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ABSTRACT

The computer's potential for education, and most particularly for instruction, is contingent on the development of a class of instructional decision models (formal instructional strategies) that interact with the student through appropriate peripheral equipment (man-machine interfaces). Computer hardware and software by themselves should not be expected to accomplish educational miracles. One way of viewing Computer-Administered Instruction (CAI) is as a simulation. The teacher, qua instructional agent, can be reduced to recurring cycles of decisions about information to be displayed to the student. A randomly operating teacher is totally unresponsive to the student's requirements as an information processing and assimilating agent. The ideal agent is optimally adaptive to the requirements of the student. To serve these purposes the man computer man communication channel must be of adequate capacity and relatively free of constraining filters. Issues are discussed in the context of an ongoing CAI systems development project (IMPACT). (Author)

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The Computer as Adaptive Instructional Decision Maker

by

Felix F. Kopstein and Robert J. Seidel

Paper for
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THE COMPUTER AS ADAPTIVE INSTRUCTIONAL DECISION MAKER

Felix F. Kopstein and Robert J. Seidel

CONCEPTUALIZATION OF INSTRUCTION

There will be no need to document a growing interest in the use of the digital computer in instruction. A variety of labels has been applied to attempts of this sort: computer-based instruction, computer-assisted learning, computer-assisted instruction, and computer-administered instruction. These differences in terminology may be a mere quibbling over words or they may reflect fundamentally different conceptions of the computer's role in instruction.

Basic Function of Instruction

What is the role of any instructional agent—classroom teacher, private tutor, film, programed book—relative to a student? What is the basic function of the instructional situation? Without deciding whether certain particular functions are or are not essential in instruction (e.g., maintaining discipline), it would seem undeniable that capabilities must be conveyed to students that they did not possess previously. All else (e.g., maintaining motivation, directing attention, prompting "independent thinking") must be viewed as incidental to this primary purpose no matter how important in itself. Efforts that do not succeed in enabling a student to perform in a way of which he was previously not capable cannot properly be called instruction.

Constraints

Figure 1 is a schematic representation of the basic properties inherent in any instructional situation. It is intended to illustrate certain inescapable constraints. If any instructional interaction is to take place, the instructional agent, whether human or digital automaton, must present information to the student. Thus, a flow of information from the instructional agent to the student is indicated and has been labeled "Teach Channel."

There must also be a flow of information from the student to the instructional agent. At the very least, the instructional agent must have some indications of the student's progress in mastering the subject matter, although he might also want to know whether the student is attentive, momentarily confused, distracted, and so forth. This flow of information from the student to the instructional agent has been labeled "Test Channel."

The critical property of the situation derives from the self-evident fact that *direct* control over each of the two channels of information transmission is divided between the instructional agent

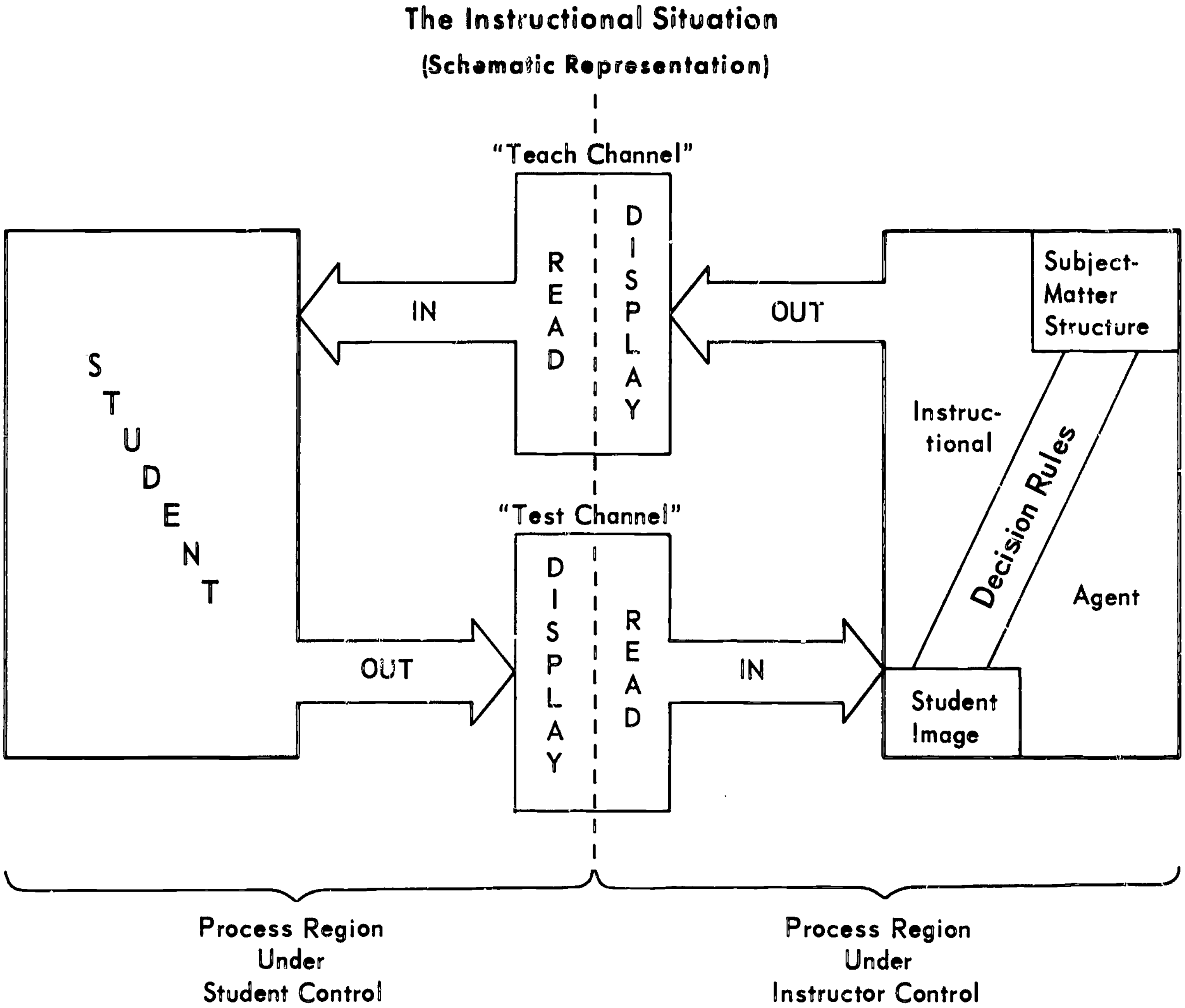

Figure 1

and the student. In fact, the instructional agent is limited to displaying (transmitting) a quantity of information. Only the student determines how much of the displayed information he will accept (receive). The instructional agent's direct control over the "Teach Channel" ceases at the dashed line. The reverse is true for the "Test Channel." The student directly controls the information inserted into that channel, while the instructional agent directly controls the information extracted from it. This limited span of control would appear to impose an absolute and inescapable constraint in any instructional situation. The reasons for representing a student image, a subject-matter structure and decision rules linking them within the instructional agent will be mentioned briefly later.

Instruction as Information Exchange

What has been sketched here is a single information exchange cycle. Normally, a long series of such successive cycles will be necessary to engender the desired end-of-course proficiency in a student. Ideally, over the series, the information flow within the instructor-student loop should decline from an initial maximum to zero. This is so, because at the end of *successful* instruction in a course, the instructor has conveyed all course-relevant information to the student, and he has confirmed that the student has assimilated it and verified the student's ability to use it. In a loose sense, instructor and student have become indistinguishable, because either of them is able to answer any course-relevant question.

From this point of view, if effective and efficient instruction is to take place, the information flow within each instructional information exchange cycle must be optimized. The problem for the instructor or instructional agent is to take, in each cycle, the optimal action in keeping with an overall "best" strategy for transmitting information. The recurrent decision to be made concerns the optimal instructional action to be taken relative to the subject matter being taught, the specific student being taught, the momentary circumstances, and the *available* options, if specified end-of-course proficiency is to be attained effectively and efficiently.

Other Adaptive Characterizations

The view outlined here corresponds with that of Pask (1) in that the instructional interaction has the form of a partly cooperative, partly competitive game. The cooperative aspect derives from the instructor's interests in conveying information to the student and the student's interest in acquiring and assimilating it. The competitive aspect derives essentially from the instructor's interest in testing whether he is not below maximally feasible information transmission rates and the student's interest in convincing him that he is exceeding them. For Pask, too, the instructor's problem is to maximize a payoff function related to the ultimate objective (proficiency).

Stolurow (2) also stresses that an adaptive capability is essential in the design of a technologically advanced instructional system. He lists three basic dimensions of adaptivity:

(1) " . . . (the) instructional system should be able to present only that information needed by each student to perform according to the terminal objectives."

(2) " . . . it should be able to present each student with that sequence of information blocks that best suit his particular needs."

(3) " . . . it should be able to select the rate of presentation that suits the student's information-assimilation rate . . . "

SPACE OF ADAPTATION

Clearly, the three views outlined here are highly compatible, if not identical. From all of them the notion of a space of adaptation can be developed. A student has a unique location within such a space at any given time, and it is the instructional agent's task to match himself (itself) or rather his presentation to that location. The basic dimensions of this space of adaptation may be seen in Figure 2.

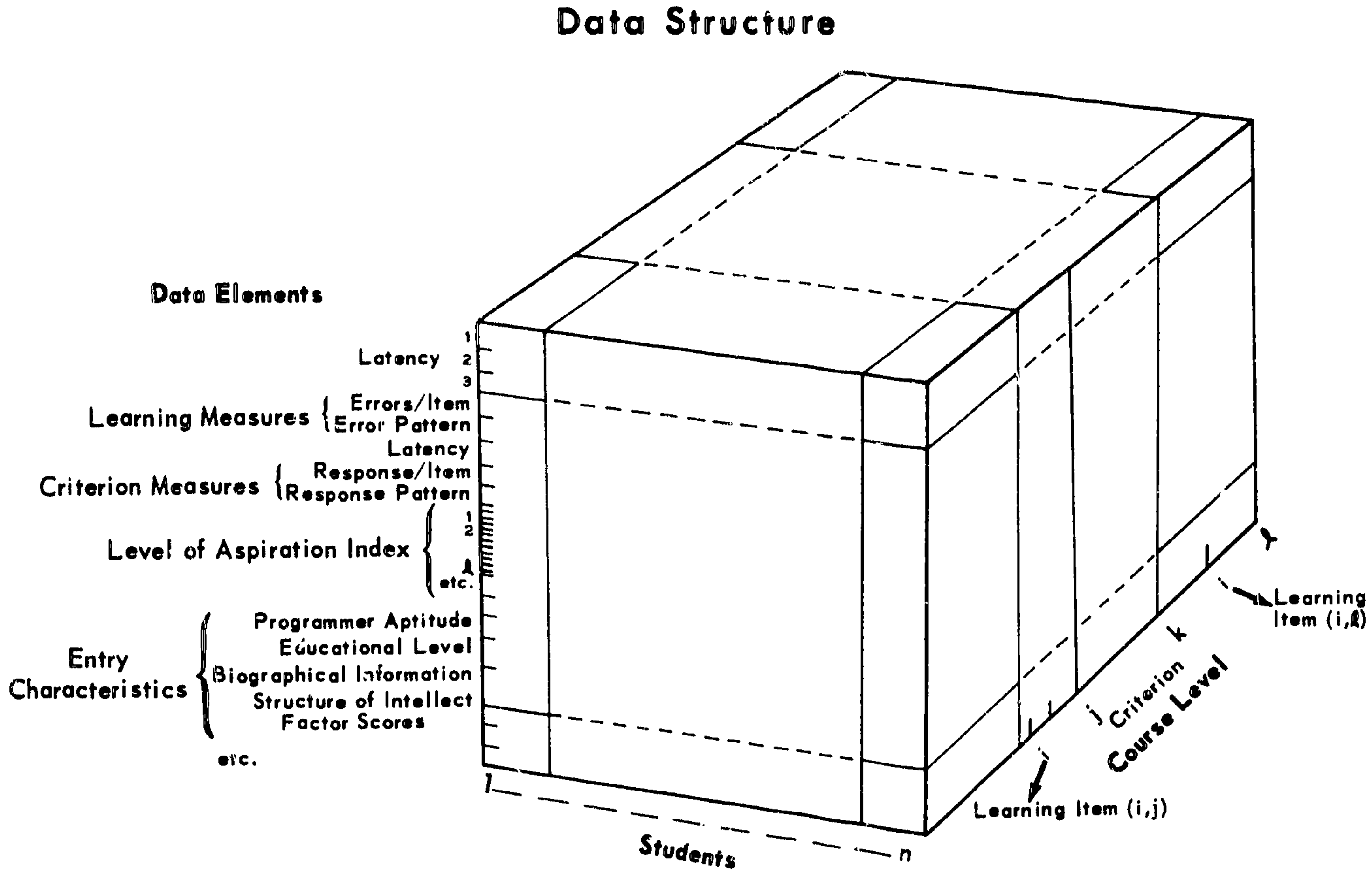

Figure 2

There is, first of all, a set of characteristics descriptive of each individual student (y-dimension). Second, there is a set of such individuals comprised of all students undertaking a particular course of instruction (x-dimension). Finally, there is a set of informational items (displays, frames, pages, units) comprising the informational content of the instruction (z-dimension). While it is probably true that each of these sets could be partitioned in any number of ways so as to generate an n-dimensional space, it is certainly true that three dimensions represent an irreducible minimum.

Details of Data Structure

In Figure 2 the space of adaptation has been labeled a "Data Structure," because it is only in the form of such a data structure that it can be described to the computer. *Data elements* are divided into two basic types: (a) Those pertaining to the general characteristics of the individual student or entry characteristics, and (b) those deriving from the specific history of instructional interaction. The choice of entry characteristics shown here has been influenced by the specific aim to provide instruction in computer programing via the COBOL programing language. This context and many details of rationale that cannot be recapitulated here have been described by Seidel, *et al.* (3). Response latencies, thought to be an index to the duration of a student's ideational or information processing activities, are divided into (a) instructional display reading time, (b) elapsed time to start of response, and (c) elapsed time to completion of response.

Learning measures are those deriving from responses made to or within a sequence of instructional items (displays). Criterion measures are those deriving from responses made to end of sequence, end of block, or end of course test items. Level of aspiration (LoA) index is the familiar ratio between obtained/expected scores (Lewin, *et al.*, 4) and is regarded as a sensitive index to the individual's motivational state (Seidel and Hunter, 5). *Students* are simply the number of separate individuals entering into any normative comparison.

Course level refers to the sequence of learning items that a given student will, in fact, traverse in moving toward criterion proficiency. It does not imply a simple linear sequence of the type promulgated by Skinner (6), but a particular route through a net of instructional items. Items may differ from each other in the specific information they contain, the form in which the information is presented (e.g., verbal, symbolic, graphic), the number of new concepts (terms) that are introduced, the number of relations among concepts that are discussed, and so forth.

Design of Control Functions

The question that arises now, as it does in all sciences of the artificial (Simon, 7), pertains to the design of the control functions by means of which the instructional agent can maintain at all times a minimal distance between his own position and that of a student within the space of adaptation represented by the data structure in Figure 2. It may be well to point out that the sets constituting the three dimensions are both finite and discrete. Thus, the control functions reduce to a choice represented by the triple (I, S, C), which might be read as Individual, Students, Course levels.

This will explain the necessity for including in the schematization of the instructional agent a "Student Image" and a "Subject-Matter Structure" linked by "Decision Rules" (Figure 1). Unless the instructional agent has such an image (i.e., measures of individual students' characteristics per Figure 2) and unless he (it) has a "map" of the way the subject matter being taught is structured (i.e., possible routes of sequential item presentation throughout the course per Figure 2), he (it) cannot match any *next* instructional action, especially the presentation of the next informational item, to the individual student's current location.

DESIGN OF INSTRUCTIONAL DECISION MODELS

The control functions, then, reduce to a decision structure which presumably parallels that of the successive instructional decisions made by a totally rational teacher of some given level of competence. We may think in terms of a simulation or a model of this hypothetical individual and refer to this entity (program) within the computer as an Instructional Decision Model (IDM). The task of the IDM at any given moment and with respect to any given student is to assess a set of decision factors, examine the available instructional options (courses of action), and to relate them with a decision rule that will minimize (optimize) the distance between student-instructional action in the space of adaptation.

Initial Version of IDM

Table 1 illustrates a first version of an IDM intended for the general instructional objective of conveying to students the capability of solving computer programing problems and expressing them in COBOL. It represents the IDM currently operating in Project IMPACT, an advanced development effort designed to evolve a prototype of an operational computer-administered instruction (CAI) system that is cost/effective and efficient (Seidel, *et al.*, 3).

Valid Confidence Testing

The initial decision rules are based upon the numerical expression of a student's confidence in his constructed responses (or in having him split his bets over multiple choices). With Valid Confidence Testing (VCT), the student's rational strategy is one of telling the instructor what he does *not* know, as well as that which he does know. Valid Confidence Testing is a diagnostic tool developed by Shuford, Albert, and Massengill (8). This technique has already proved effective in classroom teaching and seems most appropriate for the proposed computer controlled environment. The combination of objective response correctness or incorrectness and the subjective degree of confidence provides for the decision maker a more sensitive indication of the student's state of skill development relative to the concepts at hand.

In traditional achievement testing a student's response to a test item represents his *objective* assessment of its correctness (or supplies the correct answer). If the response given is, in fact, incorrect, then this is the sole basis on which to classify the capability state of the student. With VCT the student states his *subjective* confidence (probability) in the correctness of an answer. Now, if he is, in fact, incorrect, at least two states may be distinguished. He may be incorrect after having expressed little confidence in his response (i.e., he is guessing) and he would be classified as "uninformed"; he may be incorrect with high confidence in his response and would be classified as "misinformed." Additional State of Skill classifications are indicated in the second column of Table 1.

Table 1

Project IMPACT Decision Table
Iteration I—Instructional Decision Making

Problem Type	State of Skill (SOS) Diagnosis	Decision Rules			Instructional Options
		A	B	C	

I Program Writing
A. Comprehend Specifications
B. Identify & Sequence Elements
C. Code in COBOL
 	
II COBOL Questions
C. Construct Responses
	(1) Well-informed (correct & highly confident)
	(2) Informed (correct & somewhat confident)
	(4) Misinformed (incorrect & somewhat confident)
	(5) Highly Misinformed (incorrect & highly confident)
	(3+) (3–) Uninformed (correct or incorrect with 50-50 confidence)
	(6+) (6–) Partially Informed (6+, correct & very little confidence recognizing correctness; 6–, incorrect & some confidence recognizing incorrectness)
	(7) First Attempt
	(8) Second Attempt
	(9) Third Attempt
		IF A. & (1), THEN (i) (or (h)).
		IF A. & (2), THEN (a), THEN (h).
		IF A. & (3), THEN (a) & IF (7), THEN (b); Else, IF (8) & (3+), THEN (d), THEN (b).
		IF (8) & (3–), THEN (f), THEN (b).
		†Else IF (9), THEN (ℓ), THEN (h).
		IF A. & (4), THEN (a) & IF (7), THEN (b).
		Else, IF (8), THEN (f), THEN (b).
		†Else, IF (9), THEN (ℓ), THEN (h).
		IF A. & (5), THEN (a); THEN same as for (4).
		IF A. & (6), THEN (a) & IF (7), THEN (b).
		Else, IF (8) & (6+), THEN (c), THEN (b).
		IF (8) & (6–), THEN (f), THEN (b).
		†Else, IF (9), THEN (ℓ), THEN (h).
		*(n) Can occur at any instructional display.
		† Sequence unique to A, B, or C question-category.
			IF B. & (1), THEN (i) (or (h)).
			IF B. & (2), THEN (a), THEN (h).
			IF B. & (3), THEN (a); IF (3+), THEN (d) or IF (3–) THEN (f) &
			IF (7), THEN (b).
			†Else, IF (8), THEN (e), THEN (h).
			IF B. & (4), THEN (a), THEN (f); IF (7), THEN (b).
			†Else, IF (8), THEN (e), THEN (h).
			IF B. & (5), THEN (a); THEN same as for (4).
			IF B. & (6), THEN (a); IF (7) & (6+), THEN (c), THEN (b).
			IF (7) & (6–), THEN (f), THEN (b).
			†Else, IF (8), THEN (e), THEN (h).
			*(n) Can occur at any instructional display.
			† Sequence unique to A, B, or C question-category.
				IF C. & (1), THEN (i) (or (h)).
				IF C. & (2), THEN (a), THEN (h).
				IF C. & (3), THEN (a); IF (3+), THEN (d) or IF (3–), THEN (f) and †IF (7), THEN (m), THEN (b).
				Else †, IF (8), THEN (g), THEN (h).
				IF C. & (4), THEN (a), THEN (f) and †IF (7), THEN (k), THEN (b).
				†Else IF (8), THEN (j), THEN (h).
				IF C. & (5), THEN (a), THEN same as for (4).
				†IF C. & (6), THEN (a).
				IF (6+), THEN (c), THEN (h).
				IF (6–), THEN (f), THEN (h).
				*(n) Can occur at any instructional display.
				† Sequence unique to A, B, or C question-category.
					(a) SOS Feedback
					(b) Present Display Again
					(c) Confirm Type 1 (correct SOS (6))
					(d) Confirm Type 2 (correct SOS (3)).
					(e) Present Correct Answer
					(f) Feedback For Incorrect Answer
					(g) Mandatory Global Review
					(h) Present Next Display
					(i) Accelerate if Possible
					(j) Mandatory Glossary Review
					(k) Optional Glossary Review
					(ℓ) Remediate Based on Qu Type (Optional per Qu within category and Mandatory at end of category)
					(m) Optional Global Review
					*(n) Student Glossary Request

Stimulus Support

From a large Programed Instruction study by Seidel and Hunter (5) refined hypotheses have been generated regarding the value of what may be called *stimulus support* during learning (*stimulus support* is intended to encompass both prompting and confirmation techniques). Specifically, the findings from that study clearly demonstrate that the students receiving an excessive amount of support during learning were hindered in later criterion performance requiring synthesis of what had been learned. The implication for the current decision-making strategy is to avoid prompting or confirmation where the student is performing well, and provide only that amount of support which is required to keep the student coping with the materials. Greater discussion of this rationale can be found in the Seidel and Hunter (5) report.

Problem Types

The other aspect of the decision making concerns the instructional options available for the student. In order to place these options in a proper framework, it is well to understand the nature of the learning tasks in the course of instruction. The learning of COBOL programing (computer programing) is an example of a problem-solving type of task. It can be broken down into understanding the elements of the problem (Problem Type A), identifying and sequencing these (Problem Type B), and then coding them in the language, COBOL, which the student is being taught (Problem Type C). Constructing responses to questions about COBOL is thought to be essentially equivalent to C.

In developing the types of remediation to be used, little in the psychological or educational literature seemed relevant to determining the nature of the instructional options. The rationale for choosing remediation was based, of necessity, upon scientific intuition. At any rate, if the responses requiring remediation occurred at the global problem-solving level, comprehending the problem specifications, and so forth, then the remediation to be provided would be of a general problem-solving nature. If, on the other hand, the necessary remediation followed the specific questions requiring constructed responses in the language that the students would be learning, then the types of remediation would be simplification, redundancy, or other informational contextual changes.

Decision Rules

All of the decision rules and options then represent the independent variables of the evaluation study and are indicated succinctly in Table 1. Other features to the decision model, also included in Table 1 in brief form, involve the use of a glossary technique providing a sensitive probe of the student's understanding of the organization of the material at any given point in time. This is under both student control and instructor (i.e., program) control. The student can request, at any time during the presentation of material, definition of concepts and sub-concepts in order to better establish the relationships amongst these for himself. In addition, as indicated in Table 1 with respect to remediation, in certain instances the glossary will provide a review for the student contingent upon his performance.

The Decision Table can be read as follows: Given a category of problem type A, B, or C, and given a State of Skill diagnosis, 1 through 6, if there is a first, second, or third attempt, then the actions to be taken are drawn from the fourth column. These diagnoses and options can then be read from the third column(s) in a series of IF-THEN statements. The basis for instructional decisions during the initial iteration will be confined to the immediate past responding of the student.

Role of the Computer

Although it has not been treated explicitly, the relation of the IDM to the computing system (hardware/software) may have become abundantly evident. Even a minimally sophisticated IDM, such as the one implemented in the current, first iteration of HumRRO Project IMPACT, imposes information processing demands exceeding the capabilities of any human being or hitherto existent instructional medium. Only the capabilities resident within modern information-processing machinery are adequate to the task of executing the decision process embodied by the IDM. However, computers have no inherent capabilities such that their mere presence or utilization in an instructional situation can be taken as a guarantee of effective instruction (Kopstein and Seidel, 9).

Man-Machine Communication

Any IDM exists within the framework of a computer as a program. Its interactions with a student can take place only via a communication channel linking IDM and student. To the extent to which the bandwidth of this channel is limited and constraining filters (e.g., mechanical typewriters, keyboards, rigid conventions) are imposed on it, natural rates and modes of interaction are inhibited. As an inescapable concomitant, also, restrictions are thereby placed on the instructional options available to the IDM and, consequently, on the possibilities for evolving it to higher levels of sophistication.

Evolution of IDM

What has been described above is a first version or iteration of the IDM. Patently, if a cost/effective CAI system is to be evolved, it must embody a more sensitive IDM and one whose instructional strategies (decision rules) have had some degree of validation. This will be accomplished in successive evolutionary iterations of the IDM.

For example, during the current and first iteration, the only active decision factors are based on immediate responses of a student. Other factors outlined in Figure 2 will be merely measured so that intercorrelations among measures can be examined. Expansion and elaboration of the IDM will occur as a concomitant of selectively increasing the number of decision factors, elaborating the decision rules, and increasing the number of decision options. Each successive version of the IDM will then be tested empirically in order to diagnose and isolate the most appropriate combination of elements for the next succeeding version. This means that the correlational data from the preceding output will be assigned weightings and provide the input decision-making characteristics for subsequent iterations. In order to refine further the new decision factors, simulations of students will also be used prior to moving to the next iteration.

Evolution will come through the development of a sequence of IDMs. Each succeeding IDM will result in an increase in detail and effectiveness. The form of the i^{th} IDM, say M_i, will depend upon the combination of experimental and theoretical information gained from experience with all IDM iterations preceding M_i. Processes used to develop M_i will have two activity components. The first component consists of activities mainly concerned with searching for M_i design alternatives. The selection of a particular alternative constitutes the major activities of the second component. Intuitive judgments and empirical data will be used in conjunction with formal arguments in both activity components. Thus, Bayesian decision theory will be one of the basic conceptual devices in the evolutionary process (Raiffa, 10; Chernoff and Moses, 11). Eventually, the set of heuristics will be reduced to a comprehensive, formalized instructional strategy, providing an algorithmic representation for optimizing the individual path through a course of instruction, and implemented in the form of a computer program.

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13. ABSTRACT

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