TEACHING MACHINES: AN APPLICATION OF PRINCIPLES FROM THE LABORATORY¹

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Much has been said of teaching machines recently—but the emphasis has tended to be on the gadgets rather than on the much more significant development of a new technology of education initiated by B. F. Skinner (1954, 1958). The technology does use a device called a teaching machine, which presents a finely graded series of problems and provides immediate “reward” or reinforcement for the student’s correct answers. But emphasis on machines has tended to obscure the more important facets of the new technology based on application of principles from the laboratory. The machines of today are not necessarily better than those of yesterday. Indeed, adequate machines could have been built hundreds of years ago. The movement today is not simply the mechanization of teaching, but instead the development of a new technology—a behavioral engineering of teaching procedures.

The history of unsuccessful teaching machines illustrates the relatively greater importance of the technique as opposed to the gadgets. The first teaching machine was patented 93 years ago. There have since been a series of patents and a promising burst of activity initiated by Sidney Pressey (1926) in the 1920’s. None of these early efforts really caught hold. But during this period in which the idea of mechanized teaching has been latent, the science of behavior has developed principles which permit extremely precise control of behavior. This new technology is not only the so-called automation of teaching, but is an attempt to obtain the kind of behavioral control shown possible in the laboratory.

We have, of course, seen other practical applications of scientific psychology. We are all familiar with the development of a technology of testing, which permits placing an individual in situations suited to his abilities. We are also familiar with another technology called human engineering, which fits machines and jobs to the capacities of man. One places a man in a job that suits him; the other alters the job to suit the man; *neither* attempts to alter or control man’s behavior.

For years in the laboratory we have controlled the behavior of experimental subjects—both animal and human—by a widening array of principles and techniques. The new technology of education is the application of behavioral laws in modifying or controlling behavior. Such a technology became possible with the realization that we are actually referring to a verbal repertoire (Skinner, 1957) controlled by the same laws as other behavior. The old, defunct explanatory concepts of knowledge, meaning, mind, or symbolic processes have never offered the possibility of manipulation or control; but behavior, verbal or otherwise, can be controlled with ease and precision.

While machines are not the essential or defining aspect of this technology, they do play an important role in providing some of this fine control the technology requires. We will now examine several machines and notice the advantages they offer.

At Harvard there is a self-instruction room with ten booths, each containing a machine such as the one shown in Fig. 1.

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Figure 1. Student working at a write-in teaching machine.

The student gets one set of material from the attendant and places it in the machine. He closes the machine and begins his studies.

This machine presents one item of material at a time. The subject reads the statement, which has one or more words missing, and he completes it by writing in the answer space. He then raises the lever and a small shutter opens, revealing the correct answer. Simultaneously, his answer is moved under glass, where it can be read and compared with the now-exposed correct answer. After comparing his answer with the correct answer, the student indicates to the machine, with an appropriate movement of the lever, whether his answer was correct or incorrect, and the next item appears in the window. He repeats all items answered wrong after he completes the set of items. He does not repeat correctly answered items.

A critical feature of the machine is that it provides immediate reinforcement for correct answers. Being correct is known to be a reinforcer for humans. In machine teaching, reinforcement is immediate. We know from laboratory work (Perin, 1943) that a delay between a response and its reinforcement of a few seconds will greatly reduce the effectiveness of the reinforcement. Adult human subjects can sustain at least small delays; nevertheless, any delay makes reinforcement less effective.

Although other techniques such as programmed workbooks (Homme & Glaser, 1959) and flashcards are sometimes used in this new behavioral technology, they offer less control. Teaching machines eliminate undesirable forms of responses which would also be suc-

cessful in obtaining the right answer. For example, the teaching machine insures that the student answers before peeking at the indicated answer. There is a strong temptation to glance ahead with only a poorly formulated, unwritten answer when programmed workbooks or flashcards are used.

This write-in machine is a prototype of the most common machine. There is another machine used for teaching young children material which consistently has a single possible answer. In the machine the constructed answer is automatically compared with the true answer. The child is presented a problem, perhaps a statement such as $2 + 2 = ___$, and he must provide the 4. By moving a slider appropriately, he can insert the 4 into the answer space. He then turns the crank, and the next item appears immediately, so that immediate reinforcement is provided.

Both of the machines we have seen thus far require the student to compose the answer. Figure 2 shows a machine for a less mature organism who cannot yet compose an answer. This machine can be used for teaching preschool children.² There is a large top window and

Figure 2. Child working on the preverbal machine. In the upper rectangular window is a sample which is to be matched with a figure in one of the three lower windows. If the child presses the correct lower window, the material advances to the next frame. In this case, the match is in terms of form, with size and color irrelevant.

²Hively, W. An exploratory investigation of an apparatus for studying and teaching visual discrimination using preschool children. (In preparation.)

three small windows. In the large window, there is some sort of problem; and in the three smaller windows, there are three alternative choices. For example, in the machine as seen in the picture, the subject chooses one of the three alternatives which has the same form as the sample, independent, in this case, of color or size. When the correct choice is made, the next frame is presented.

A teaching machine for a still lower organism is shown in Fig. 3.

Figure 3. A pigeon "naming colors." The pigeon pecks the color name corresponding to the color of the light projected above him.

This pigeon, with the aid of a teaching machine, has learned to hit the name plaque appropriate for a color projected above him. The principal difference between this and the other machines is that food reinforcement is used. With humans, simply being correct is sufficient reinforcement—pigeons will not work for such meager gains.

Enough of machines. They should not be allowed to obscure the truly important feature of the new technology, namely, the application of methods for behavioral control in developing programs for teaching. We need to say no more about the well-known principle of immediate reinforcement. Our second principle is also well known. Behavior is learned only when it is *emitted* and reinforced. But in the classroom, the student performs very little,

verbally. However, while working with a machine, the student necessarily emits appropriate behavior, and this behavior is usually reinforced because the material is so designed that the student is usually correct. Not only is reinforcement needed for learning, but a high density of correct items is necessary because material which generates errors is punishing. Laboratory experiments (Azrin, 1956) have shown that punishment lowers the rate of the punished behavior. In our experience with teaching machines, we have also observed that students stop work when the material is so difficult that they make many errors. Furthermore, they become irritated, almost aggressive, when errors are made.

The third important principle is that of gradual progression to establish complex repertoires. A visitor once asked if Skinner had realized that pigeons were so smart before he began using them as subjects. The answer given by a helpful graduate student was that they weren't so smart before Skinner began using them. And indeed they weren't. The behavior developed in many experiments is like that developed in the classroom. Both are complex operants. Both require a careful program of gradual progression. We cannot wait for a student to describe the content of a psychology course before reinforcing the performance; nor can we wait for a pigeon to emit such an improbable bit of behavior as turning a circle, facing a disk on the wall, pecking it if lit, and then bending down to a now-exposed food tray and eating. When developing a complex performance in a pigeon, we may first reinforce simply the behavior of approaching the food tray when it is presented with a loud click. Later, the pigeon learns to peck a key which produces the click and the food tray. Still later, he may learn to peck this key only when it is lit, the peck being followed by the loud click and approach to the food tray. In the next step, he may learn to raise his head or hop from one foot to another, or walk a figure eight, in order to produce the lighted key which he then pecks; the click follows, and he approaches the food tray. This principle of gradual progression runs through many of the teaching-machine techniques. Both human and avian scholars deserve the same careful tutorage. The teaching-machine program moves in very finely graded steps, working from simple to an ever-higher level of complexity. Such a gradual development is illustrated in Table 1 by a few items taken from a psychology program.³

The principle of gradual progression serves not simply to make the student correct as often as possible, but it is also the fastest way to develop a complex repertoire. In fact, a new complex operant may never appear except through separately reinforcing members of a graded series (Keller & Schoenfeld, 1950). Only this way can we quickly create a *new pattern* of behavior. The pigeon would not have learned the complex sequence necessary to receive the food if it had not learned each step in its proper order. Obviously, a child can't begin with advanced mathematics, but neither can he begin with $2 + 2 = 4$ —even this is too complex and requires a gradual progression.

Our fourth principle is, in a sense, another form of gradual progression—one which involves the gradual withdrawal of stimulus support. This we shall call fading. This method will be illustrated with some neuroanatomy material.⁴ Figure 4A is a fully labelled cross section of the medulla oblongata. This is placed before the student while he works with a large set of items pertaining to the spatial arrangement of the various structures. For example, "posterior to the cuneate nuclei are the _____." The answer is: "the cuneate

³This program, prepared by J. G. Holland and B. F. Skinner, is entitled *A self-tutoring introduction to a science of behavior*.

⁴This material has been prepared by D. M. Brethower in collaboration with the present author, and it is being used at Harvard for research purposes.

Table 1
Items from the Psychology Program (11). These Items Illustrate
the Gradual Development of a New Concept.

Item	Correct Answer	Percentage of Students Giving the Answer
1. Performing animals are sometimes trained with "rewards." The behavior of a hungry animal can be "rewarded" with _____.	Food	96
2. A technical term for "reward" is reinforcement. To "reward" an organism with food is to _____ it with food.	Reinforce	100
3. <i>Technically</i> speaking, a thirsty organism can be _____ with water.	Reinforced	100

50. A school teacher is likely, whenever possible, to dismiss a class when her students are rowdy because she has been _____ by elimination of the stimuli arising from a rowdy class.	Reinforced	92
51. The teacher who dismisses a class when it is rowdy causes the frequency of future rowdy behavior to (1) _____, since dismissal from class is probably a(n) (2) _____ for rowdy children.	(1) Increase (2) Reinforcement	86

54. If an airplane spotter never sees the kind of plane he is to spot, his frequency of scanning the sky (1) _____. In other words his "looking" behavior is (2) _____.	(1) Decreases (2) Extinguished (or: Not Reinforced)	94

fasciluli." After many such items, he begins another set and has another picture (Fig. 4B); but now the structures before him are labelled only with initials. A new set of items again asks a long series of questions pertaining to the spatial position of the various structures. For example, "between the gracile and the trigeminal nuclei are _____." The answer is the "cuneate nuclei." After many more items, he proceeds to a new set and the next picture. This time (Fig. 4C), the picture is unlabelled. Again, he goes through a series of new items, not simple repetitions of the previous ones, but items pertaining to the same problem of the spatial location of the different structures. This set is followed by still another but with no picture at all. He is now able to discuss the spatial position of the structures without any visual representations of the structures before him. In a sense, he has his own private

Figure 4. An illustration of the technique of fading. Section A is in front of the student while he is working on the earliest items of a neuroanatomy program; Section B is in front of the student for later items; and Section C, for still later items.

map of the medulla. He may further demonstrate his newly acquired ability by accurately drawing the medulla. The neuroanatomy example is an elaborate example of fading. Fading is also applied in a more simple form in constructing verbal programs without pictorial displays. A single item may in one sentence give a definition or a general law and in a second sentence in that same item, an example in which a key word is omitted. This would be followed by a new example in the next frame, but with the definition or law lacking.

This brings us to our fifth principle: control of the student's observing and echoic behavior. In the classroom the student is often treated as though he were some kind of passive receiver of information, who can sop up information spoken by the teacher, written on the blackboard, or presented by films. But all of these are effective only insofar as the student

has some behavior with respect to the material. He must listen carefully, or read carefully, thus engaging in usually covert echoic behavior. Ineffectiveness of classroom techniques is often credited to "inattention" or poor "concentration." It has been shown (Reid, 1953; Wyckoff, 1952) that if a discrimination is to be learned, adequate observing behavior must first be established. We have further found that observing behavior, or speaking loosely, "attention," is subject to the same forms of control as other behavior (Holland, 1958). This control of observing behavior is of prime importance. When the student becomes very "inattentive" in the classroom, the teaching material flows on; but with a machine, he moves ahead only as he finishes an item. Lapses in active participation result in nothing more than the machine sitting idle until the student continues. There is, however, a more subtle aspect to the control of observing behavior than this obvious mechanical one. In many of the examples we have seen, success in answering the problem depends only on the student's careful observation of the material in front of him at the moment. This may be illustrated by more material from the psychology program. A graph showing stimulus-generalization data is in front of the student while he works on the machine. In the program he may complete a statement: "As the wave length changes in either direction from the wave length present during reinforcement, the number of responses _____." The answer is "decreases." The item serves only to control the behavior of observing the data. Of course, many more such items are used to discuss the same data.

This principle of controlled observation extends to the details of writing a single item. For example, "Two events may have a common effect. An operant reinforced with two reinforcers appropriate to different deprivations will vary with _____ deprivations." The answer is "two" or "both." Here, the programmer's choice of the omission serves to insure a careful reading of the item. *Only* those parts of an item which must be read to correctly complete a blank can safely be assumed to be learned.

Our sixth principle deals with discrimination training. In learning spoken languages, for example, it is necessary to be able to identify the speech sounds. A student may listen to a pair of words on a special phonograph which repeats the passage as many times as he desires. The visual write-in machine instructs him to listen to a specific passage. For example, the student may hear two words such as: "sit, set." He listens as many times as he needs and then writes the phonetic symbols in the write-in machine. He then operates the machine, thereby exposing the true answer and providing immediate reinforcement for his correct discrimination.

However, little academic education is *simple* discrimination. More often, it is abstraction or concept formation. An abstraction is a response to a single isolated property of a stimulus. Such a property cannot exist alone. Redness is an abstraction. Anything that is red has other properties as well—size, shape, position in space, to name a few. There are red balls, red cars, red walls. The term red applies to all of them, but not to green balls, blue cars, or yellow walls. To establish an abstraction (Hovland, 1952, 1953), we must provide many examples. Each must have the common property, but among the various examples there must be a wide range of other properties. This is best illustrated by examples from the preverbal machine shown in Fig. 5.

These are from a program⁵ which teaches a child to respond to the abstract property of form. In each item, the upper figure is the sample and the lower three are the alternatives. While developing a program for establishing an abstraction, we remember our earlier prin-

⁵This program was prepared by B. F. Skinner.

Figure 5. Selected items from a program which teaches young children to respond in terms of the abstract property of form. The upper rectangle in each of the frames is the sample. The child must pick the alternative which corresponds to the sample in form. The color of each letter, as it appeared in the program, is indicated by the various shaded areas.

ciples and move through a gradual progression. The first several items would be like the first one; here, there is a sample and a single match, the other two being blank. The sample and its match are exactly alike at this stage. After many such items, we would begin to have others like the next one, in which the sample and its match again correspond in size, color, and form—but an additional incorrect alternative has been added which differs from the sample in all these aspects. Later, we move on to frames with three choices; again, the sample and its match correspond exactly. Next, the sample and the match may differ in some property such as color, in the case of the next item shown, or size in the next. It is essential that the program contain many items among which the sample and correct match differ in all properties except the one providing the basis for the abstraction. Otherwise, the abstraction will be incomplete because the extraneous property will share some of the control over the abstract response. As we move on with additional examples, the sample and the correct match differ both in color and in size, and the incorrect alternatives are beginning to share some of the extraneous properties with the sample. The student continues with many such problems in which the only common property between the sample and the correct match is the shape, regardless of size and color. Even now our abstraction may be incomplete. We have kept the figures in only one orientation. Therefore, we also have a series in which the samples are rotated as in the next item. A great deal of academic education consists of trying to teach abstractions. Concepts such as force, reinforcement, supply and demand, freedom, and many, many other possible examples are all abstractions. Furthermore, in the academic setting, the student seldom adequately forms abstractions. The trigonometry student commonly uses triangles with the right angle as one of the two

lower angles. If the triangle is rotated 90° , so that the right angle is upward, the student often does not recognize it as a right triangle. Neither is an abstraction developed simply by learning a definition. The psychology student who learns the definition of reinforcement in formal terms and is acquainted with a laboratory example of food reinforcement may not realize the horrible consequences of sending his girl friend flowers to end an argument. Thus, in the psychology program, we follow the pattern in the preverbal example to develop a new concept. Wide ranges of examples are analyzed which differ in as many aspects as possible, each still having the common property which characterizes the concept.

The last principle I shall discuss is really a question of a methodology which has served so well in the laboratory. This principle is to let the student write the program. A few years ago, the cartoon shown in Fig. 6 was published in the *Columbia Jester*.

"Boy, do we have this guy conditioned. Every time I press the bar down he drops a pellet in."

Figure 6.

The rat leaning on the bar is saying to the other rat: "Boy, do we have this guy conditioned. Every time I press the bar down, he drops a pellet in." Although said in jest, it is true that the rat controls the experimenter's behavior. When interesting things are observed about the rat's behavior, the control circuits are rewired to investigate the interesting new facet of behavior. In a sense, the rat is wiring the control circuit. Similarly, the behavioral engineer who prepares good teaching-machine material must be under the control of the student's responses. When the student has trouble with part of a program, the programmer must correct this. The student's answers reveal ambiguities in items; they reveal gaps in the program and erroneous assumptions as to the student's background. The answers will show when the program is progressing too rapidly, when additional prompts are necessary, or when the programmer should try new techniques. When unexpected errors are made, they indicate deficiencies *not* in the student but in the program.

The most extensive experience with this principle of modifying the program to fit the student has been at Harvard with the psychology program. In 1958, we had a program consisting of 48 disks or lessons of 29 frames each. After using the program and making a

Table 2
A Comparison of the Students' Errors in Using the Revised (1959)
and Unrevised (1958) Program in Psychology

	Percent Errors	Percent Items Improperly Scored by Students
1958	20.1	3.6
1959	11.0	1.4

detailed, item-by-item analysis of the students' answers, we diagnosed the particular deficiencies in the program and revised it accordingly. The program was also extended to cover a larger amount of subject matter; and in 1959, it consisted of 60 disks. You have already seen a few items from the course. After using the revised material in 1959, we evaluated the extent of its improvement. The next figure shows the percentage of errors on the first 20 disks for each of the 2 years.

The revision eliminated about half the errors. The last column of the table gives percentage of improper self-scoring by the students. Revision also cut these scoring errors approximately in half. Furthermore, the revision decreased the time required to complete the material. Although the second year's material had more disks—60 as opposed to 48—it actually required the average student about 1 hour less to complete the work than the shorter, first version had done. Frequency distributions on the median times in minutes for completion of the various disks are shown in Fig. 7. These are the times required for the

Figure 7. Frequency distributions for the median times to complete the disks or "lessons" for the revised (1959) and unrevised (1958) psychology program. Raw frequencies were converted to percentages to equate the area under the curves.

median student to move through each set of material answering every item once and to repeat items answered incorrectly. Notice the considerable time required for many disks in the first year's material. Primarily, this was because students repeated the larger number of items missed in the first cycle.

But the improved material provided faster performance, even when the delay due to repetition of incorrectly answered items is not considered. The frequency distributions for the first cycle only are provided in Fig. 8.

Figure 8. Frequency distributions for the median times to complete only the first cycles for the revised (1959) and unrevised (1958) psychology program. Raw frequencies were converted to percentages to equate the area under the curves.

These data exclude the time used in repeating items. Here, too, the revision produced slightly more rapid progress.

Such careful tailoring of material to fit the student is impossible with most teaching techniques. With teaching machines, as in no other teaching technique, the programmer is able to revise his material in view of the students' particular difficulties. The student can write the program; he cannot write the textbook.

We have seen that the principles evolved from the laboratory study of behavior have provided the possibility for the behavioral engineering of teaching. This new technology is thoroughly grounded in some of the better-established facts of behavioral control. The future of education is bright if persons who prepare teaching-machine programs appreciate this, and appropriately educate themselves in a special, but truly *not* esoteric, discipline. But it is vital that we continue to apply these techniques in preparing programs. The ill-advised efforts of some of our friends, who automatize their courses without adopting the new technology, have an extremely good chance of burying the whole movement in an avalanche of teaching-machine tapes.

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