCHING BEGINS

YOUR OUTPUT FILE CONSISTS OF 32 STUDENTS.
THE SEARCH IS COMPLETED

M:  END OF JOB
```

---

* Lines typed following the > were typed by the terminal user. The other lines were typed under computer program control.

Printout 4. Illustration of the tape retrieval program.

```
>$$att d d8stuff(e65wwc) as F8.
>$$load d main.
LOADING STARTS AT LOC 070200
```

PRETEST, PRESCRIPTIONS, AND POSTESTS FOR MATH D8 SKILL 2.

ID	PRETEST	PRESCRIPTIONS (UNIT TASK NUMBERS)	PRESCRIBER	POSTEST
294	70	1 2 3 5 6 7 15 16	6	90
102	70	2 3 8 9 10 13 14 15 17	6	99
124	60	4 6 7 10 11 13	6	60
168	80	9 12 3 16 17 15	6	80
181	70	4 6 7 8 9 10 12 14 16	0	99
226	70	1 2 3 4 5 6 7 8 10 11 13 14 15	9	80
317	80	1 5 6 7 16 17	5	99
341	80	4 6 9 11	5	90
352	70	1 2 3 4 5 7 9 10 12 14 17	10	90
363	70	6 7 8 9 10 11 12 14 17	10	99
385	60	5 6 7 8 12 13 14 15	5	99
408	70	2 3 4 6 7 13 15	10	99
432	80	5 6 7	10	90
476	50	1 2 3 4 6 7 9 11 12 14 17	10	70
501	60	1 2 4 6 7 8 9 13 15	5	90
567	60	1 2 6 7 11 13 15 16 17	5	70
578	50	4 5 6 7 11 13 15 16 17	5	90
614	80	1 5 7 11 12	10	90
636	30	1 3 6 10 13 14 17	5	99
647	70	1 16 17	5	99
669	60	1 2 3 4 7 9 11 13 15 17	10	80
671	70	5 6 7 11 12 13 14 15 16	5	90
682	80	5 7 8 9 22 23 13 15	5	99
693	60	1 2 3 4 5 6 7 9 10 13 15 16 17	5	80
1058	50	1 2 3 4 5 6 7 8 10 11 12 13 14	4	70
1036	80	3 7 8 9 13	4	99
1025	70	1 2 10 16 17	4	80
1814	60	1 2 3 4 5 6 7 8 9 10 11 12 13	9	80
999	60	1 2 3 4 5 6 7 8 9 10 11 12 13	4	70
738	50	1 2 3 5 6 7	4	50
1105	80	7 11 13 9	3	99
1116	50	1 2 3 4 5 6 8 10 13 15 17	3	80
1173	80	1 2 3 4 5 7 8 9 11 13 15 16 17	11	90
1231	60	1 2 3 5 6 8 10 11 12 14 17	3	99
1242	70	3 4 5 6 7 8 9 15 16 17	3	90
1297	50	1 2 3 4 6 7 8 10 11 13 15 16 17	3	90
1333	0	1 2 3 4 6 7 13 14 16 17	3	99
1377	70	1 3 5 6 7 8 9 10 11 12 13 14 15	3	90

M:END OF JOB

Printout 5. Pretest, prescriptions and posttests for skill 2 of mathematics unit D Division.

ID	ORIGINAL SEQUENCE OBJECTIVE 1	2	3	4	5	6	7	REORDERED SEQUENCE OBJECTIVE 1	4	7	2	6	3	5
0421	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0113	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0875	1	1	1	1	0	0	1	1	1	1	1	0	1	0
0567	1	0	1	1	0	1	1	1	1	1	0	1	1	0
0432	1	1	0	1	0	0	1	1	1	1	1	0	0	0
0614	1	1	0	1	0	0	1	1	1	1	1	0	0	0
0328	1	1	0	1	0	0	1	1	1	1	1	0	0	0
0339	0	1	0	1	0	1	1	0	1	1	1	1	0	0
0192	1	0	0	1	0	1	1	1	1	1	0	1	0	0
0055	1	1	0	1	0	1	0	1	1	0	1	1	0	0
0124	1	0	1	1	0	0	1	1	1	1	0	0	1	0
0088	1	1	0	1	1	0	0	1	1	0	1	0	0	1
0922	1	0	1	1	0	1	0	1	1	0	0	1	1	0
0259	1	0	0	1	0	0	1	1	1	1	0	0	0	0
0512	1	0	0	1	0	0	1	1	1	1	0	0	0	0
1253	1	0	0	0	0	1	1	1	0	1	0	1	0	0
0556	1	0	0	1	0	0	0	1	1	0	0	0	0	0
0066	0	1	0	0	0	0	1	0	0	1	1	0	0	0
0077	1	0	0	1	0	0	0	1	1	0	0	0	0	0
0168	1	0	0	1	0	0	0	1	1	0	0	0	0	0
0179	1	1	0	0	0	0	0	1	0	0	1	0	0	0
0181	1	0	1	0	0	0	0	1	0	0	0	0	1	0
0237	1	0	0	0	0	0	1	1	0	1	0	0	0	0
0248	1	1	0	0	0	0	0	1	0	0	1	0	0	0
0738	1	0	0	0	0	0	1	1	0	1	0	0	0	0
0272	0	1	0	0	0	1	0	0	0	0	1	1	0	0
0625	1	0	0	0	0	0	0	1	0	0	0	0	0	0
0682	1	0	0	0	0	0	0	1	0	0	0	0	0	0
1003	1	0	0	0	0	0	0	1	0	0	0	0	0	0
0408	1	0	0	0	0	0	0	1	0	0	0	0	0	0
0818	1	0	0	0	0	0	0	1	0	0	0	0	0	0
0011	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0443	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Printout 6. Comparison of original versus reordered response pattern for mathematics unit E Division.