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TOWARD A BEHAVIORAL SCIENCE BASE FOR INSTRUCTIONAL DESIGN.

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THE PROCESS OF EDUCATIONAL DESIGN, WHICH IS THE APPLICATION OF THE KNOWLEDGE AND METHODOLOGY OF BEHAVIORAL PSYCHOLOGY TO THE DESIGN OF THE TEACHING PROCESS AND EDUCATIONAL ENVIRONMENTS, IS PRESENTED, AND THE PROFESSIONAL SPECIALTY OF THE EDUCATIONAL DESIGNER IS DESCRIBED. THE PRESENTATION OF THE COMPONENTS OF THE EDUCATIONAL DESIGN PROCESS COMPRISE THE MAJOR SECTIONS OF THIS REPORT. THEY WERE (1) ANALYZING THE CHARACTERISTICS OF SUBJECT-MATTER COMPETENCE, (2) DIAGNOSING PREINSTRUCTIONAL BEHAVIOR, (3) CARRYING OUT THE INSTRUCTIONAL PROCESS, AND (4) MEASURING LEARNING OUTCOMES. THIS REPORT WAS PREPARED AS THE FINAL CHAPTER TO A VOLUME DEDICATED TO POINTING OUT SOME OF THE CONSIDERATIONS AND QUESTIONS INVOLVED IN DEVELOPING A BEHAVIORAL SCIENCE BASE FOR THE TEACHING PROCESS. (GD)

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REPRINT I

TOWARD A BEHAVIORAL SCIENCE BASE FOR INSTRUCTIONAL DESIGN

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Toward a Behavioral Science Base for Instructional Design

Over the past decade, the work on teaching machines and programed learning has been one response to education's growing demand for a scientific and technological base. Particularly, it is the response of certain behavioral scientists, primarily experimental psychologists, who have attempted to apply their knowledge and methodology to the design of the teaching process and educational environments. The behavioral scientist, as an educational designer, begins to work as a technologist supplied with a presently meager, but apparently increasing, body of technological principles and practices which is emerging from the interplay between practical attempts at education and relevant research from the sciences which contribute to pedagogical methods. Ideally, he has approached the job of teaching subject matter knowledge in terms of the following tasks.

First, he has analyzed the behavior under consideration and specified some performance which will represent a standard of competence to be attained at the end of a sequence of educational experiences. This performance specification establishes a model or standard around which individual differences will be displayed. The selected performance must be specified in terms of the properties or a representative sample of instances which exemplify it. The stimulus, response, and structural characteristics of these instances of subject matter content and the behavioral repertoires involved will determine what to teach and, correspondingly, how it is to be taught. One cannot be too rigid, however, in sticking to an early specification of this performance because certainly the selection of instructional goals will be influenced by the designer's analysis of the behavior under consideration.

Second, he has specified the characteristics of the students that are to be taught. These characteristics need to be determined either prior to instruction or in the process of early learning. It is necessary to know the extent to which the student has already acquired some of the things to be learned, the extent to which he has the prerequisites for taking the next instructional steps, the extent to which antecedent learning facilitates or interferes with new learning under the conditions the designer has in mind, and the extent to which the student can make the necessary sensory discriminations and can exhibit the motor skills required for initial learning steps.

With information about both the target performance to be attained and the existing preinstructional behavior, the educational designer can proceed from one state to the other. This sets up the third task: he must guide or allow the student to go from one state of development to another and construct the procedures and materials that are to be employed in the educational process. As part of this process, he must take account of motivational effects; this means providing conditions which will result in the maintenance and extension of the competence being taught.

Finally, the educational designer must make provision for assessing and evaluating the nature of the competence achieved by the learner in relation to the performance criteria that have been established.

This description of the process of educational design may sound harshly technological and, indeed, perhaps some elegance has been lost in analysis. But presumably, once the basic techniques are constructed, it is time for the teacher-practitioner to use the tools of his profession with all the artistry and sensitivity he can muster. The components of the above plan of operation for the design of teaching comprise the major sections of this chapter: analyzing the characteristics of subject matter competence, diagnosing preinstructional behavior, carrying out the instructional process, and measuring learning outcomes. The intention of this chapter is to follow the leads of the previous authors in this volume and to point out some of the considerations and questions involved in developing a behavioral science base for the teaching process. These matters are of common interest to experimental psychologists and educational designers since they are relevant to instructional practice and of significance to the science of learning.

Analyzing the Characteristics of Subject Matter Competence

When the experimental psychologist turns his attention from analysis of the behavior involved in standardized, arbitrary tasks used in the laboratory to the identification of the processes involved in learning the nonarbitrary behavior generally taught in society, he runs head on into the problem of the analysis of subject matter tasks. The significance of this problem is highlighted by the fact that task analysis has preoccupied the activities of psychologists when they have turned their attention to training, as they did in the Air Force program under the direction of Arthur W. Melton (19). The concern with task analysis is a reaction to the fact that while the investigator in a laboratory decides upon and constructs an experimental task pertinent to his particular purposes, he is not in a position to do this in the training and educational situation. In the laboratory, by preselecting his task to fit a problem, he has in a sense analyzed its stimulus and response characteristics. However, when working with nonarbitrary behavior, he is faced with the problem of identifying the properties of the behavior involved so that he can proceed to operate in his usual way. As a behavioral scientist he is used to working with specified behavior, and he needs to do so in the instructional situation. The transition from the laboratory to application frequently requires this additional consideration. The recent writings and explorations of Bruner (6, 7), for example, continuously emphasize a concern with subject matter structure, and this most likely develops out of his concern with real-life subject matter.

The significance of subject matter analysis is emphasized when Lane[3], involving himself in the learning of a second language, points

[3] In this final chapter, formal references to other chapters in this book are indicated merely by the name of the chapter author.

out that he had the good fortune to discover that, in this subject matter field, much time had been devoted to the systematic specification of the terminal behaviors of instruction. In contrast, when working in the field of English, Markle indicates that a major problem centers around the fact that instructional designers demand better specification of the behavior to be taught by English teachers. She points out that in English, the prescriptive nature of traditional grammar has "apparently settled in prescriptive methods of instruction." Needless to say, the stimulus and response requirements of subject matter properties affect instructional technology and, in turn, detailed analysis of subject matter characteristics will probably demand advances in instructional procedure. Some illustrative influences of subject matter characteristics upon the investigation of learning and instruction will be suggested here.

Component Repertoires and Content Repertoires

A subject matter expert usually can divide his subject into subtopics primarily on the basis of content interrelationships and subject matter logic and arrangement. In contrast, a psychologist considers subject matter analysis less in terms of content-orientation and more in terms of the behavior of the learner and the kind of stimulus-response situations involved. "Content" and "subtopic repertoires" are terms that can be used to refer to a subject matter oriented analysis. The term "component behavioral repertoire," or merely "component repertoire," can be used to refer to a behavioral analysis. The concern of psychologists with taxonomies (30, 31) reflects initial attempts to develop schemes for describing and analyzing component repertoires.

From the point of view of instruction, the practical requirement for component repertoire analysis is to identify the kind of behavior involved so that the learner can be provided with instructional procedures and environmental conditions which best facilitate the learning of that kind of behavior. The underlying assumption is that the learning of various kinds of component repertoires requires different kinds of teaching procedures, and an important research task is to identify the learning processes and appropriate instructional procedures associated with different component repertoires. This kind of thinking underlies Gagné's "analysis of instructional objectives for the design of instruction" when he lists the following as categories of behavior: response differentiation, association, multiple discrimination, behavior chains, class concepts, principles, and strategies; he then attempts to suggest learning conditions relevant to each category.

A useful taxonomical distinction with respect to component repertoires has been made by Skinner (39) in distinguishing between formal repertoires and thematic repertoires. In formal repertoires there is point-to-point correspondence between stimulus and response, as in imitating, reading, and copying; in thematic or mediated repertoires, responses are controlled by common sets of variables, but without formal correspondences, as in responding appropriately to a question with a meaningful answer. Formal repertoires are the less complex of the two to study and have received most work in operant analysis. In second language learning, Lane indicates that kinds of formal repertoires have been categorized, such as echoic behavior, when both stimulus and response are spoken; transcription, when both stimulus and response are written; textual behavior, when a spoken response is controlled by a written stimulus; and dictation, when the stimulus is spoken and the response is written.

There is much less applicable research on thematic repertoires, although research on mediation is a burgeoning enterprise at present. Much of language learning consists of thematic repertoires involving syntactic sequences, grammatical structures, contextual constraints of the language, etc. Understanding of the behavioral characteristics of these intraverbal sequences requires laboratory research along the lines of such things as the effects of language patterning on recall (32) and the acquisition of syntactic patterns in children (5).

One ramification, then, of the analysis of behavior upon instructional design is the necessity to distinguish between subject matter content and component repertoires. The designing of optimal instruction may be a matter of choosing the proper tactics for categories of behavior implied by the component repertoire characteristics of instructional objectives (16). In this context, disciplines that study subject matter disciplines, like linguistics and logic, should become increasingly useful in providing interaction between subject matter structure and the behavioral structure required for learning. For example, a contrastive analysis of the linguistic requirements of a student's first language and the target second language to be learned can provide details for an instructional prescription.

Process and Objective

The trend toward the behavioral analysis of instructional objectives has led to the term "process" objectives. For example, the recent AAAS curriculum for science in the elementary grades (1) considers process objectives, such as observation, classification, prediction, and inference. The content as such—whether magnetism, sound, light or heat phenomena, or biological events—is of secondary importance in this curriculum. The learning of "processes" is most important. Also, at higher levels of science teaching, there is increasing concern with more than "formal and descriptive knowledge" of the current body of science, and emphasis is placed on such behaviors as generating hypotheses, selecting fruitful hypotheses, testing hypotheses and deciding upon experiments, and the more generalized traits of a scientist such as perseverance and curiosity. The trend toward the statement of so-called process objectives reflects a recognition of the importance of the component repertoire.

It should be pointed out, however, that the word "process" in process objective can be somewhat misleading. A statement of objectives refers to a behavioral state which is some performance by the student; the performance itself, or the results of the performance, can be measured in some way. It is important to distinguish between the terminal behavioral state and the process of attaining that behavioral state which is carried out by an instructional sequence. For example, the terms "formal" and "thematic" repertoire describe certain kinds of behavioral classes, whereas words like "discrimination," "differentiation," and "chaining" refer to learning and instructional processes utilized to attain certain terminal behavioral states. It can be said that a person is discriminating or he is performing chaining behavior, but the instructional process required and the behavioral state attained need to be recognized as different things. Sequential statements of hierarchical subobjectives, as Gagné suggests (15), essentially list behavioral states. The cognitive simulation workers (34, 38), in contrast, are primarily concerned with the process between states. Either state or process description alone is only part of the requirements for instructional design.

Perhaps nowhere in recent years has the confusion between process and state been more rampant than in the recent emphasis on "discovery learning." In both the practical and the research work in this area, there is a confusion between two kinds of events: one event has to do with learning *by* discovery (process), that is, teaching certain objectives by a discovery method; the other event has to do with learning *to* discover (a behavioral state), or teaching for a terminal state which is manifested by the ability to make discoveries.

Transfer and Concept Formation

Subject matter properties very significantly determine the dimensions along which the student must be taught to generalize and transfer his knowledge. Presumably the ability to generalize and transfer is a function of experience with a variety of examples and different subject matter instances. What, however, defines variety, and what defines different instances? For some stimulus dimensions of subject matter, there is little ambiguity about generalization gradients and whether variations are instances of a basic case. However, as a subject matter becomes complex, definition of a range of examples may become difficult, and problems arise concerning whether training in various instances does indeed carry over to new situations. What seems to be required is investigation of stimulus variation and generalization gradients in the dimensions and multidimensions determined by analyses of subject matter. In instruction in critical reading, Markle states that while "the recognition of unsound interferences" might be a behavior that is clear, the stimulus conditions under which the behavior occurs are not clear. What is the population of stimulus material involved? It is obviously material which the student can comprehend, but the teaching objective is that it should extend to new material as the student learns to comprehend this new material.

The influence of the analysis of subject matter dimensions can be made most clearly when one considers the teaching of concepts. Many psychologists would agree that the basic procedure for teaching the ability to use concepts involves teaching the student to generalize within classes and to discriminate between classes. The student must learn to make the same responses to all members falling within a class and to make different responses to members of different classes. Mechner illustrates the procedure involved by the simple case of teaching a child the concepts of red and blue. Discrimination and generalization trials are presented with the colors red and blue. Other properties of the objects are varied randomly so that the student learns to generalize among objects having in common no characteristic other than their color. For example: First, the child is shown successive sets of three objects, two red objects and one not red. Each time these three objects are presented the question is asked, "Which is not red?" This is repeated a number of times with blue objects. In this way discriminations are established between red and not red and blue and not blue. The child might then be presented with two objects, one red and one blue and asked "Which one is red?" or "Which one is blue?" The number of nonred and nonblue objects could then be increased so that only one out of a number of objects is red or blue. In order to carry out training for generalization, objects with a variety of characteristics would be included in the sequence of color discrimination training—large and small objects, dark and light ones, rough and smooth ones, near and far ones, square, triangular, and irregularly shaped ones, etc. This would prevent the responses "red" and "blue" from being attached to stimuli other than the appropriate ones. With the properties of the objects varied, the child would learn to generalize among objects in which the common characteristic is color. In this way the child is presented with a series of progressively graded experiences by which he acquires the concepts of redness and blueness. As Mechner points out, this instructional process becomes complicated when the subject matter properties to be generalized and discriminated are not clear-cut or are very subtle—for instance, such concepts as classic and neoclassic art or early Mozart and late Mozart. A major problem in teaching such subtle and complex concepts is the definition of the subject matter classes. This becomes increasingly problematical when there is disagreement among experts and where there are semantic imprecisions. Sometimes the distinction between classes is not clear to the learner because he does not have the necessary preliminary training required. At other times the confusion is subject matter imprecision itself.

Response and Reinforcement Modes

After reviewing the studies carried out on response mode in programed instruction, Holland suggests that the results indicate that the nature of the learning task determines the preferred response form. For example, when the criterion performance includes a precise response topography, such as writing a new Spanish word, constructed response seems to be the better form. When recognition is the criterion of performance, the response form seems to be unimportant, and for fine stimulus discriminations, alternative response choices may be preferable. In elementary concept learning (44), the ability to transfer was more effective when subjects had to choose the presence or absence of the concept than when they selected it in a multiple-choice arrangement.

The response mode investigations in programed instruction up to the present time have been very feeble attempts to match learning task with appropriate stimulus and response characteristics. The underlying problem is the design of the means of display and response by which the student interacts with his subject matter. Analysis of the properties of the subject matter stimuli in terms of their content, duration, scheduling, and novelty will influence instructional design. Skinner points out that "there are potentially as many different kinds of teaching machines as there are kinds of contingencies of reinforcement." Analysis of the subject matter changes fed back to the student as a result of his interacting with the subject matter provides for the arrangement of appropriate response contingencies. Such feedback need not be so patently artificial as repetitive presentation of the correct answer contingent on every small step. For example, in solving a problem, the response of a student may produce new information, lose information, or introduce a delay in receiving information. In chemical analysis, a response may result in a predictable change, an unpredicted occurrence, or no change at all. The stimulus feedback the student receives is the result of his manipulation of the subject matter and is hence a function of its special properties.

Analysis of subject matter stimulus and response requirements suggests breaking away from the confines of the primarily paper-and-pencil learning environments prevalent in school learning and examining in detail the requirements of the "interface" between the student and his subject matter. The trend in this direction is not toward the restricted sense of usual audiovisual aids; the challenging direction seems to be that taken by such work as is going on in computer-based instructional laboratories (10), for example oscilloscope-screen teaching of graphical representation (27). In such work, more than computer capabilities should be taken into account; the capability of engineering technology to provide ways of interacting and manipulating subject matter is of primary importance (20). This trend is a useful meaning of "mechanizing education": mechanizing is not necessarily doing by machine what was formerly done by people. What is needed is an analysis of the content and component repertoires involved and the instructional functions to be served, followed by the design of appropriate equipment. The adaptation of generally available all-purpose equipment, like slide projectors and tape recorders, will tackle only a small part of the need in this area. Initially, experimental setups should be built which are highly overdesigned in complexity and capability. Research and development with such facilities can help determine the requirements for appropriate hardware demands and tolerances, programing requirements (both computer and instructional), and teaching advantages.

Summary

The analysis of behavioral objectives is an area that cannot be overlooked in research and development on learning leading to effective instructional practice. To emphasize the point, one can resort to testimonial quotes. "So important is the principle of programing that it is often regarded as the main contribution of the teaching machine movement, but the experimental analysis of behavior has much more to contribute to a technology of education." This is from the chapter by Skinner, and while he means somewhat more than only the analysis of behavioral objectives, his point is certainly related. In analyzing English teaching, Markle says, "In the case of the critical and evaluative skills in literature, not the technology of designing frames but the technology of task analysis is crucial." Gagné, with his emphasis on sequential objectives, says "the entire sequence of objectives ... is considered to be the most important set of variables in the instructional process, outweighing as a critical factor more familiar variables like step size, response mode, and others." Crawford, in considering the extensive experiences of HumRRO, says that "perhaps the most important single contribution to the development of training through research has been the determination of methods for the formulation of objectives of instruction" (11, p. 326). The importance of this first component in a plan for the design of teaching cannot be emphasized enough. It has been neglected in psychological research, and, as Crawford says, it is probably the most important element in recent improvement in instruction. It is the first step in the sequence of tasks in instructional design, and without it the succeeding components will be inadequate.

Diagnosing Preinstructional Behavior

Once the subject matter behavior objectives have been analyzed, the instructional designer turns his attention to the characteristics of the learner who is to attain these objectives. This raises the problems involved in diagnosing the preinstructional behavior or the entering repertoire of the learner. For measurement psychologists, this has been a primary concern. For psychologists interested in learning, preinstructional individual differences have, for the most part, been relegated to error variance in experimental design. It is increasingly obvious, however, that a psychology of learning relevant to instructional practice cannot consider individual differences as error variance. Classroom and laboratory studies are constant reminders that individual differences is one of the most important conditions of learning as yet unaccepted in both learning theory and subject matter teaching (see 42).

In research on programed instruction, one is uniformly impressed with the extent of variability in student learning rates (22). Rate of learning, however, is only one relevant dimension of individual differences. It is the dimension which programed instruction has emphasized, and it is probably the easiest one to accommodate (even though it certainly can upset the organization of a school). There are other dimensions of individual differences of equal or more important significance which pertain to the component and content repertoires of the student, i.e., his aptitude pattern, skill level, etc. At least four classes of preinstructional variables are determinants of the course of achievement (50): (a) the extent to which the individual has already learned the responses to be acquired in instruction, e.g., previous achievement of certain of the skills to be taught; (b) the extent to which the individual has acquired the prerequisites for learning the responses to be acquired, e.g., knowing how to add before learning to multiply; (c) learning set variables which consist of antecedent learnings which facilitate or interfere with new learning under certain instructional conditions, e.g., prior experience or information in a particular area; and (d) the ability to make the discriminations necessary to profit from instruction, e.g., aptitude in spatial visualization.

In the instructional process, just as objectives define the target behavior which is accepted as a given to be attained, so must preinstructional behavior also be accepted as a given, if one does not or cannot rigorously control or delimit student behavior up to the point of entry into instruction. The array of concepts involved in the preinstructional measurement of aptitudes, readinesses, and diagnostic measures of achievement must be systematized for theoretical development and for use in instructional design. For example, the long-term prediction by aptitude tests of achievement scores at the end of a course might be supplemented by measures of behavior which predict whether the individual can achieve the next immediate instructional step. "In certain of the new curricula, there are data to suggest that aptitude measures correlate much less with end-of-course achievement than they do with achievement in early units" (12).

While most of the available products in programed instruction show an appalling lack of recognition of differences in entering behavior, recent discussions of programed instruction are very much concerned with it. Markle points out that student variability ranges from no information to misinformation and that the majority of presently available programs in English make no provision for diagnosing and then using this diagnostic information. She says, "There can be little doubt that individualized instruction is a necessity, not a luxury, in English class. The English instructor . . . must begin at many points and go at many paces while covering a multitude of points. . . . The task is impossible." Carroll (9), in discussing implications of language development in children for teaching, says "teachers must ponder the extent to which they can . . . attempt to alter a system of habits which are not only highly practiced, but which also probably serve a supportive role in the child's adjustment to his non-school environment" (p. 342).

Stolurow and Davis consider the relationships between entering behavior, teaching strategies, and achievement outcomes. They suggest research concerned with such questions as: For specified objectives in a given subject matter, how many strategies would a computer-based instructional system need to teach effectively with a given range of student entering behavior? What are the relationships between the characteristics of certain teaching strategies and the nature of subject matter content? How do different strategies effect the ordering and dispersion of the achievement of students in a class? In discussing accommodation to individual differences, Stolurow and Davis point out that in studies that have compared programed textbooks with teaching machines, the pertinent variable does not get manipulated. In the typical machine-versus-book study, the number of teaching programs is the same, and the branching capabilities of the machine are not used, so there is no reason to expect any differences.

If the assessment of preinstructional behavior is considered to be the determination of an entering behavioral repertoire which the instructional process is designed to guide and modify, then research becomes reoriented in a number of areas. In the analysis of readiness, for example, measurement of the fact that readiness factors differ with age and with individuals must be supplemented by analyses of the conditions influencing these differences and the contribution of these differences to learning.

The approach to developmental norms requires reconsideration. When is a child "normally" capable of distinguishing a "b" from a "d" so that it is useful to teach him to learn to read? Prevailing norms necessarily assume prevailing learning conditions; however, new learning environments can change the norms. One approach for research and development in education is to adjust a learning environment to preinstructional behavior capabilities and then to study maturational limitations. A valuable discussion of the question of when to teach what has been presented by Tyler (51).

Research on aptitudes might be reoriented. If designing instructional environments for early ages is considered, it is conceivable that the "curriculum" will not be formal subject matters like mathematics or spelling, but instruction in behaviors which look more like aptitudes. For example, Skinner (41) has been concerned with teaching rhythm behavior, Holland (24) and Bijou (2) with teaching inductive reasoning, and Brinkman (4) with attempts to use programed instruction to influence scores on tests of spatial visualization. It is exciting to hypothesize that if certain of the behaviors generally classed as "aptitudes" are treated as instructional requirements in a sequence of educational progress, then teaching these behaviors, e.g., foreign language aptitude, should enhance subsequent learning and achievement.

With respect to preinstructional repertoires, the important problem is to investigate the relationships between individual differences and learning variables and, more practically, to develop techniques for the accommodation of instruction to individual differences. Work along these lines (21) points out that the identification of pertinent entering behavior can be a complex and subtle task. The determination of entering behavior that facilitates the next learning step requires the solution to difficult problems such as the identification of transfer hierarchies of learning. Furthermore, the identification of the relevant differences in preinstructional behavior when one student learns and another student does not may be extremely difficult to accomplish. Identification in nonspecific terms such as "inadequate aptitude level" or "poor motivation" does not provide the behavioral detail required for the design of an appropriate teaching sequence.

Carrying Out the Instructional Process

Once the content and component repertoires involved in terminal behavior objectives and subobjectives have been described, and once the entering behavior of the student is described, the instructional process can be implemented. For example, if a student is learning to sound out phonemes that correspond to displayed graphemes, and he does not have the pronunciation of phonemes in his repertoire, he must first be taught this. If these responses have already been learned, then instruction concentrates on bringing the pronunciation responses under the control of appropriate graphemes. In subject matter learning, the instructional process can be defined as a way of arranging the student's environment to expedite such kinds of learning which comprise subject matter competence.

At least three kinds of processes seem to be involved: (a) setting up new forms of student behavior, such as new speaking patterns or a new skill like handwriting; (b) setting up new kinds of subject matter stimulus control, for example, learning to read after having learned to speak, so that the already learned response of making speech sounds is attached to particular visual symbols; and (c) maintaining the behavior of the student. This third category is less involved with behavior change and more concerned with increasing the student's likelihood to behave and therefore often falls under the label of motivation. Brief elaboration of these general categories can be made here.

Setting Up New Forms of Response

A very evident characteristic of learning which leads to subject matter mastery is the increasing precision of the student's responses. In learning complex behavior, the student's initial performance is variable and quite crude and rarely meets the criteria of subject matter competence. Effective instructional procedure tolerates the student's initially crude responses and gradually takes him toward mastery. In order to accomplish this, the instructional process must involve the establishment of successively more rigorous standards or criteria for the learner's performance. Increasing competence in new learning is accomplished by gradually contracting the permissible margin of error, that is, contracting performance tolerances. For example, if precise timing and tempo were being taught to a student of music, it would be unrealistic to reward the student only on those rare occasions when he briefly maintained an accurate response. Since the performance of the beginning student will be quite variable, standards should be initially gross and performance criteria changed at a rate which insures continuing progress toward mastery. Each successive range of acceptable performance should include a major portion of the range of variations already in the student's performance so that there will be frequent opportunity for the reinforcement of success. Over the sequence of instruction, the range of observed performance will align itself with the particular range of acceptable performance defined as subject matter competence. In the course of the instructional sequence, a sudden or inappropriate constriction of performance criteria is one environmental change which can lead to extinction and loss of interest.

Setting Up New Kinds of Stimulus Control

While the category just described is interpreted as the operant shaping process and has been quoted as a paradigm in programed instruction, an equally if not more significant process in subject matter learning is the stimulus control of performance. Second language learning, for example, has stressed the importance of the transfer from an initial repertoire to a target repertoire. There is often the difficulty, as in teaching translation, of transferring from one stimulus class to another. The oral response "flower" has to be transferred from the English word "flower" to the German "die Blume." In learning a concept, the responses "apple," "peach," "pear," etc., are transferred as responses to the word "fruit." The restructuring of the student's entering repertoire is the pertinent instructional task, and this involves not only differentiating out new forms of response but also transferring stimulus control. With respect to this, Lane points out that the learning conditions involved in restructuring a student's initial repertoire have a limited resemblance to laboratory research on the control of behavior. He says, "Transitional behavior effected by shifting contingencies of reinforcement, patterns of discriminative stimuli, or both, is little studied and poorly understood in comparison with the shaping, maintenance, and extinction of behavior in initially naïve organisms." The transfer of stimulus control is a major process involved in teaching students to make responses to more precise subject matter discriminations and teaching them to use previously learned skills in response to new stimuli (46).

Maintaining Behavior

The processes just described of setting up new forms of response and new kinds of stimulus control assume only that the behavior of an expert in a given subject matter is characterized by the facility with which it is called out by particular subject matter contexts. A further characteristic of an expert's behavior is that it is apparently self-sustaining. The expert may continue to respond for relatively long periods of time without seeming external support and without support from aids and references that are needed by the novice. Not only is the expert's behavior guided or controlled by the subject matter, but with increasing competence it can be characterized as self-sustaining and highly independent of environmental supports. Research and development into the teaching and learning of such self-sustaining sequences is an important problem—a problem that is related to the behavior-maintaining situations which come under the labels of motivation and curiosity.

Some Conditions Influencing the Instructional Process

If it can be assumed that learning involves the kind of processes just described, attention can be turned to some conditions which influence these processes. The conditions to be described are those suggested by the work of experimental psychologists and by practical attempts at instructional programing. In discussing these conditions, it is useful to emphasize the term "transitional behavior." If an instructional sequence is concerned with modifying student performance in order to get from entering behavior to specified terminal behavior, then transitional behavior is defined as the performance carried out by the student in the course of attaining terminal behavior competence. Conceivably the stimuli involved in terminal behavior are not necessarily the most effective transitional stimuli. While it is sometimes difficult for educators to accept, efficient learning conditions for transitional behavior may be radically different from the eventual conditions under which subject matter competence occurs. As illustration of conditions influencing the instructional process which can be subjected to psychological study, the following shall be considered: sequencing, stimulus and response factors, self-monitoring, interference, and response contingencies.

Sequencing

The sequencing of transitional behavior is a condition of learning which requires detailed analysis. The notion of gradual progression in programed instruction of course is related here. However, more subtle analyses are required. Subject matter scholars frequently point out that their subject is not organized as sequentially as, say, mathematics, and that instruction cannot be so carefully sequenced; in addition, their subject matter requires that many considerations be handled at one time so that the student can perform in an integrated fashion. However, it appears that when one undertakes to lay out details in instructional sequences and establish partial attainments goals, as Markle says, the "all things at once" idea seems to fail. Decisions need to be made, on some basis, about what is to be learned before what. The sequencing requirement cuts across many areas of interest in psychological research, certainly the area of transfer, particularly transfer from the learning of one subobjective to the entering requirements for learning the next subobjective. For example, in experiments with elementary mathematics concepts (42) and with teaching time-telling (21), one is surprised by the very specific nature of transfer in young children. Generalization and transfer to new situations cannot reasonably be assumed, and the learner must be provided with conditions which facilitate generalization. As has been pointed out, the identification of the structure of subconcepts determining the nature of transfer is a central problem in learning theory related to instruction (42).

Sequencing cuts across the notion of a gradual progression of difficulty in learning hierarchies. An analysis of what is meant by "difficulty" and of the variables that influence "learning difficulty" can involve an amazing number of subject matter factors. Silberman's analysis of the factors influencing sequencing in learning to read illustrates the complexity involved. The variables he lists include word frequency, letter frequency, syntactic structure, meaningfulness, redundant patterns, pronounceability, word and sentence length, word familiarity, stimulus similarity, and grapheme-phoneme correspondences.

Sequencing requirements point up at least three general problems in designing instructional sequences: (a) regularity of structure, (b) response availability, and (c) stimulus similarity and dissimilarity. Regularity of structure refers to the structure of concept development. The neglect of this area is very forcefully brought out when one examines most present-day methods of teaching reading. There seems to be little structural regularity in the development of, say, phonemic concepts, or morphemic regularities as the former is taught in the reading program by Buchanan (8) or the latter in the word analysis program by Markle (29).

Response availability refers to the notion that the responses to be learned in the course of an instructional sequence should be available at the time these responses are to be associated with or come under the control of relevant subject matter stimuli. This is an area investigated in studies of verbal learning; for example, Underwood and Schulz (52) concluded that the pronounceability of certain verbal units is a predictor of the extent to which these units were learned in word association experiments. Response availability would seem to be neglected in instructional design. In teaching reading, for example, there is little relationship in language and syntactic patterns between the oral language of children and the material by which they learn to read. It has been suggested that a closer relationship between the two can profit from facilitation involved in response availability. In everyday school practice, experience charts take account of the availability of already strong responses. In Gagné's hierarchial charts on subobjectives (15), an important factor is response availability which facilitates the learning of the next subobjective.

Stimulus similarity and dissimilarity in the sequencing of instruction relates to such procedures as introducing subject matter content in terms of increasing similarity of form or meaning. This means that simple dissimilarities are introduced initially, and as these discriminations become learned, more difficult ones are introduced. In learning grapheme-phoneme correspondences, some programed instructional procedures take account of this by not using all of the letters of the alphabet in early reading instruction (8). It is further possible to use only maximally discriminable letters early in instruction and to reserve difficult letter discriminations until after a sizable reading vocabulary has been built up with the initially learned letters.

Stimulus and Response Factors

In addition to sequencing conditions in the instructional process, it is necessary to decide upon the specific responses that are desired and to determine what subject matter stimuli will be related to them. This matter has already been mentioned in the discussion of objectives and the analysis of behavior. Stimulus and response factors are primarily concerned with the dimensions along which the content of subject matter can be presented to the learner and the dimensions along which he can respond to it. Although some concern with stimulus and response factors has resulted in much work with visual and auditory media, as Silberman points out, the full range of these channels has not been explored. For the most part, the primary contact of the student with his subject matter in general education is through the printed page, with supplementation by audiovisual aids and field and laboratory experiences. Despite all the service that printed materials and traditional aids have provided, it seems appropriate, in the light of present engineering technology, to examine new possibilities for providing interaction between the student and his subject matter environment. It seems possible to be able to present the learner with ways of seeing and manipulating his subject matter that extend and enrich his contact with it and form a learning environment in which subject matter dimensions need not be so drastically reduced as they are when forced into a primarily paper-and-print learning environment. In engineering, the term "man-machine interface" is commonly used to describe the point at which a human comes into contact with a machine, and in engineering psychology much work has gone into the experimental analysis of the appropriate display and response characteristics by which a human can communicate with the machine and provide an optimal man-machine unit or system. The term "student-subject matter interface" can be used to express concerns similar to this in education—at least to the extent that it suggests examination of the display and response characteristics by which a student can interact with a subject matter discipline (20).

In broad outline, a learning environment consists of the display of the subject matter to the student, controls or manipulanda (e.g., a pencil or a teaching machine) by which the student works with the subject matter, and some logic between these two. If the objective of a teaching sequence is the manipulation of symbols—for example, addition and subtraction or phoneme-grapheme correspondences—what combinations of information displays are required and how should students manipulate these symbols in order to learn to generalize and apply their competence to a wide range of future instances? The manipulanda are related to the nature of the student response and also to the kind of manipulation of the subject matter required by subject matter characteristics, the nature of the learning process, and the kind of subject matter competence to be attained. For example, concepts of more or less, of speed and acceleration, of rate of change in functional relationships as related to the terms of an equation, and conceptual models in science may be taught best if the student can operate a display in which the results of manipulating a variable are shown or fed back in a dynamic fashion in terms of its influence on related variables or outcomes. This feedback requirement is an integral part of the display and response logic of an instructional interface. Feedback characteristics are dictated by the kind of logic (both subject matter and teaching logic) that is established between student response to the display and a change in the display as a result of the response.

A major research issue in the development of teaching machines is the problem of interface requirements, feasibility, and effectiveness. Teager (47) indicates the importance of the development of graphical input and output facilities in automated instructional systems that can remove the student from the restrictions of keyboards, limited sets of characters, and one-dimensional inputs. He points out that in the use of modern technology and computer-based instruction, major innovations are required in the form of input and output consoles. Work is proceeding along these lines; Licklider (27), for example, uses oscilloscope displays to teach German and the graphic representation of equations, and Uttal (53) employs an electroluminescent character generator in teaching stenotypy. The work of Licklider is a good illustration of the potential of new technological developments for an instructional interface: in a computer-based arrangement, the student works with a typewriter response unit and an oscillosope display unit. As a means of developing an understanding of the relations between symbolic and graphical representation of mathematical functions, the student types coefficients of an equation on the typewriter, and the oscilloscope screen displays the corresponding curve. This arrangement also permits the student to use the automated context for exploration of the concepts he is learning.

Self-Monitoring

Programed instruction has highlighted the importance of the study of self-monitoring and self-sustaining repertoires. Evans describes a program in which children were taught to write numbers by making only discrimination responses during the course of instruction. Throughout the programed sequence, no numbers were actually constructed by writing; the child responded with multiple-choice discriminations, either by circling a correct matching response or by pushing an appropriate button in a multiple-choice machine. A posttest showed that the children learned to write numbers fairly well. It seems that the learning of appropriate discriminations made it possible for them to monitor their own motor responses.

Markle points out that out from under the eye of the English teacher, the student is no longer subjected to differential reinforcement from the school environment. He must reinforce himself with good writing. The student must be able to make the discriminations that an English teacher would make when confronted with the material. If the discriminations involved are too difficult to be put into a program, the teacher is needed to make them. However, it may be more efficient to train the student to make these discriminations so that he can immediately reinforce himself as his progress demands. Kersh concludes from his studies that it is not difficult to train observers to identify the occurrence of hypothesis-formation behavior in problem solving from verbal reports or written notes. Since it seems possible for people to learn to recognize examples of "forming hypotheses" in the behavior of others, it should be possible for the student to learn to recognize such behavior in himself by appropriate training. Markle writes that Klaus has discussed the possibility of a program on "creative writing." In the procedure suggested, not only are there multiple right answers but also the possibility that the student will come up with an unpredicted response. This response, after it has occurred, can only be reinforced by the instructor's discriminations or by teaching the student the appropriate discriminations so that he is independent of the instructor. Even in present-day programs, the student must make appropriate fine discriminations.

The suggestion, then, is that the process of teaching new responses can be facilitated by first teaching the student to discriminate the desired response in others. Once this is done it becomes possible to teach "self-discrimination" or self-monitoring so that he may become his own observer and evaluator. Self-monitoring as a class of behavior might be strengthened with effective reinforcement for self-observation and self-error detecting.

Interference

In general, it can be stated that interference in learning is a function of competition between a response repertoire and other responses learned prior to or subsequent to it. This response competition results in forgetting and in a decreased rate of acquisition. Competing responses, when they exist in the entering behavior of the student, affect instructional design and necessitate special training sequences. For example, in order to anticipate interference in second-language discrimination training, Lane indicates that confusion matrices can be prepared and contrastive analyses undertaken prior to programing in order to identify sources of interference between entering repertoire and terminal behavior. Inappropriate sequencing also produces sources of interference. The work of Morton in foreign language training (see Lane), for example, suggests that when formal repertoires are learned first, the later introduction of meaningful utterances impairs the performance of the previously learned sound patterns.

Sources of interference in the course of instruction may be reduced by employing what Lane calls "collateral" stimuli as is done in Schaefer's redundancy programing procedure rather than direct controlling stimuli. In this procedure, German vocabulary is learned in the course of transitional behavior by utilizing the context and redundancy of English texts to provide the meaning for a foreign word in a passage of English text (17, 37). The "fading" technique frequently used in the context of operant conditioning and programed instruction is similar to this procedure as a way of transferring stimulus control in order to minimize interference effects.

Practice

Many of the early experiments in programed instruction involved the manipulation of the number of steps in a program so that programs with different numbers of frames but teaching the same things were compared. Holland's chapter indicates that the results obtained from quite a few studies along these lines cannot be unambiguously interpreted. However, they serve to make one aware of how little is known that can be applied about the variable of practice, which is an old and respectable topic in learning. With present techniques for designing programs, the amount of practice and review employed needs to be completely empirically determined and is certainly subject to individual differences. The situation is exemplified by a study in which one-fifth of the frames of a published program were removed; average performance for the original program and the shortened version showed no differences.[3]

A study completed by Reynolds and Glaser (36), in which experimental sequences in junior high school general science were imbedded in a larger general science program, investigated the amount of repetition of stimulus and response and the spacing of review sequences in the learning of technical terms in biology. The results, measured for immediate learning and retention, showed that variations in repetition had only transitory effects, but that spaced review in the course of a programed instructional sequence significantly facilitated retention of the reviewed material. Similar results in a laboratory situation have been reported by Greeno (23) in paired-associate learning with

[3] Personal communication, James R. Hawker and Lois S. Lackner, 1964.

massed and distributed repetitions of items. The results suggest that the often-criticized monotony of repetition found in many early programs may in fact be of little value in enhancing retention for certain kinds of subject matter content and may profitably be replaced by a series of short instructional sequences in several related topics, each interspersed with reviews of the preceding material.

The general conclusion is that the entire question of practice, review, and retention with *meaningful* academic subject matter needs to receive more help from experimental psychology and requires extensive investigation in both laboratory and educational contexts.

Response Contingencies

The fact is that practice as such does not change behavior, but that practice conditions which supply consequences of an individual's actions serve to modify his behavior. These response contingencies influence the course of learning. Reinforcing events which are a consequence of behavior fall into one class of response contingency. Other classes, of course, are extinction, punishment, and one that has been generally ignored in psychological study, called correction. The study of the contingent relationships between the behavior of an organism and consequent events is a key area for both basic and applied research in learning relevant to instruction. There are so many things which are not known. Many studies show the powerful influence of various reinforcing operations (e.g., 13, 26); then there are studies like that by Swets and his co-workers (45), where, in a task of categorizing the characteristics of different sounds, the authors conclude that "fairly extensive feedback may be detrimental . . . and provide no support for the hypothesis that efficiency of learning varies directly with the probability of reinforcement." As Lane indicates, such negative findings may be attributed to many sources and need to be analyzed carefully, particularly with respect to the nature of the terminal behavior and the relationship between transitional and terminal behavior. In most available small-step programed instructional sequences, response determination is a programing principle; this results in few response errors. Under these conditions a major mechanism is the occurrence of reinforcing events following an appropriate response, the crucial aspect being the contingency between the relevance of the answer and the critical subject matter content in the frame. The primary questions in programs of this sort are what factors serve as reinforcing events and what operations are involved in the reinforcement process.

Errors and Correction: If correct responses are not so highly determined as they are in a small-step linear program, then the student makes some errors. It is known, at least on a common sense basis, that individuals learn from making errors, but very little is known about the process involved and how to use error behavior efficiently. The area of response contingencies that can be called correction seems to have been neglected, if one looks at the literature. Correction refers to the contingency whereby an incorrect response is followed by a stimulus event which serves to inform the student of the nature of the correct response in such ways as telling him the right answer, showing him how to get the right answer, making him perform the correct response, and so forth. There has been work in "corrective" feedback in motor skill learning; a "correction" trial in animal learning means something different than what is meant here. There has been little work in verbal learning, even though some studies have been appearing recently. Some writers flatly assume that, in verbal learning studies, providing the correct answer following an incorrect response is a reinforcing event in the same way that confirmation following a correct response serves as a reinforcer (3).

How do students learn from their errors? Some investigators, like Kaess and Zeaman (25), when they have studied multiple-choice items with incorrect alternatives in a Pressey punchboard-type situation, conclude that incorrect alternatives increase the probability that the subject will repeat his error. Suppes and Ginsberg (43) report the desirability of overt correction procedures to facilitate learning in children. The suggestion is that there may be differences in the effects of correction between adults and children and also differences as a function of the behavior being learned. In this latter respect, formal repertoires may be learned more efficiently with highly determined correct-response reinforcement; thematic repertoires may profit from the use of corrective feedback.

The chapters by Lewis and Pask and by Evans provide provocative contrasts on the subject of errorful vs. "errorless" learning. Skinner's work has emphasized the minimization of error, and the interesting work of Terrace (48, 49) has questioned discrimination learning theories in which the extinction of responding to an inappropriate stimulus, and hence the occurrence of errors, is a necessary condition for the formation of discriminations. The general rationale for error minimization in instruction seems to be the following: (a) When errors occur, there is lack of control over the learning process, and opportunity is provided for the intermittent reinforcement of incorrect responses; this results in interference effects highly resistant to extinction. (b) Frustration and emotional effects that are difficult to control are associated with extinction and interference. And (c) richer learning, that is, richer in associations, takes place when the associative history of the learner is employed to extend his learning; this is accomplished by mediators or thematic promptings which make positive use of existing knowledge and serve to guide learning. Perhaps another reason behind the drive to minimize errors is the fact mentioned above, that the use of errors and the possible value of incorrect responses have not been as widely nor systematically investigated as other response contingencies in studies of learning related to the educational process.

Lewis and Pask make the case that error responses must be used in the course of an adaptive teaching procedure. Such a teaching procedure requires the student to reveal, by making some sort of error, the kind of instruction he should receive next. If adaptive control is competently designed, student weaknesses are revealed by his selection of response alternatives. Where no adaptive procedures are available for dealing with error, the minimization of error is forced upon a teaching procedure. Error minimization advocates might suggest that the adaptive system could do better by preventing errors from occurring in the first place. Lewis and Pask react to this by pointing out that the presence of error is tacitly acknowledged by the error minimizers when they cue or prompt in the course of a program to adjust a program to the population of students who are being taught. These nonadaptive programs remove error factors without allowing them to be manifested in the form of overt mistakes. This necessarily involves working in the dark, and hence programs which forestall error often make provisions for far more error possibilities than any one student is likely to have; they therefore consist of less-than-challenging tasks. An important area for learning research relevant to instructional practice is study of the effects of response contingencies, called correction, which follow the occurrence of incorrect responses.

Effective Reinforcers: A second broad problem that the work on programed sequences has emphasized is the question of what the effective reinforcers in a subject matter learning sequence are and the related practical problem of what reinforcing contingencies can be employed in designing instruction. As is known, reinforcement can be quite subtle. For example, Skinner points out that certain "consequences are used to motivate the beginning reader when a textbook is designed to be 'interesting.' Such reinforcement is not, however, contingent upon accuracy of response in the manner needed to shape skillful behavior" (39, p. 66). Silberman points out that an interesting text may reinforce the behavior involved in obtaining meaning from printed material, but may not differentially reinforce correct phonemic responses. Reinforcing events must be determined on the basis of detailed analysis of appropriate subject matter and component repertoire relationships. Just as one identifies what stimuli feel hot or cold, or pleasant or frightening, one needs to identify what events can serve as reinforcers for students in the course of learning certain subject matters.

Studies in learning and instruction do suggest the effectiveness of certain events as reinforcers. Some illustrative leads can be mentioned: One of the most interesting discoveries about reinforcement especially related to what has been referred to in this chapter as self-sustaining behavior repertoires has been described by Premack (35). Premack points out that of any two responses, the one that occurs more often, when both are available, can reinforce the one that occurs less often, so that, for a child, if playing is a higher strength behavior than eating, it might be used as a reinforcing event for eating behavior, or if certain words occur with a higher probability than others, they might be used as reinforcing stimuli for words that have a lower probability of occurring. Implicit in this kind of analysis of reinforcing stimuli is that the particular event that constitutes a reinforcement is not a situation external to the learner so much as it is the behavior produced by the situation. For example, it may not be the food but the eating which reinforces a hungry person; it may not be so much the achievement of the goal but the behavior produced by obtaining the goal. Thus reinforcers may be defined either in terms of behavior or in terms of stimuli; either definition may serve a particular purpose, and both are useful ways of thinking about the operation of reinforcement. If carrying out a learned performance can be reinforcing, it seems reasonable to hypothesize that in a chain of activities which terminate in a reinforcing event, each response acts as a reinforcer for previous responses. However, a response will only act as a reinforcer if it has a higher probability of occurrence than the behavior it is reinforcing. This kind of analysis suggests studies that lead to the interesting suggestion (16) that in an instructional sequence which teaches a chain of operations, e.g., long division, instruction need not proceed in the order in which the sequence is finally performed; that is, learning the first operation, A, which is performed in carrying out the chain and then learning the second operation, B, and then learning C, the third operation. Since B is a weaker response than A which was first learned, and C weaker than the others since it is newly learned in the sequence, the suggestion is that operation C be learned first, then BC (since C is a higher strength behavior that can reinforce the new response B), and then operations ABC.

Another apparently powerful reinforcer in learning is overt control of the physical environment. This has been particularly suggested by the work of Moore (33) and what he calls a responsive environment. Reinforcement of this kind seems to be related to the study of behavior generally labeled as curiosity and exploration to which an increasing amount of research has been directed within the past decade (14). In infrahuman studies, research has been aimed at the discovery and identification of variables which serve to elicit and maintain curiosity and exploratory behavior in the absence of conventional laboratory motives such as hunger or thirst or other conditions of deprivation. The specific responses which have been observed are such behaviors as orienting, approaching, investigating, manipulating, etc. The significant variables influencing such exploratory responses have been characterized as stimulus objects or patterns that are novel, unfamiliar, complex, surprising, incongruous, asymmetrical, etc. All these aspects can generally be described as a change in the stimulus displayed to the individual. Research has indicated that the strength of exploratory behavior which is elicited is positively related, within limits, to the degree of change in the stimulus situation provided by the novel, unfamiliar, or incongruous situations introduced into the environment. Too great or too abrupt a change, however, is disrupting and may preclude exploration. In complex situations, an individual encounters change by way of his interaction with or manipulation of the elements involved. Such interaction provides the stimulus change which can elicit curiosity and exploratory behavior.

Investigations have demonstrated that behaviors are learned that lead to a change in the stimulus display. Thus, in addition to stimulus change eliciting exploratory behavior, experiments show that organisms will respond in order to secure novel, unfamiliar stimuli. In general, these findings demonstrate that stimulus change or sensory variation may be employed selectively to reinforce behaviors which result in stimulus change and that this variation in the stimulus situation will serve concomitantly to elicit exploratory behavior. When stimulus change is used as a reinforcing stimulus, it seems reasonable to hypothesize that learning variables which influence acquisition and extinction of other learned behavior will influence the acquisition and extinction of exploratory and curiosity behavior. This suggests that a student's curiosity and explorations may be both elicited and selectively maintained in an instructional environment which provides for appropriate variation and change in both the stimulus characteristics of the subject materials confronting the student and also the responses required of him by these materials.

Looking over the topics and issues covered in this section on conditions influencing the learning process, one may be struck by the fact that there is no *explicit* mention of transfer or meaning and mediation effects as special topics. Transfer phenomena do represent an important class of problems which obviously has been recognized in this discussion, but the suggestion is that perhaps the notion of transfer can be more definitively analyzed in terms of the topics that are discussed. Meaning and mediation effects have been emphasized in programed instruction in terms of thematic prompting and the shaping of thematic repertories. Mediation is an increasingly busy area for experimental psychologists, and its implications for instruction need to be made more explicit. The general implication of the work by experimentalists, which can be profitable for an analysis of instructional operations, is that meaning and mediated behavior can be treated in terms of stimulus and response events which are amenable to learning processes such as discrimination, generalization, chaining, and stimulus control in a manner similar to other kinds of student responses.

Measuring Learning Outcomes

An effective technology of instruction relies heavily upon the detailed measurement of subject matter competence at the beginning, in the course of, and at the end of the educational process. The mastery of the skills and knowledge required to begin an instructional sequence and to continue along its course insures the availability of behavior on which the teacher and the student can rely in subsequent learning. Elsewhere the author (18) has pointed out that the presence of teaching machines and programed instruction has raised into prominence a number of questions concerning the nature and properties of measures of student achievement and the assessment of subject matter competence as it may be defined by recognized subject matter scholars. Achievement measurement can be defined as the assessment of criterion behavior involving the determination of the characteristics of student performance with respect to specified standards. Achievement measurement is distinguished from aptitude measurement in that the instruments used to assess achievement are specifically concerned with the properties of present performance, with emphasis on the meaningfulness of its content. In contrast, aptitude measures derive their meaning from a demonstrated relationship between present performance and the future attainment of specified knowledge and skill. In certain circumstances, of course, this contrast is not quite so clear, for example, when achievement measures are used as predictor variables.

The scores obtained from an achievement test can provide primarily two kinds of information. The first is the degree to which the student has attained criterion performance, for example, whether he can satisfactorily prepare an experimental report or solve certain kinds of word problems in arithmetic. The second is the relative ordering of individuals with respect to their test performance, for example, whether Student A can solve his problems more quickly than Student B. The principal difference between these two kinds of information lies in the standard used as a reference. The standard against which a student's performance is compared in order to obtain the first kind of information is the criterion behavior which defines increasing subject matter competence along a continuum of achievement. Criterion levels of competence can be established at any point in instruction where it is necessary to obtain information as to the adequacy of a student's performance. Behaviorally defined objectives describe the specific tasks a student must be capable of performing in order to achieve a particular knowledge or competence level. The student's score with respect to these tasks provides explicit information as to what he can or cannot do and indicates the correspondence between what the student does and the achievement criteria at that point in his learning. Measures cast in terms of such criterion standards provide information as to the degree of competence obtained by a particular student which is independent of reference to the performance of others.

On the other hand, achievement measures also convey information about the capability of a student compared with the capability of other students. In instances where a student's relative standing is the primary purpose of measurement, reference need not be made to criterion behavior. Educational achievement examinations, for example, are administered frequently for the purpose of ordering students in a class or school, rather than for assessing their attainment of specified curriculum objectives. When such norm-referenced measures are used, a particular student's achievement is evaluated in terms of a comparison between his performance and the performance of other members of the group. Such measures need provide little or no information about the degree of proficiency exhibited by the tested behaviors in terms of what the individual can do. They tell that one student is more or less proficient than another, but do not tell how proficient either of them is with respect to subject matter tasks. In large part, achievement measures currently employed in education are norm referenced, and work needs to be done which will contribute to the development of criterion-referenced tests in order to assess the outcomes of learning.

A further point along these lines relates to the fact that achievement tests are used not only to provide information about the student but also to provide information about the effects of different teaching procedures and instructional designs. It seems likely that tests which are constructed to be sensitive to individual student differences may not be the same kinds of tests which are sensitive to the differences produced by different instructional conditions. Test theory for the most part has been primarily concerned with the development of tests that are maximally sensitive to individual differences. Less work has been concerned with test development for the purpose of curriculum evaluation and curriculum design. This point is further discussed in the article referred to above (18) and more fully in an article by Cronbach

(12) concerned with course improvement through evaluation. Among many provocative statements, Cronbach writes, "I am becoming convinced that some techniques and habits of thought of the evaluation specialist are ill-suited to current curriculum studies. . . . How must we depart from the familiar doctrines and rituals of the testing game?" (p. 672) and "The three purposes—course improvement, decisions about individuals, and administrative regulation—call for measurement procedures having somewhat different qualities" (p. 677). Particularly with respect to instructional design, test data are becoming important indicators of the properties of the learning environment that effected certain behavioral changes. As Lumsdaine indicates, there is a difference between the data obtained in the course of constructing an instructional sequence and the data obtained to prove its final effectiveness. The former kind of data will become increasingly significant as the design of instruction becomes a more rigorous enterprise. Cronbach writes, "Evaluation, used to improve the course while it is still fluid, contributes more to improvement of education than evaluation used to appraise a product already placed on the market" (12, p. 675).

A final point to be made about the measurement of learning outcomes is that such measurement cannot be narrowly conceived. Other effects must be evaluated along with, for example, gains in achievement. To again quote Cronbach:

> Outcomes of instruction are multidimensional, and a satisfactory investigation will map out the effects of the course along these dimensions separately. To agglomerate many types of post-course performance into a single score is a mistake, because failure to achieve one objective is masked by success in another direction. Moreover, since a composite score embodies (and usually conceals) judgments about the importance of the various outcomes, only a report that treats the outcomes separately can be useful to educators who have different value hierarchies (12, p. 675).

Trends in Practice

The chapters surveying the use of programed instruction in schools, industry, and government agencies show somewhat different reactions from these three sources. In the federal government, utilization is active but tentative. Hopes have been high enough that disappointments have been inevitable. The guess of Bryan and Nagay is that programed instruction will increase in government agencies if it yields tangible benefits; in this respect they feel that the experience of certain present activities is critical. In industry, Shoemaker and Holt indicate a growth of acceptance that has been greater than in public education or the government (with the exception of the Air Training Command). For many industrial applications, the self-instructional, self-pacing features are highly valued. In elementary and secondary schools, Hanson and Komoski document an important trend—a trend toward increasingly effective individualization of instruction. They write:

> There should be no question that programs of the future will be designed and presented for a still greater variety of students to use them in increasingly varied ways. If research into the design and use of programed materials is carried out on a large scale, there is little doubt that the school of the not-too-distant future will be able to boast a curriculum that may be offered in as many different ways as there are pupils in the school. In such a school, each learner will seek and achieve mastery of a subject matter or a skill by proceeding along a path largely of his own choosing, a path that is neither too easy nor too difficult for him to traverse. Ideally the teacher will help the learner to discover a system of learning that suits his own capabilities. In other words, the learner will be taught how to learn; he will be provided with new tools for learning. . . . Both the techniques and the materials of learning will be very different in the schools of tomorrow, and there can be little question that today's programed instruction is helping to lay the foundation for such schools.

To be superimposed on this trend toward the self-resourceful learner is the development of group tuition systems. Lewis and Pask suggest, "The ability of one human to understand the difficulties of another derives from the richly complex ways in which they are capable of sharing common dimensions of experience. . . . But this ability is not peculiar to the teacher-student relationship. Two students can have it equally well, and this raises the possibility of a computer-controlled system which *induces students to teach each other.*"

A recurrent theme in many of the chapters in this book is the emergence of the individual as the entity of instruction. Educators and educational psychologists need to take seriously the fact of individual differences and the platitude of accommodating individual needs. The existence of individual differences must be more strongly reflected in educational design. In 1920, the insightful Pressey was keenly aware of the inefficiencies of the instructional procedures used in schools to adjust to individual differences. Kersh points out that the Winnetka

Plan of almost 40 years ago attempted to do this. He reports that Washburne, who served as the force behind it, gives the following reasons why individualized instruction had not spread more widely by 1940: (a) there were not available adequate tests and texts for individual work, (b) there was a swing away from subject matter emphasis to an emphasis on child-centered learning, and (c) there occurred the development of "compromise plans" of ability grouping and group projects in which each child could presumably participate according to his own abilities.

At present, a fresh start on research and development for instructional procedures and organizational requirements for the individualization of instruction seems possible in light of the following events: (a) increasing study of the relationships between learning and environmental factors affecting individual differences, (b) the renewed emphasis of curriculum groups on subject matter, and (c) the success of certain programed instructional materials when they are used in ways not constrained by fixed classroom groupings.

In the future, the design of instructional procedures will be modified as behavioral science and educational practice begin to be related in a mutually helpful way—a way not atypical of science and practice in other fields. As this occurs, it is hypothesized that four main areas of the educational process will be influenced: (a) the setting of instructional goals will be recast in terms of observable and measurable student behavior including achievements, attitudes, motivations, and interests; (b) the diagnosis of the learner's strengths and weaknesses prior to instruction will become a more definitive process so that it can aid in guiding the student along a curriculum specially suited for him; (c) the techniques and materials employed by the teacher will undergo significant change; and (d) the ways in which the outcomes of education are assessed, both for student evaluation and curriculum improvement, will receive increasingly more attention.

As these changes occur, it is likely that they will result in the following changes in school operation: (a) Obviously, the role of the teacher will be restructured; it seems likely that the teacher will be able to become more concerned with individual student guidance and individual progress in addition to the role of group mentor. (b) The educators' goal of the individualization of student progress based upon student background, aptitude, and achievement will come closer to realization through school reorganization and the adoption of new practices. (c) Instructional materials and devices supplied by industry will come under close scrutiny as to their instructional effectiveness. (d) Mastery of subject matter competence will be easier to attain for a larger number of students, and tests which measure progress toward mastery will become important aids for the quality control of educational excellence.

By and large the educational profession will show an increasing trend toward professionalization so that the teacher will have to be provided with tools and procedures designed on the basis of scientific research and development; the most effective use of these new designs will be influenced by the personal artistry and skill of the practitioner.

Certain other directions seem to be clearly outlined: Programed learning will continue to offer the opportunity for an investigator to obtain detailed records of a controlled reproducible sequence of instructional events in which independent and dependent variables can be manipulated to study the learning process.

The amount of research oriented toward the unsystematic empirical testing of the characteristics of instructional sequences will decrease in favor of research oriented toward theoretical derivation of the characteristics of an effective instructional sequence prior to experimental investigation.

Research on long-term, sustained educational environments will increase along with measurement of the long-range effects of these environments upon retention and transfer.

Research will increase on the application of programed instruction to training in manipulative and psychomotor skills.

Now that some dust has settled on the machine-program distinction, major effort will be devoted to the teaching hardware and automation possibilities in instruction.

Increasing attention will be paid to subject matter competence and mastery, and this will be accompanied by teaching of the heuristics of thinking and discovery.

In the foreseeable future, published instructional materials will be accompanied by manuals describing their teaching philosophy and rationale, their educational objectives, target student population, and evidence of their effectiveness and limitations. This development will be brought about by technical developments in the publication of educational material and by increasing sophistication of the educational consumer in the criteria for evaluating these materials.

There will develop a new professional specialty in education, perhaps called "educational designer," to serve the engineering function between scientific developments and teaching practice.

Increasing effort will be devoted to the determination of the quality and characteristics of ongoing educational systems. Extensive and detailed assessment will be made of educational outcomes so that these measurements can serve as baseline information for the evaluation of innovation.

In 1954, in a talk entitled, "The Science of Learning and the Art of Teaching," subsequently published in Volume I of *Teaching Machines and Programmed Learning* (40), Skinner concluded with the following:

> We are on the threshold of an exciting and revolutionary period, in which the scientific study of man will be put to work in man's best interests. Education must play its part. It must accept the fact that a sweeping revision of educational practices is possible and inevitable. When it has done this, we may look forward with confidence to a school system which is aware of the nature of its tasks, secure in its methods, and generously supported by the informed and effective citizens whom education itself will create (p. 113).

The chapters in this book give the impression that educators, subject matter scholars, and behavioral scientists have stepped over the threshold and have been invited to sit down together.

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