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ABSTRACT

A selective review of the literature on self-instructional devices is presented, with emphasis on those studies which provide for a functional analysis of such devices. Three major classes of variables which influence the effectiveness of learning by means of self-instructional devices are discussed: the characteristics of the device, the characteristics of the program, and the characteristics of the learner. Attention is devoted to an analysis of the sequencing of material which maximizes the rate of learning and degree of retention with a focus on those variables which affect this programing process. A working model of the learning process is presented which is based on the theories of conditioning. The report includes a 37 reference bibliography. (KB)

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SELF-INSTRUCTIONAL DEVICES: A REVIEW OF CURRENT CONCEPTS

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FOREWORD

This report represents a selective review of the recent literature dealing with self-instruction and the automation of teaching. This literature has grown so rapidly and so profusely of late that workers in the field have found it difficult to keep abreast of it. It is hoped that the present report will provide a summary of emerging issues and that it will serve as a point of reference for future research and development in this field.

The author wishes to acknowledge his indebtedness to the many people who have loaned him their unpublished manuscripts and who have thus, or in personal discussion, stimulated his thinking. They are too numerous to mention individually. Dr. J. B. Sidowski and Mr. F. F. Kopstein reviewed the manuscript and made several helpful suggestions.

Work on this report was originally begun because of the author's interest in self-instruction. It was later amplified and submitted to the Training Psychology Branch, Aerospace Medical Laboratory as part of the author's service as a consultant under Air Force Contract No. 33(616)-6526 with the University of Dayton. The report is published in support of Project 1710, "Human Factors in the Design of Training Equipment," Dr. Marty R. Rockway, Project Scientist, Task 77535, "Automation of Training Systems," Mr. Felix F. Kopstein, Task Scientist

ABSTRACT

A selective review of the literature on self-instructional devices is presented, with emphasis on those studies which provide for a functional analysis of such devices. Three major classes of variables which influence the effectiveness of learning by means of self-instructional devices are: characteristics of the device, characteristics of the program, and characteristics of the learner.

Major attention is devoted to an analysis of the process of programming, or the arrangement of the materials to be learned in proper sequence which maximizes rate of learning and degree of retention. Discussion is focussed on a number of variables of which the effectiveness of the process of programming might be a function. Some of these variables have not yet been subjected to experimental analysis. A working model is presented, based upon the familiar processes of conditioning.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Walter F. Grether
WALTER F. GRETHER
Director of Operations
Aerospace Medical Laboratory

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INTRODUCTION

Self-instruction holds out the promise to solve, or alleviate many of the problems that beset education and training. The primary purpose of this report is to present a review of a portion of the fast-growing literature on the design and utility of self-instructional devices. Special attention will be given to those studies which provide for a functional analysis of such devices.

Other reviewers have concerned themselves with different aspects of the literature on automated instruction. Pressey (28), Skinner (34), and Ramo (29) have written brief histories on the subject and have discussed some of its economic, social, and even political implications. Skinner (33) and Gilbert (11, 12) have present rationales for self-instructional devices, based upon generally accepted principles of learning. Finally, Porter (24) has reviewed the evaluation studies which compared the effectiveness of automated instruction with instruction by the more conventional procedures. Porter also presented an excellent system of classification of the many types of devices which have been suggested as useful adjuncts to the teaching process. The present paper will not be directly concerned with a review of these aspects of the literature.

Briefly, a self-instructional device might be thought of as an automatic tutor that presents the learner with a series of problems each requiring some appropriate action on his part. In his review of the literature on the many types of devices employed, Porter (24, pp 130-131) has listed three essential features which distinguish the self-instructional device or teaching machine from the teaching aid. First, the self-instructional device provides a sequence of problems which are designed to take the learner from a low to a high level of proficiency in a given subject. Frequently, the problems also contain information which helps the learner respond correctly. The sequence of problems is graduated carefully so that the probability of responding correctly to a given problem is quite high, provided that previous problems have been correctly answered. The sequence of problems employed in a particular learning situation is sometimes called the program.

The second essential feature of a self-instructional device is that its use requires some action by the learner at every stage of the program. With some devices the learner must answer each problem correctly before being presented with another, while other devices permit occasional errors. The latter usually provide for recycling the program. The third requirement of a teaching machine is that the device provide immediate confirmation or knowledge of results about the correctness of the learner's responses. Porter believes that devices having all three of these features might properly be called teaching devices, since no human teacher is mediate between the learner and the device. He suggests that other devices, such as textbooks, blackboards, models, and films, might best be thought of as teaching aids, since a teacher must perform one or more of the three essential functions.

PARAMETERS WHICH INFLUENCE THE EFFECTIVENESS OF SELF-INSTRUCTIONAL DEVICES

A considerable portion of the research on self-instructional devices has taken the form of evaluation studies, in which the effectiveness of teaching by machine has been compared with teaching by some more conventional method of instruction. The present writer shares with Gilbert (11, p 29) the view that while a certain amount of evaluation research is necessary in order to justify continued interest in the basic concept of automated instruction, the major portion of research effort should be devoted to an experimental analysis of the parameters which influence the effectiveness of self-instructional devices.

A distinction may be drawn among three classes of variables of which the effectiveness of automated instruction may be a function. They are characteristics of the device, of the program, and of the learner. Each of these classes of variables will be discussed in some detail, and the pertinent research findings will be summarized.

CHARACTERISTICS OF THE DEVICE

For purposes of discussion, a self-instructional device may be thought of as having four major components: (1) a display, which presents the program; (2) a response panel, which the learner uses in forming his response; (3) a confirming mechanism, which provides the learner with information as to the correctness of his response; and (4) a reinforcement mechanism, which provides the impetus for further operation of the device.* This four-fold analysis establishes a convenient framework in which to place a discussion of research on characteristics of self-instructional devices.

Display or Input Characteristics

Porter (23) has reviewed the literature on the devices which qualify as self-instructional devices, according to his criteria. No attempt will be made to describe the devices in the present paper. Suffice it to say

* The confirming and reinforcing mechanisms are assumed to be combined in some types of self-instructional devices.

that workers have used mechanical, electrical, and optical components to present materials to the learner. One very simple device seems sufficiently unique to warrant special note. Crowder (5), and Homme and Glaser (15) have developed two different types of programs in the form of radically modified textbooks.

Porter has distinguished between two important ways of presenting the program. The first way might be called "learner-paced," in which the device "waits" for the learner to respond before it reacts. Both Pressey and Skinner have made use of this technique. The second way of presenting the program might be called "machine-paced," in that a given problem is presented for a period of time and then the machine acts, whether or not the learner has responded to the problem. The well-known memory drum is an example of this latter way of presenting the program.

Gilbert (12, pp 3-6) has discussed some of the practical problems connected with the presentation of materials, but to the writer's knowledge, no investigator has compared the effectiveness of two or more methods of presenting the program to the learner. One research problem which might well receive immediate attention is the relative efficiency of group-paced (e.g., motion pictures) versus learner-paced devices. Lumsdaine (20) has pointed to some of the similarities and differences between the two types of presentation.

A great deal of research is necessary before we know much about the optimum means of presenting materials for automated instruction. It is likely that the most effective means of presenting the program will vary as a function of such other variables as the response characteristics of the device, the type and amount of subject matter to be learned, and perhaps with the characteristics of the learner.

Response or Output Characteristics

Two basically different modes of operating teaching machines have been employed. Following the lead of Pressey (27), many have used the recognition or multiple-choice method of responding. Others have employed Skinner's recommended construction or fill-in method of responding. Gilbert (12, pp 7-10) has discussed some of the practical problems connected with the two methods of responding, but no study has been found which compares them experimentally.

However, Evans, Glaser, and Homme (8) did compare the effectiveness of the construction method of responding with no overt response at all. In this experiment, two groups of subjects learned a program entitled "Fundamentals of Music." One group made one or more written responses to each problem, while the other group made no overt responses. Interestingly enough, the group which made no overt responses spent less time in learning and earned higher retention test scores than did the group which responded overtly to each problem. However, the differences were not statistically significant. This variable is worthy of more careful attention, since it is possible that at least some responses need be made only covertly.

Characteristics of the Confirming Mechanism

Gilbert (12, pp. 10-13) has defined the confirming mechanism of a teaching device as the means by which the learner receives information as to the correctness of his response to a given problem. The designers of self-instructional devices frequently assume that confirmation also provides reinforcement, which in turn produces more responses. However, the present writer agrees with Gilbert that confirming and reinforcing mechanisms might best be discussed separately, since they refer to separate classes of independent variables of which the effectiveness of automated instruction might be a function.

The confirming mechanisms employed in self-instructional devices can be varied in at least two important dimensions. First, they may vary in the type or amount of information provided to the learner; and second, they may vary in the temporal delay between the response of the learner and the delivery of the confirmation. These sub-classes of variables will be discussed separately.

Irion and Briggs (16) have described four types of confirming mechanisms appropriate to the Pressey type of self-instructional device. The first is the <u>quiz mode</u>, in which the learner, by pressing a special button, interrogates the machine as to which of the 20 options is the correct one. Immediately a light comes on to indicate the correct option. The second confirming mechanism is called the <u>modified-quiz mode</u>, in which the learner presses the button adjacent to the option which he believes is correct. If the correct option is chosen, a green light adjacent to that option comes on. If the option is incorrect, both a red "wrong" light and the green light next to the correct option come on. In order to proceed to the next problem the learner must first press the button next to the correct option. The third confirming mechanism is called the <u>practice mode</u>, in which the learner is required to keep choosing options until the correct one is chosen. The last confirming mechanism is the <u>single-try mode</u>, in which the learner can respond only once to each problem. A green light comes on if the choice is correct; if the choice is incorrect, the red light comes on. Then the next problem is presented.

Irion and Briggs compared the effectiveness of the four types of confirming mechanisms on each of three types of learning tasks: serial learning, paired-associate learning, and problem solving. Independent groups of 20 subjects each were given 20 minutes of practice under one of 12 experimental conditions. The dependent variable in the experiment was the number of errors committed on a retention test given immediately after practice and two weeks later. In general, the relative efficiency of the four types of confirming mechanisms was in the following order: quiz mode, modified-quiz mode, practice mode, and single-try mode. The amount of difference in efficiency varied as a function of the type of learning task.

Unfortunately, the types of confirmation studied by Irion and Briggs were such that a number of basic independent variables probably were included. For example, as Irion and Briggs point out, it may be that the quiz mode of confirmation proved to be generally the most effective: (1) because it permitted more practice trials per unit-time, (2) because it reduced the number of errors which could be committed, (3) because it eliminated the aversive stimulation resulting from the error buzzer, or (4) because of some combination of these variables. Although Irion and Briggs answered an important practical question, it would seem that, ultimately, the problem of optimizing the confirming mechanism of a self-instructional device must be attacked in such a fashion that the effects of each variable can be properly interpreted.

Investigators who prefer to have the learner construct his answers to problems, rather than simply recognize them, have also employed at least two types of confirming mechanisms. Skinner (33) has used a device which presents the learner with the correct answer to a problem as soon as the learner completes his response, whether or not the response is correct. By recycling the program, the learner eventually answers all problems correctly. Recently, Skinner (35) expressed dissatisfaction with this device because the second attempt to answer a given problem may be partly under the control of the previously revealed response. Skinner has also developed a device which continues to present a given problem until the learner responds correctly. These two types of confirming mechanisms parallel Irion and Briggs' quiz mode and practice mode, respectively.

Gilbert (12, pp 10-15) has discussed some of the practical problems connected with the use of the quiz mode and practice mode of responding, and he has suggested a third method of responding. It incorporates features of both the construction and the recognition methods of responding. When faced with a given problem, the learner first constructs his answer; then he views a number of alternatives and chooses the one which most closely resembles his response. The machine then informs the learner as to the correctness of his choice. Gilbert has also suggested that the confirming mechanism might present additional information at the same time it confirms the learner's response. The promise of this latter suggestion is supported in the findings of Evans, Glaser and Homme (8), who showed that the learner need not respond overtly to all of the materials in a program. To date, none of these suggestions has been subjected to experimental comparisons using the construction method of responding.

[illegible] confirmation mechanism of a self-[illegible] between the learner's [illegible]. It is frequently stated that [illegible] of automated instruction over standard [illegible] of confirmation. However, Porter [illegible] reviewed the literature on such evaluation studies [illegible] the subjects who learned by [illegible] as well as receiving it more [illegible]. [illegible], we are left without knowing much about the separate roles [illegible].

[illegible] the context of research on automated instruction [illegible] for the belief that the rate of learning is a function of [illegible] between the learner's responses and the confirmation. [illegible] learn a list of six paired-[illegible]. [illegible] received immediate confirmation. For the other [illegible], a [illegible] interposed between the disappearance of the [illegible] of the correct response. Saltzman [illegible] increase in trials to criterion for the group which [illegible] confirmation. It is possible that increasing the [illegible] learned might appreciably increase the effect of [illegible] learning time.

[illegible] between delay of confirmation and [illegible], especially since certain types of [illegible] have been considered as self-instructional devices ([illegible]). [illegible] such devices may render them capable of [illegible] of learners simultaneously. Each learner might have [illegible] panel which could be connected with a central computer. The latter would present the program and react to the responses of [illegible] at one time. The maximum number of students [illegible] would depend upon the maximum permissible delay between the responses and the confirmation.

The [illegible] of the confirming mechanism used in self-instructional devices implies that learning is most rapid when immediate confirmation follows the learner's attempt to answer a given problem. However, some recent evidence suggests that a technique called response-prompting might prove even more effective (8, 2, 4). These investigators compared the effectiveness of two procedures in a paired-associate learning situation. The confirmation technique involved the presentation of the response term after the learner had attempted a response. The prompting technique involved the presentation of the response term before the learner made his response. The results of the experiment showed that the response-prompting technique yielded faster learning that the confirmation technique. Similar results were obtained by Kopstein and Roshal (19), who also reported that the advantage of response-prompting over confirmation decreased as the degree of learning increased. Further research of the sort described here is very much needed.

Reinforcement Characteristics

The writer has distinguished between confirmation and reinforcement mechanisms inherent in teaching machines on the grounds that they refer to two distinct classes of variables which probably influence the effectiveness of automated instruction techniques. Confirming the correctness of a learner's responses to problems may be expected to be reinforcing only if the learner's motivation is intrinsic to the task being learned (16, pp 10-12).

Consideration should be given to a number of questions having to do with the reinforcing characteristics of self-instructional devices. First, it is frequently stated that perhaps the most important benefit resulting from automated instruction is the frequent reinforcement which the learner receives. However, an important question to be answered is whether the benefit results from a practice effect or from an increase in motivation-to-learn. No experiments which bear directly on this problem have been uncovered, but Michael and Maccoby (22) performed a relevant experiment on the effect of training films on test performance. These workers concluded that the benefit from audience participation seems to stem primarily from the effects of practice, and not from an increase in motivation. More research seems required on this important question within the context of automated instruction.

A second question related to reinforcing characteristics of self-instructional devices stems from a warning made by both Porter (24, p 135) and Keislar (17) of a novelty effect in connection with the use of confirmation as the sole reinforcement. It may well be that confirmation would lose its reinforcing property over a period of time. Porter (25) reports that the advantage of automated instruction over a standard method of teaching showed no diminution over a period of five months. However, more research is necessary before we can be sure that confirmation can be relied on to maintain its reinforcing property for longer periods of time.

A third question has to do with the optimal schedule of reinforcement to be employed. Most researchers agree that the program should be carefully calibrated so that the probability of the learner's answering questions correctly should be very high, resulting in a schedule approaching 100 per cent reinforcement. Skinner (33, p 45) stated that the completion of a given number of problems on his machine also constitutes reinforcement. He thinks that learners are operating under a special type of partial reinforcement schedule which has been called "reinforcement on a fixed-ratio with counter." Further, both Pressey (27) and Skinner (32) think extrinsic reinforcement might also be employed. No research has been uncovered which tells us about the optimal kinds and schedule of reinforcement to use.

Finally, one should be careful to distinguish between two kinds of events which might be reinforced. The first is responding per se, and the second is responding correctly. Presumably, the second kind of event is the proper one to reinforce. Skinner (33, p 45) reports that learners have a tendency to respond carelessly during the first cycle of the program, trusting to a look at the correct answer to clear up the assignment. He attributes this tendency to too high a level of motivation, stemming from the design of his machine, presumably the reinforcing mechanism. Skinner (33, pp 32-33) has suggested that the frequency of deliberate errors will be reduced by imposing a 5-second delay in presenting the next problem, whenever such errors occur.

It seems clear from this brief discussion that the nature of the reinforcement employed in self-instructional devices has not yet been carefully analyzed, much less adequately studied.

CHARACTERISTICS OF THE PROGRAM

Programming refers to the arrangement of materials to be learned in the order of presentation which will tend to maximize the rate of acquisition and retention. It is possible that some simple tasks require little in the way of programming, but it is very likely that the development of efficient programs to be used in the teaching of complex skills must wait on a thorough functional analysis of the characteristics of a program which influences both rate of acquisition and retention.

Attempts have been made to program many different kinds of subject matter, ranging from the teaching of contract bridge (7) to the development of managerial skills (23). However, the present paper is not concerned with the programming of any particular kind of subject matter, but rather with the characteristics which are probably common to many kinds of materials.

Skinner (32, 33) was the first investigator to give serious attention to the problem of programming for automated instruction. More recently, Gilbert (11, 12) has described in considerable detail some of the principles of program composition. In addition, Crowder (5, 6, 7), Meyer (21), Beck (1), and Glaser, Homme and Evans (13) have made important contributions to our understanding of the process. The description which follows is an attempt to synthesize some of the views of these investigators. The analysis is directly concerned with the development of verbal and symbolic skills, but it might also apply to the development of psychomotor skills.

Meyer (21) has described three major steps in composing a program for the automatic teaching of a given subject. A description of these steps may be couched in terms meaningful either to the curriculum specialist or to the psychologist. In the interest of clarity, the writer intends to use both groups of terms.

Programming as the Curriculum Specialist Views It

From the point of view of the curriculum specialist, the first step in program composing is to delineate the entire field or subject matter to be taught. Terms, methods, facts, principles, theories, etc. must be collected. (One might think of these as answers to questions which might appear on a final examination for a given course.) The second step is to ascertain the learner's level of understanding of the subject matter before any training has begun. The third step is to arrange the subject matter into a logical order which is conducive to rapid learning and good retention.

The arrangement of the subject matter into a logical order can be further analyzed into three distinct steps. First, a hierarchy of the materials must be established, so that the learner will first master elementary skills which he will later use to develop more complex ones. Second, the materials must be arranged in steps small enough to be taken readily by the learner without being so small as to impede learning. Finally, the program must provide for sufficient learning at each step in order to be sure that each step will be adequately learned. Otherwise, forgetting might well take place before the skill is put to use later in the program.

Programming as the Psychologist Views It

The psychologist who is interested in the study of the process of learning might describe in quite different terms the steps involved in composing a program for use in self-instructional devices. Presumably the psychologist's major contribution to the study of automated instruction techniques would stem from his understanding of the optimal means of effecting the transition from low to high levels of proficiency with respect to the subject matter to be learned. For this reason, a somewhat detailed analysis of the program seems required, in an effort to isolate the variables of which the effectiveness of a program might be a function.

For ease of communication, one might characterize an entire program as consisting of three types of stimulus-response connections.* <u>Terminal S-R connections</u> refer to the stimulus-response connections which we want the student to learn. <u>Initial S-R connections</u> refer to those stimuli which, at the outset of training, are already the occasions for those responses which, to some degree, approximate the responses the programmer wants to teach. Finally, <u>transitional S-R connections</u> stand for the steps

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* In this paper, the term stimulus-response connection is used only as a matter of convenience. The writer does not imply an absence of covert stimuli and/or responses which mediate the connection.

which can be expected to mediate the initial and terminal S-R connections. A number of transitional S-R connections might be required to bridge the gap between a particular pair of initial and terminal S-R connections. The first transitional S-R connections would only crudely approximate the terminal connections, both with respect to stimuli and responses; the second transitional connections would approximate the terminal connections more closely; the third even more; and so on, until the terminal S-R connections are reached. Figure 1 shows a schematic representation of this conception of a program.

$$\begin{array}{llccc}
\text{Initial stimulus-response connections} & \left\{ S - R_a, \right. & S - R_b, & \cdots & S - R_i \\
 & \quad\downarrow & \downarrow & & \downarrow \\
 & S - R_{a_1}, & S - R_{b_1}, & \cdots & S - R_{i_1} \\
 & \quad\downarrow & \downarrow & & \downarrow \\
\text{Transitional stimulus-response connections} & S - R_{a_2}, & S - R_{b_2}, & \cdots & S - R_{i_2} \\
 & \quad\vdots & \vdots & & \vdots \\
 & \quad\downarrow & \downarrow & & \downarrow \\
 & S - R_{a_n}, & S - R_{b_n}, & \cdots & S - R_{i_n} \\
 & \quad\downarrow & \downarrow & & \downarrow \\
\text{Terminal stimulus-response connections} & \left\{ S - R_A, \right. & S - R_B, & \cdots & S - R_I
\end{array}$$

Figure 1. Matrix showing the development of a program from initial stimulus-response connections, through the transitional connections, and finally approaching the terminal stimulus-response connections.

The psychologist might continue his analysis of programming by pointing to two problems connected with the ordering of materials to be used in automated instruction. First, the learner must be caused to emit the appropriate responses, and second, these responses must be brought under the control of the appropriate stimuli. Clearly, these operations cannot be performed in one great step from the initial to the terminal S-R connections. Rather, a series of intermediate steps must be established which guide the learner at every point along the way. At the outset, the program should consist primarily of initial S-R connections. The topography of these connections must undergo a systematic change to become transitional S-R connections, and these must undergo further changes, until the terminal S-R connections are reached. At least two well-known processes of conditioning seem to be involved in changing the topography of the S-R connections. They are stimulus-discrimination and response differentiation.

Various investigators have described three steps involved in guiding the learner through the program from initial S-R connections, through the transitional connections, to the terminal connections. In order to simplify matters, consider the development of only one terminal S-R connection. First, the stimulus of the initial S-R connection is paired with the stimulus of the first transitional S-R connection. (The reader will recall that the former type of stimulus is, by definition, already the occasion for the response which approximates the desired one.) When these two kinds of stimuli are paired, the learner's first response should be the response of the initial S-R connection. Gilbert (11, pp 20-23) calls this process augmenting.

The second step in the process is to extinguish the response of the initial S-R connection through non-reinforcement,* thus permitting the first transitional response to appear and be strengthened through reinforcement (Skinner, 34, p 970). The third step in the process is gradually to eliminate the stimulus from the initial S-R connection, leaving only the stimulus from the first transitional S-R connection. This process has been called fading or vanishing (34, p 972 and 11, pp 23-26). The connection is said to be established when only the stimulus from the first transitional S-R connection evokes the response from that connection.

The three steps may then be repeated by pairing the stimulus from the first transitional S-R connection with the stimulus from the second transitional S-R connection. Then, by differential reinforcement, the response of the first transitional connection is weakened and the response of the second transitional connection is strengthened. Next, fade or vanish the stimulus from the first transitional connection, leaving only the second, until the second transitional connection is firmly established. This process is repeated over and over, until finally the terminal S-R connection is established.

At least two classes of independent variables are suggested by the present analysis. The first variable has to do with the amount of stimulus-augmenting built into the program. In other words, the extent to which the correct response is prompted by stimuli which accompany the problem is a variable of which the efficiency of a program might be a function. The implication is that there is an optimum degree to which the stimulus of the first transitional S-R connection should be augmented by the stimulus of the initial S-R connection. Too high a degree of augmenting would waste learning time, while too low a degree of augmenting would result in frequent errors.

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* In this case, extinction is assumed to be either stimulus- or response-produced, and in either case, it does not necessarily require overt responses on the part of the learner.

The second variable suggested by the present analysis is the rate of fading of the augmenting stimuli, once the response of the first transitional S-R connection has been evoked. Once again, there should be an optimum rate of fading or vanishing of these augmenting stimuli. Too slow a rate of fading would waste learning time and too rapid a rate would result in frequent errors. The frequency of errors committed by the learner as he proceeds through the program can be manipulated either by varying the amount of augmenting or the rate of fading. The effect of frequency of errors upon the efficiency of a program is discussed later.

In addition to the methods already described, Skinner (33, pp 38-40), Beck (1), and others have suggested a number of techniques which might be used to evoke correct responses from the learner at every point in the program. Beck has called these rules of programming and has attempted to classify them. One technique consists of giving the learner some materials to read, either before he sets to work on the program or while he is working on it. Another technique involves the use of the context of the problem as a means of eliminating some strong competing response. For this purpose, the correct answer might require a word which rhymes with a word in the problem or which is the opposite of a word in the problem. All sorts of techniques have been suggested. It seems clear that these techniques simply provide stimuli which reduce the probability of an error response which might otherwise occur. In a sense, the techniques provide for something akin to stimulus-produced extinction.

It is clear that the conception of a program as described in this paper does violence to "programs" as they appear in real life. Skinner (35) has already noted that it is probably unwise to teach students specific responses to specific stimuli. Students should learn to respond correctly to questions about particular subject matter, but they should also be able to deal effectively with closely related materials not presented in the program, and certainly, they should learn to answer questions in their own words and not simply parrot the responses as they appeared in the program. In short, the learner must establish relations between a class of functionally equivalent stimulus events and a class of functionally equivalent responses. There, the writer would agree that it is probably impossible to specify completely the terminal S-R connections or the initial or the transitional S-R connections.

However, such considerations should not lead us to stop building models, especially if the model permits us to see more clearly some of the variables which influence behavior in a learning situation. The present analysis cannot be said to say anything new. Researchers interested in programming have already implied all of these processes. It merely summarizes their thinking to make the current issues more explicit.

It should be noted that the matrix shown in Figure 1 is defective on at least three counts. First, the matrix fails to show that some transitional S-R connections are also terminal S-R connections. Second, it fails to make clear that two or more transitional connections might be combined to form one terminal connection; and third, the matrix fails to show that a given transitional connection might play a role in the formation of more than one terminal connection. A more complex matrix could incorporate all of these features.

Sources of Error in Program Writing

It is relatively easy to describe in generalized stimulus-response terms the nature of a program to be used for the automatic teaching of a subject, but it is quite another matter to specify precisely how to go about composing one. At least five sources of error may enter into the process. First, the programmer may incorrectly specify the sum total of the terminal S-R connections to be formed. This would amount to saying that the curriculum specialist failed to delineate completely the subject matter to be taught. Second, the programmer may err in his estimate of the extent of the initial S-R connections, which amounts to saying that the curriculum specialist overestimated or underestimated the learner's level of understanding of subject matter before training has begun. Third, the programmer may not provide for sufficient conditioning of one or more transitional or terminal S-R connections. This error would be comparable to the failure on the part of the curriculum specialist to provide for sufficient training on any aspect of the subject matter. Fourth, there may be one or more defects in the order of the progression of the transitional S-R connections. In the parlance of the curriculum specialist, such a defect would amount to teaching complex skills before the learner has mastered more elementary skills which make up the complex ones. Finally, the programmer may make premature progressions in the topography of the transitional S-R connections. To the curriculum specialist, this means the level of complexity of the subject matter is being raised too rapidly and the learner cannot keep up.

In considering these five sources of error inherent in the process of composing a program, one should keep in mind the important concept of individual differences. For example, the initial S-R connections and the amount of conditioning required at each transitional step may differ considerably from one learner to another. This problem and ways of dealing with it will be examined later in this report.

Any of these five sources of error may seriously impair the effectiveness of a program to be used for automated instructional purposes, and the sheer number of sources may lead some to believe that there is little chance of writing successful programs. Indeed some of these errors have already been reported in the literature. Meyer (21) apparently overestimated the extent of the initial S-R connections. In developing a program for the teaching of arithmetic to elementary school children, she assumed that the children could match numbers which were presented as stimuli with numbers to be used as responses. The program also assumed a minimal reading vocabulary (words like "is," "here," "and," etc.). Later Meyer found that these assumptions were not warranted.

Moreover, Keislar (17), who developed a program for the teaching of certain mathematical concepts, also apparently erred either by making premature transitions of the transitional S-R connections toward the terminal connections or by failing to provide for sufficient condition once the connections had been established. Keislar reported that subjects made too many errors in going through the relatively short program. Undoubtedly, other investigators have committed one or more of the five kinds of error here described, without reporting it. Both Meyer and Keislar attributed the faulty performance of the learners to defective programs. Although such errors clearly point to the need for further research, teachers who employ the more conventional methods of instruction might be less inclined to be so self-critical.

In any event, the sources of error which enter into the composing of a program to be used in a teaching device are precisely the same ones which enter into the use of standard pedagogic methods. Further, although the evidence is far from clear-cut, it appears that when self-instructional devices are experimentally pitted against standard methods of instruction, the former prove to be the more effective (26, p 139; 8).

A FUNCTIONAL ANALYSIS OF THE PROCESS OF PROGRAMMING

Several investigators have described what have been called principles of programming and while there has been considerable overlapping, each worker has contributed something new. The present writer has attempted to incorporate into one statement the principles which have been suggested by Skinner (32), Gilbert (11, 12), Meyer (21), and Glaser, Homme and Evans (13).

However, it should be noted that these principles of programming, as stated by most workers, simply constitute problems which the programmer faces when he attempts to compose a program. As such, they offer no solutions and each programmer must solve these problems as best he can. In the interest of scientific efficiency, each of these principles might better be thought of as a class of independent variables of which the efficiency of a program might be a function. Glaser, Homme and Evans (13) appear to think of them this way, and these investigators have already begun a functional analysis of one class of variables and have suggested a line of attack upon another. Such functional analysis of the process of programming provides a convenient framework in which to summarize previous research findings and to suggest new approaches which might be taken. A description of five classes of independent variables which may influence the effectiveness of a program used in self-instructional devices follows.

1. Relevance

At the outset, the programmer must specify precisely the terminal S-R connections to be formed, i.e., what responses are to be brought under the control of what stimuli. Skinner (32, p 93) first described this principle, but the term relevance comes from Gilbert (11, pp 10-17), who stated that the problems to be presented in the program should represent the kinds of problems which you want the learner to solve, and the responses in the program should approximate the responses you want him ultimately to make.

Glaser, Homme and Evans (13) have reference to relevance variables when they speak of "behavioral end-products" and they emphasize the importance of specifying precisely what form the skills to be learned are to take. For example, the optimal properties of both the teaching device and the program are likely to depend on whether the learner is to acquire facts, solve problems, or make practical applications of the materials to be learned. This is the old problem of transfer from the learning situation to the task for which the learning is intended. Porter (24, p 136), Kendler (18), and Keislar (17) have discussed some of the problems of transfer which might arise from the use of self-instructional devices. In short, these investigators seem to be saying that a complete functional analysis of the process of programming would include consideration of the problem of transfer from the training situation to the actual task situation.

2. Availability

The programmer must also specify precisely the initial S-R connections, i.e., those connections already in the learner's repertory which approximate the terminal S-R connections and from which the transitional S-R connections are to be developed. Skinner (32, p 93) and Meyer (21) have described this principle but it seems to have been overlooked by others.

To the writer's knowledge no research has been done on the problem of specifying the initial S-R connections, on which the program is to be built. Presumably, most researchers think of this as a problem for the curriculum specialist or the psychological tester.

3. Sequence

The programmer must specify the optimum order of presentation of the transitional S-R connections which will enable the learner to proceed from the initial to the terminal S-R connections in such a way as to maximize the learner's performance on some criterial measures of learning and retention. Gilbert (11, pp 26-28) described this class of variables, but he had reference to the ordering of machine instruction with expository teaching and simulated field experience. In the present paper, this class of variables is given a broader definition to include both the views of Gilbert and those of Glaser, Homme and Evans (13).

Although no research has yet been done within the context of automated instruction on the problem of how best to order a program, two suggestions have been made. Skinner (34, p 974) thinks that, if possible, a single program should be developed through which all learners must proceed. This might be thought of as a straight-line program. On the other hand, Crowder (5, 6, 7) has developed a program which permits the branching of the subject-matter so that allowances might be made for characteristics of the individual learner. More recently, Gilbert (12, pp 19-23) has presented a rationale which gives his reasons for preferring the straight-line to the branching type of program, but he points out that the issue must ultimately be resolved by the appropriate experiments.

Whether one uses the straight-line or the branching program, the problem of sequence still remains. Proper sequence would permit the most rapid shaping of the learner's behavior and result in maximal retention. The process of shaping has been described in this report in terms of the well-known processes of stimulus discrimination and response differentiation, and the writer has proposed two independent variables of which the efficiency of a program might be a function. So far, no research of this type has been published.

4. Stepping

After the proper sequence of transitional stimulus-response connections has been developed, the programmer must specify the size-of-step from one transitional S-R connection to the next. The size-of-step can be defined operationally in at least two ways. When it is used as an independent variable in an experiment, it is usually specified as the number of steps in a program which takes the learner from the initial to the terminal stimulus-response connections (15). The greater the number of steps, the smaller the median size-of-step. When the term is used as a dependent variable, it is usually specified by the percent of incorrect responses. Thus, if learners make few error responses on a given program, the size-of-step is inferred to be small.

At one time, Skinner (34, p 975) believed that the size-of-step should be so small that the learner rarely if ever made error responses, but more recently, he has adopted the position that the optimal size-of-step is an empirical question, which may be answered by finding the size-of-step that maximizes learning and retention (35, p 1).

In one of the first experiments designed to provide a functional analysis of the process of programming, Evans, Glaser and Homme (13) investigated the effect of number of steps in a program on learning time, on the frequency of errors during learning, and on immediate and delayed test performance. Using a single program on elementary number theory, these workers varied the number of steps over four values: 30, 40, 51 and 67. Since the initial and terminal stimulus-response connections were held constant, presumably the greater the number of steps, the smaller the median size-of-step. Independent groups of five subjects each were used. The results show that, within limits, increasing the number of steps in the program resulted in decreases in the number of errors on immediate and delayed performance tests. In addition, smaller steps also resulted in less time-per-step and fewer errors during the course of learning. Evans, Glaser and Homme point out that the optimum size-of-step might be expected to vary as a function of the type of subject matter being programmed. Clearly, further research is in order before this important question can be answered unequivocally, but a start has been made.

5. Maintenance

The programmer must specify the amount of conditioning required of both transitional and terminal stimulus-response connections to guarantee adequate learning and maintenance of these connections. Gilbert (11, pp 17-20) has discussed this problem in some detail, under the principle of repetition. He states that optimum repetition requires the use of a minimum number of problems and a minimum sample of problems in a given class and a minimum amount of time invested per student which will produce a satisfactory probability of correct responses. He suggests that review materials be seeded at various points in the program to be sure that transitional stimulus-response connections will be maintained. Although the problem of repetition or maintenance lies clearly within the province of the psychologist interested in the learning process, no experiments were found on this problem as it relates to automated instruction. However, the abundant data on overlearning and underlearning (36, pp 728-732) seem appropriate.

CHARACTERISTICS OF THE LEARNER

A third major variable of which the effectiveness of automated instruction might be a function has to do with characteristics of the learner. The concept of individual differences has been implicit throughout the preceding discussion of the variables which might influence the efficiency of a program to be used for the automatic teaching of a given subject. For example, the kind and number of initial S-R connections available to the programmer for use as starting points for the program will obviously depend on the learner's previous reinforcement history. Moreover, the learner's intelligence and his aptitudes and interests with respect to the subject matter being taught might influence the characteristics of the program having to do with repetition, sequence, and stepping. Although other workers have implied that the concept of individual differences is important to a discussion of the variables which affect program efficiency, only Glaser, Homme and Evans (13) have mentioned it explicitly.

One might hypothesize that effective instructional devices might wipe out differences in achievement measures associated with intelligence or aptitude test performance. The findings of a number of experiments seem to support this hypothesis. Porter (26) found that the correlation between IQ and achievement in spelling was not significantly different from zero for a group of learners taught by a self-instructional device, but among the control subjects taught in the standard fashion, a significant positive relationship was found. Irion and Briggs (16, p 8) reported that scatter plots revealed little relationship between intelligence test scores (Otis) and retention, after learning by self-instructional devices. Ferster and Sapon (9) reported similar findings between aptitude and achievement in a course in German. Finally, Lumsdaine (20) found that the advantage of active or passive participation in a simple learning task decreased with increases in intelligence.

One explanation which might be offered to account for the decrease in correlation between achievement and intelligence or aptitude test performance is that the learning of a subject by teaching machine results in more homogeneous achievement scores. Homme and Glaser (15); and Evans, Glaser and Homme (13) report data in support of this hypothesis, but Keislar (17) found that machine instruction rendered the learners more variable on the achievement measure than the control group. Clearly, more research of this sort is necessary before we can be sure of the effects of automated instruction upon relations between achievement and its classical predictors.

Porter (26) is the only investigator who has reported on relations between a few non intellectual factors and achievement test scores earned by learners who used the teaching machine. He found no relationship between the sex of the student, the liking for the instructional method, and achievement. These and other non intellectual factors, such as level of anxiety of the learner, deserve careful attention.

It should be noted that the studies described in this section simply relate some characteristics of the learner to achievement resulting from automated instruction, as opposed to instruction by way of more standard teaching methods. While such studies shed light on this important problem, they do not touch on the possible interactions between characteristics of the learner and the other variables which influence the effectiveness of automated instruction. For example, a study relating optimum size-of-step to the intelligence of the learner seems very much in order. Such a study and others like it would add the concept of individual differences to the other classes of variables, all of which must be examined as a part of a functional analysis of automated instruction.

SUMMARY

This report has sought to review the current literature of self-instructional devices with the aim of identifying and examining significant concepts and issues. Three major parameters are thought to determine the effectiveness of self-instruction. These are (a) the characteristics of the device or situation, (b) the characteristics of the program, and (c) the characteristics of the learner.

Device characteristics are thought to be a function of display (input) characteristics, response (output) characteristics, and means for enhancing desired performance. With respect to the latter factor a distinction is made between characteristics of the confirming mechanism and characteristics of the reinforcement mechanism. Major attention was devoted to an analysis of the process of programming. Sundry variables on which the effectiveness of programs may depend were suggested and discussed. A dearth of relevant experimental studies was noted. A provisional model of the learning processes to be controlled by effective programs was presented. Finally, the effects of individual differences on self-instruction were considered.

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