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The Computer and Individualized Instruction

An automated information system now supports the development of individually prescribed instruction.

William W. Cooley and Robert Glaser

One of the most important potential uses of computers in schools is their use 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 (i) the instructional procedures, materials, and school environment and (ii) the data and research information needed for performing the desired educational functions effectively.

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Therefore, before any fruitful discussion on how the computer might facilitate such education can begin, it is necessary to specify just how individualization is to be accomplished. The instructional model can serve as the beginning of a system which can then be improved on the basis of information obtained from the model's application. If there is no model, or if it is 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 with this as a base for discussing the individualized school and the computer, that we present a model of educational practice which can underlie individualized instruction.

Individualized education is essentially the adaptation of instructional practices to individual requirements. Three major factors are involved, each of which defines a set of variables in the system: (i) educational goals, (ii) individual capabilities, and (iii) instructional means. *Goals* are defined to suit the individual, as when individuals choose different courses of instruction for different desired vocations. The term *individual capabilities* refers to the capabilities that the individual brings to a particular instructional situation; these 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 his educational goals. These three factors 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 a particular educational goal or level of competence is to be attained; that the individual has particular capabilities; and that there is available a set of instructional means and conditions relevant to assessed capabilities and to 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 (*1*).

1) The goals of learning are specified in terms of observable student be-

havior and the conditions under which this behavior is to be manifested.

2) When the learner begins a particular course of instruction, his initial capabilities—those relevant to the forthcoming instruction—are assessed.

3) Educational alternatives suited to the student's initial capabilities are presented to him. The student selects or is assigned one of these alternatives.

4) The student's performance is monitored and continuously assessed as he learns.

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. Various degrees of automation can be used in implementing the model. It is possible to begin without any automation at all. With a redesigned school organization and appropriate tests and materials, teachers and teacher aides can carry out individualized instruction in a particular school. The system known as Individually Prescribed Instruction (IPI), introduced at the Oakleaf School (*2*), was such a nonautomated version during its early years. The effectiveness of individualized education is not necessarily related to the degree of automation involved. However, it seems possible that automation can be a significant aid in the conduct of an individualized system and in the collection of research data on which improvements can be based.

Automation can be introduced in individualized education as a *means of assisting the teacher* in managing the process. The computer can service classroom terminals which assist the teacher in assessing the student's capabilities and prescribing a course of instruction. When automation is used in this way it is referred to as "computer-managed instruction" (CMI) (*3*). 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 conventional instruction. On the other hand, when the computer is used by the student as a *means of instruction*, the term commonly used is "computer-assisted instruction" (CAI). Both CMI and CAI carry out educational functions. CMI can be used without CAI, but if CAI is used, the information necessary for CMI is usually present. CMI will probably precede CAI in the evolutionary individualization of a school.

The general instructional model presented can be implemented in any one of three modes: nonautomated instruction, 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 being used for operational implementation. The nonautomated version (IPI, during the early years of its use at the Oakleaf School) represents a first application of the general instructional model. After a period of pilot work, CMI is being introduced at the school to speed up collection and analysis of the data required for the design of an improved system.

Instructional Decision-Making

All teaching involves decisions about how instruction should proceed. Individualized instruction requires instructional decisions relevant to each student. The differential decision-making function in individualized instruction is a central issue. These decisions require a great deal of information about the individual student, such as the following. (i) What criteria of competence should be applied? These criteria have traditionally been stored in the form of test grades, teacher judgments of quality, and so on. (ii) What is the student's background? This information has been stored in the student's written record, in the form of intelligence-test and aptitude-test scores. (iii) How does a student proceed in his learning? This information is usually based on the teacher's impression of the student as slow or fast, attentive or inattentive, and is rarely documented. (iv) What instructional means are available for teaching certain lessons? These have 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 the teacher will need assistance of some kind in storing, and acting upon, such data.

A computer management system has as its objectives the collecting and processing of information on each student and the supplying of this information to the teacher in summarized form such 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 in which it is 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 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 of past experience with similar students. The teacher can then decide whether to accept, revise, or reject the recommendation.

We should emphasize the fact 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. Automation cannot be justified if the computer is used simply to keep records. Clerk's tend to be cheaper record keepers than computers. In an individualized system, the teacher continuously needs information and assistance in making instructional decisions. By providing decision tables in the computer, help can be given the teacher on a continuous basis. The computer itself is not making the instructional decisions. The computer is the means whereby the psychologist and the teacher can work together on a day-to-day basis to provide a continuously improving system of decision-making.

Implementation of the Model

Let us examine the procedures that would be followed in an individualized school proceeding according to the model mentioned above. The system is oriented around the instructional decisions required for adapting the educational environment to the student. The procedures involved supply information about the student to both the teacher and the student; also, information is supplied concerning the effectiveness of the procedures and materials that are used in the school.

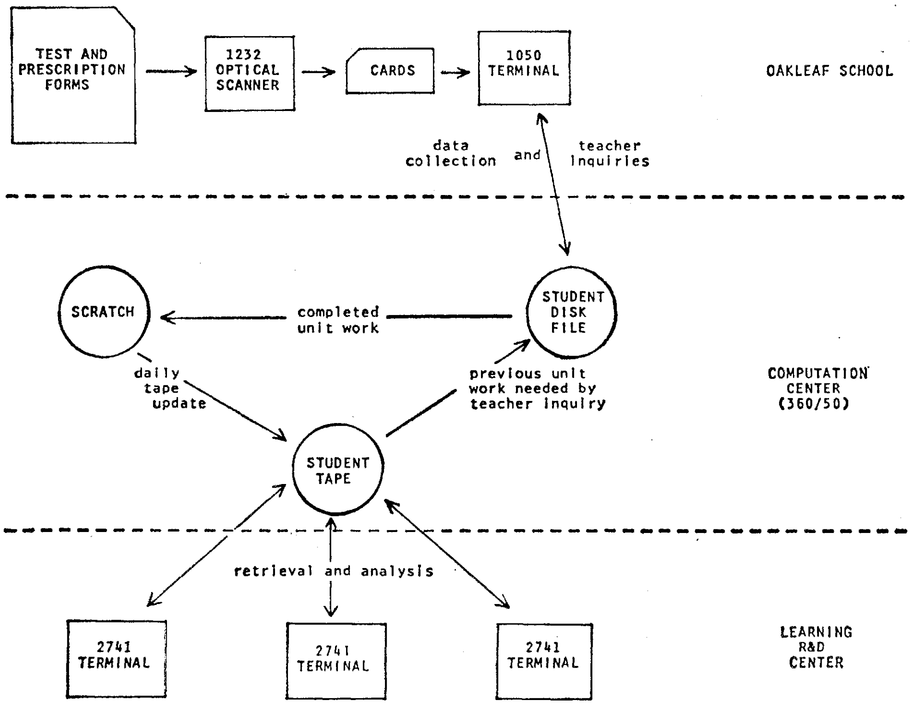

Fig. 1. Major aspects of IPI/MIS.

1) Specification of goals, subgoals, and decision nodes. Educational goal-setting is a complex problem that cannot be ignored; 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 that are valued 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, "In order to attain goal A, consider doing X, Y, and Z." The eventual result is a variety of goals from which the learner is free to select and for which instructional means are defined and made available.

Schools must provide not only the means for attaining various 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 for the individual must be defined and implemented if the school is to offer the means of attaining alternative goals and alternative paths toward these goals. No one will argue that all students should have the same educational goals or that goals must remain constant for a given student, although it is probably true that elementary school, directed as it is toward the teaching of fundamental skills and knowledge, permits less freedom for goal-setting than later schooling does. Up to a point, in the individualized elementary school, the choice is more among instructional means than among ultimate goals (*4*).

The goals specified 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 that have been selected, the approach of the course designer to the subject matter, and the instructional path that the student elects or that his performance suggests. Different students may follow different paths through these subgoals, so for any particular individual the subgoals may be omitted, added to, recombined, or rearranged. These changes take place as a function of instructional alternatives. These are discussed below; we should make the point at this time, however, that the subgoals provide nodes at which instructional decisions are made by the teacher with the aid of the psychologist, by way of the computer. Experience and research data serve to "validate" subgoal hierarchies, permissible paths, and so on. Specifying subgoals essentially involves describing student behavior and ways of measuring it. The data obtained serve to establish the degree of effectiveness with which this is done.

2) Measurement and diagnosis of the student's initial state or behavior on entering an instructional situation. Initial diagnosis requires two kinds of information: long-term history and short-term history. Long-term history refers to information on characteristics such as intelligence and aptitudes. 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 file 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. Then the computer could be used to give subject-matter placement tests pertaining to the course of instruction, and the results would be put in the student's record. The teacher could examine the data and make decisions about student placement. Or suggested placement decisions could be displayed for the teacher, who could accept, reject, or amend the 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 helping the student achieve maximum learning efficiency and motivation. As such information was obtained, placement decisions could become increasingly useful.

3) The assignment of instructional alternatives. On the basis of the information obtained from the diagnosis discussed in step 2, 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 for either the student or the teacher to choose from. Various allocations of teaching resources could be suggested to the teacher, through displays indicating which students might be available to tutor other students and which students might be grouped together for a discussion or a teacher presentation.

A basic question is what instructional alternatives are made available and how they are decided upon. Alternative instructional experiences might involve different content relevant to different subgoals, or they might utilize different instructional procedures. The student's placement test scores can indicate his present level of accomplishment and his mastery of prerequisites. Measures of general intelligence may suggest whether or not he requires more closely or less closely sequenced instruction and whether or not he can effectively manage his own progress. However, these relationships are far from clear. Aptitude measures of the kind typically used today may be somewhat predictive of long-term academic and vocational success and, as a result, may assist the student in the selection of vocational goals. Such aptitude measures, however, appear to be less relevant in determining immediate instructional requirements. For example, there is little information available about whether spatial or mechanical aptitude is related to particular ways in which the student learns. In contrast, measures of the student's 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 him.

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 similar to those used to assess initial placement are obtained, 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? 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 attain, 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 these goals. It is no longer assumed, as it is in conventional instruction, that student achievement will follow a normal distribution of grades—some students 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 of the extent to which they are taught to use their knowledge to learn new things, to generalize to new situations and thus solve problems, and to be creative.

The foregoing assumptions require techniques for measuring student achievement that are different from those generally used. 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's performance and 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 or percentile scores. These measures do not provide information

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          0977   R . . . , DAWN                DATE - 085

CURRENT MATH IS LEVEL D SYSTEM OF MEASUREMENTS

          PRETEST                      POST-TEST SCORES
SKILL     SCORES          1ST          2ND           3RD          4TH

  1         71            86
  2         43            86
  3         25            75
  4         99            99
  5         50            50

DATE       054           071

PRESCRIPTIONS AND CETS

DATE     SKILL                         PAGE - SCORE

 059      01         03-90     04-90     06-90     08-90      09-90
                     13-90     14-90
                     CET 16    PART 1-29    PART 2-67

 061      01         17-90     18-90     19-90     20-90      21-90
                     CET 22    PART 1-57    PART 2-99

 063      01         10-90     11-90     12-90     15-90
                     CET 16    PART 1-71    PART 2-99

 065      01-M       14-90
                     CET 22    PART 1-86    PART 2-99

 066      02         CET 21    PART 1-71    PART 2-99

 068      02-M       01-90     05-90     08-90     13-90      17-90
                     19-90     20-90
                     CET 21    PART 1-86    PART 2-99

 068      03         CET 15    PART 1-50    PART 2-99

 070      03-M       05-90     06-90     09-90     12-90      14-90
                     CET 15    PART 1-99    PART 2-99

 070      04-M       CET       PART 1-      PART 2-

 070      05-M       CET 09    PART 1-99    PART 2-

 078      05         94- 0     17-90     19-90     20-90      22-90
                     CET 23    PART 1-75    PART 2-99

 080      05-M       CET 13    PART 1-99    PART 2-

     SUGGESTED NEXT UNIT IS D GEOMETRY
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Fig. 2. Print-out 1: unit summary for a single student.

GRADE 6   MRS. F   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

Fig. 3. Print-out 2: class list showing how long each student has been working in his current unit.

about student performance in terms of criterion levels of achievement. In the model for individualized instruction, achievement measures do provide such information and make it possible to assess the outcomes of learning at each selected decision point.

5) Adaptation and optimization. As the student learns, information is obtained about the characteristics of his learning, instructional assignments are made, and his performance at the subgoal decisions points is assessed. This procedure is carried out continuously throughout the course of instruction. Of obvious importance is the nature of the criterion measures of performance at the subgoals. Since the measures of the student's learning history are expressed, and the instructional alternatives are evaluated, in terms of his subgoal performance, the question of which measures of mastery are selected becomes critical. Depending upon the measures used, some gains will be fully recognized and others overlooked; some kinds of student performance may be inadvertently overlooked unless they are stated as goals 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 multistage decision-making 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 concept of the way in which 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 concerning the way in which learning occurs. In a nonautomated individualized system the teacher's concept of the learning process influences the decisions he makes, and the information with which he is supplied also provides constraints. In CMI, the displays to the teacher and any more detailed suggestions presuppose concepts about the nature of learning, and since both teacher and computer are involved, the concept built into the system and the teacher's concepts interact.

6) Evolutionary operation. A primary property of the instructional system described here is the fact that it accumulates information which is used to improve its own functioning. Improvement takes place in two ways. (i) The system uses procedures and materials in keeping with the current state of knowledge, and, through data obtained during the operation of the system, these procedures and materials are made more efficient. (ii) New knowledge about the learning process and about the conduct of individualized instruction can be obtained. Since each individual's learning is carefully monitored, the system makes it possible to explore a variety of research questions. In fact, when the system is first used there should be excess monitoring for this purpose; as it becomes operational, less information is needed.

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 nonautomated individualized procedure to a CMI system which eventually will include CAI as one available means of instruction. Nonautomated IPI forces redesign of the organization of the school. It also calls to the teacher's attention the need for detailed information about the individual student. This has facilitated the introduction of teacher-inquiry terminals to be used for CMI. After the teachers have become familiar with the potential of computers, various computer-based components in various areas can be introduced. The general instructional model described above should permit incorporation of each of these components 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 is broken down into instruction units for subgoals of achievement. For example, the mathematics curriculum has identified 430 specific instructional objectives. These objectives are grouped into 88 units. Each unit is an instructional entity which the student works through at any one time. On the average there are 5 objectives per unit, the range being 1 to 14. A set of units covering different subject areas in mathematics comprises a level; levels may be thought of as roughly comparable to a school grade level. On entering the school the student takes a placement test; on the basis of his performance he is placed in a particular unit. If his placement test profile is scattered, he begins work on the lowestnumbered unit. Associated with the unit are a preliminary test (a "pretest") and a post-training test (a "posttest"), and associated with each objective (or skill, as it is called in the subsequent printouts) are one or more "curriculum-embedded tests" (CET). Following assignment to a unit, the student takes the unit pretest, designed to give an evaluation of his skills within the unit. For example, he may have mastered skills 1, 2, 4, and 5, but not 3, 6, 7, and 8; at this point the teacher prescribes work related to the skills he has not mastered. As a student works through a lesson, he takes, at the teacher's discretion, the "curriculum-embedded test," which shows whether or not he has mastered the skill and also to what extent he has attained some competence on the next skill. When he has attained all the objectives he takes the unit posttest. If his grade is 85 percent or more, he begins work on the next unit; if it is not, he is reassigned an appropriate objective in the unit he has been working on. The teacher is allowed a certain discretion in deciding whether to keep the student in a given 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 3 years. The clerical operations which had evolved over that 3-year period helped to clarify the nature of the data generated and the types of questions that teachers, evaluators, and researchers tended to ask on the basis of these data. In addition, experienced staff members prepared memoranda 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 that teachers, evaluators, and researchers wanted to make on the basis 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 includes the University of Pittsburgh IBM 360 Model 50 computer, an IBM 1050 terminal with card-reader attachment, and three IBM 2741 typewriter terminals. The central processing unit has an extended core which allows up to 131,000 characters per on-line terminal. A 250-million-byte disk and six tape drives are also part of the computer configuration. The card-reading terminal is located at the Oakleaf School and connected by leased line to the computer on the University of Pittsburgh campus. The typewriter terminals are located at the Research and Development Center. This CMI system is called the IPI Management and Information System (IPI/MIS).

The major aspects of the IPI/MIS system as it is operating today are summarized in Fig. 1. The basic data are recorded on optical scan forms by teachers, students, or 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 terminal at the school, and the data are edited and added to the current student file stored on disk at the computer. If errors are detected in the editing, the diagnostics are sent back to the school terminal for correction. The student file stored on disk contains test and prescription data pertaining to the unit in which the student is currently working, and selected background data. When a student completes a unit, the data obtained during his work on that unit are written out on a scratch file stored 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, the student's sex, his homeroom, and so on.

There are four major functions which the MIS can provide in an individualized school; it can (i) collect data; (ii) monitor student progress; (iii) provide information as a basis for prescribing a course of instruction; and (iv) diagnose student difficulties. These functions have two primary objectives: to increase the effectiveness of the model for individualizing instruction and to increase the productivity of the teacher operating the IPI system.

During the 4th year of IPI operation at the Oakleaf School, the school personnel included one principal, 12 teachers, and 12 teacher aides. The aides' primary function was to score tests and record test results. They also tabulated data pertaining to inquiries by the principal, the teachers, and the LRDC research and curriculum design staff. The teachers' three main functions have been writing prescriptions for courses of instruction, diagnosing student difficulties, and tutoring individuals and small groups of students. The clerical and teacher load can be reduced by having teachers and students enter data directly at classroom terminals. The teacher load can be further reduced by having the computer assume some of the prescription and diagnostic functions.

A description of three reports typical of those now available from the terminal at the school should help illustrate how the system is facilitating school operations. Print-out 1 (Fig. 2), which is a unit summary for a particular student (last names have been deleted), is a report of the kind most often used. A print-out of this kind is most frequently requested following failure on a posttest, so that the student's work in

```
GRADE 6  MRS. F                        DATE - 036  MATH
                                                   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
```

Fig. 4. Print-out 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.
```

Fig. 5. Print-out 4: illustration of the tape retrieval program.

that unit can be reviewed and appropriate prescriptions can be made. In Fig. 2, the numerals in the group at the top summarize the student's pretest and posttest scores for each skill in the unit. Shown at the bottom of this group are the dates (the day of the school year) upon which these tests were taken. Prescriptions and "curriculum-embedded test" scores appear in the lower part of Fig. 2, again listed by date and skill. For this unit, for example, it is possible to trace what this student did in mathematics from the 59th day of school to the 80th day of school, and how well he did.

The computer report illustrated in print-out 2 (Fig. 3) summarizes all 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 print-out 3 (Fig. 4), to help decide which students have gotten bogged down and which ones might be used to help in tutoring. Also, print-out 3 provides information on 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 in the classroom. The teacher who is prescribing courses of instruction 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 or the system, or both. Also, it usually takes a day or two for the scan forms to go through the various processing steps before reaching the computer's disk storage.

Apparently the next 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, and the teacher-inquiry and diagnosis functions needed. Classroom terminals would make it possible to enter data directly into the system quickly and easily.

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

Experience gained during the first year of developing and implementing IPI/MIS suggested several changes in both the instructional system (IPI) and 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 step 6 of the instructional model. The instructional units are used in an environment in which relevant information on the participating students and teachers is readily available. 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. Objectives for which no adequate units are now available will be discernible, and appropriate units can be developed. This, in turn, will lead to a more potent system of education for each student, one whose results more and more closely approximate desired goals.

In addition to facilitating evaluation studies of the "is it working?" type, the retrieval and analysis system 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 if he gets "hot" on a particular question he can interact with the data and evaluate his hypotheses at the moment, rather than wait for weeks after getting an idea before seeing the first print-out. Evaluation and research requirements have been given a high priority in development of the IPI/MIS. The system is now operational to the extent that 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 the data collected on all the students for one academic year, can be searched in 3 to 5 minutes, depending upon the demands being placed on the computer by other terminals at that time. An example of such a search is provided in print-out 4 (Fig. 5).

In print-out 4 the investigator was interested in examining selected data for all 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; this is indicated by the period at the end of the line. This command directs the search routine to select only those students who had taken the pretest for unit e4. The exclamation point at the end of a line indicates 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 skill in unit e4. This search resulted in a work file (called "e4 stuff" by the terminal user) for 32 students. The file contained the unit performance data for those students plus some background data requested for them—their Otis IQ scores and their Stanford arithmetic computation percentiles, if these were available in the file.

```
>$$att d d8stuff(e65wwc) as F8.
>$$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
```

Fig. 6. Print-out 5: data pertaining to pretests, prescriptions, and posttests for skill 2 of the mathematics-unit D division.

Current research applications of the MIS are primarily concerned with three major aspects of IPI and their interrelationships: (i) the diagnostic tests; (ii) the "prescription behavior" of teachers; and (iii) the content and sequence of the curriculum materials. In IPI's first 3 years a tremendous effort was needed to develop the necessary tests and curriculum materials. Also, teacher retraining was a large task. These developmental activities were primarily and necessarily departmentalized: a group of test specialists developed the test battery, while authorities on subject matter 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 these components and their interactions. The computer information system makes this large task more feasible.

For example, Bolvin (*5*) 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 tend to "follow the book" strictly in terms of the pretest scores; they prescribe no work if these scores are 85 percent or higher; if the scores are lower than 85 percent, the extent of the assignment is determined by the degree to which the pretest score deviates from that percentage. Still a third type of individual tends to "overprescribe"—that is, to assign students 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 be varied for different students and different units. For example, it may be important that the student be given extensive practice in certain skills (computation, for example) so that in subsequent, more complex units requiring those skills he is not hampered through lack of retention. Print-out 5 (Fig. 6) shows 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 concern is the structure of curriculum sequences. For only ten objectives there are over 3 million possible sequences. Fortunately, most of these sequences are ruled out by content structure and by concepts of the learning process. Instructional sequences can, however, also be empirically studied. Techniques similar to multiple scalogram analysis (*6*) of available placement and pretest results can assist in determining whether or not the skills are being taught in the order of their difficulty and in an order that facilitates the next learning stage. It is also possible to see whether or not the extent to which failure to present skills in the order of their difficulty affects (i) the time it takes students to master that particular sequence of skills and (ii) their eventual ability to use what has been learned.

A more fundamental task which MIS can facilitate is the development of alternative forms of instruction that can be adapted to the needs of particular students. Of course, at present a student can be assigned material in which he shows a lack of mastery and need not be assigned lessons in skills that he has mastered. But, in addition, lessons may involve different kinds of vocabularies; they may involve more closely or less closely sequenced instruction; or they may involve instruction which gives the student more, or less, responsibility for managing 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 appropriate alternatives and determine what alternatives should 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 "back room" 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 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 to believe that the same instructional model that 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.

References and Notes

1. R. Glaser, in *Evaluation of Instruction*, M. C. Wittrock and D. Wiley, Eds. (Holt, Rinehart & Winston, New York, in press).
2. ———, in *Proceedings of the 1967 Invitational Conference on Testing Problems* (Educational Testing Service, Princeton, N.J., 1968), pp. 3–36; C. M. Lindvall and J. O. Bolvin, in *Programed Instruction*, P. Lange, Ed. (National Society for the Study of Education, Chicago, 1967), pt. 2, pp. 217–254. Oakleaf is an elementary school in the Baldwin-Whitehall School District near Pittsburgh.
3. Although we are not completely happy with all of the connotations of the term *computer-managed instruction*, it does seem to be the term most frequently used by people currently working in this area of concern. It should be emphasized that the computer is used as a tool in the management of the information needed by teachers in planning individualized education.
4. See, for example, W. W. Cooley, "Computer systems for guidance," paper presented before the American Educational Research Association Annual Meeting, February 1968, Chicago, for a more detailed consideration of guidance in the individualized school.
5. J. O. Bolvin, "Evaluating teacher functions," Learning Research and Development Center, University of Pittsburgh, working paper No. 17 (1967).
6. J. C. Lingoes, *Educ. Psychol. Meas.* **23**, 501 (1963).

7. 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, University of Pittsburgh. We thank our many colleagues and students who have contributed to these efforts. The preparation of this article and the research and development described 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, New York.

NEWS AND COMMENT

A Surplus of Scientists? The Job Market Is Tightening

Is this country now producing more scientists than it can place in suitable scientific jobs?

The Bureau of the Budget seems to think so and is acting accordingly. Federal grants for the training of scientists have been cut by about 25 percent for this fiscal year. One reason for this cutback, in the words of a Budget official, is, "Why did we have to keep giving added inducements to train people when we were having trouble placing the people we did train? . . . The need for scientists has been exaggerated across the board."

Bureau of the Budget officials believe that recent expansion in graduate education has not been wholly beneficial to the universities involved. "The feeling we have is that graduate education has gotten too damn big for the good of the institutions," one explained, as he cited the recent Harvard faculty action to reduce the number of graduate students by 20 percent in the next 5 years (*Science*, 1 August). The official also said that graduate schools were having difficulties in recruiting good graduate students and were increasingly having to rely on recruitment of foreign students. Another added, "We privately get people in universities saying that there are too many scientists."

Of course, a primary reason for cutting back training grants, as well as for other cutbacks in federal scientific support, is to ease the federal budgetary problem which has been caused by the continuing increase in military spending. But whatever the initial motivation may have been for cutting back training grants, relevant Budget officials