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THE TECHNOLOGY OF TEACHING

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THE TECHNOLOGY OF TEACHING

More than sixty years ago, in his *Talks to Teachers on Psychology* (23), William James said:

> You make a great, a very great mistake, if you think that psychology, being the science of the mind's laws, is something from which you can deduce definite programs and schemes and methods of instruction for immediate schoolroom use. Psychology is a science, and teaching is an art; and sciences never generate arts directly out of themselves. An intermediary inventive mind must make the application, by using its originality.

In the years which followed, educational psychology and the experimental psychology of learning did little to prove him wrong. As late as 1962, an American critic, Jacques Barzun (2), asserted that James's book still contained "nearly all that anyone need know of educational method."

Speaking for the psychology of his time James was probably right, but Barzun was clearly wrong. A special branch of psychology, the so-called experimental analysis of behavior, has produced if not an art at least a technology of teaching from which one can indeed "deduce programs and schemes and methods of instruction." The public is aware of this technology through two of its products, teaching machines and programmed instruction. Their rise has been meteoric. Within a single decade hundreds of instructional programs have been published, many different kinds of teaching machines have been offered for sale, and societies for programmed instruction have been founded in a dozen countries. Unfortunately, much of the technology has lost contact with its basic science.

Teaching machines are widely misunderstood. It is often supposed that they are simply devices which mechanize functions once served by human teachers. Testing is an example. The teacher must discover what the student has learned and can do so with the help of machines; the scoring of multiple-choice tests by machine is now common. Nearly 40 years ago Sidney Pressey (35) pointed out that a student learned something when told whether his answers are right or wrong and that a *self*-scoring machine could therefore teach. Pressey assumed that the student had studied a subject before coming to the testing machine, but some modern versions also present the material on which the student is to be tested. They thus imitate, and could presumably replace, the teacher. But holding a student responsible for assigned material is not teaching, even though it is a large part of modern school and university practice. It is simply a way of inducing the student to learn without being taught.

Machines also have the energy and patience needed for simple exercise or drill. Many language laboratories take the student over the same material again and again, as only a dedicated private tutor could do, on some theory of "automaticity." These are all functions which should never have been served by teachers in the first place, and mechanizing them is small gain.

The programming of instruction has also been widely misunderstood. The first programs emerging from an experimental analysis of behavior were copied only in certain superficial aspects. Educational theorists could assimilate the

principles they appeared to exemplify to earlier philosophies. Programmed instruction, for example, has been called Socratic. The archetypal pattern is the famous scene in the *Meno* in which Socrates takes the slave boy through Pythagoras's theorem on doubling the square. It is one of the great frauds in the history of education. Socrates asks the boy a long series of leading questions and, although the boy makes no response which has not been carefully prepared, insists that he has told him nothing. In any case the boy has learned nothing; he could not have gone through the proof by himself afterwards, and Socrates says as much later in the dialogue. Even if the boy had contributed something to the proof by way of a modest original discovery, it would still be wrong to argue that his behavior in doing so under Socrates's careful guidance resembled Pythagoras's original unguided achievement.[1]

Other supposed principles of programming have been found in the writings of Comenius in the seventeenth century—for example, that the student should not be asked to take a step he cannot take—and in the work of E. L. Thorndike, who more than fifty years ago pointed to the value of making sure that the student understood one page of a text before moving on to the next. A good program does lead the student step by step, each step is within his range, and he usually understands it before moving on; but programming is much more than this. What it is, and how it is related to teaching machines, can be made clear only by returning to the experimental analysis of behavior which gave rise to the movement.

OPERANT CONDITIONING

An important process in human behavior is attributed, none too accurately, to "reward and punishment." Thorndike described it in his Law of Effect. It is now commonly referred

[1]Cohen has prepared a program of sixteen items which successfully taught the theorem to twenty-seven out of thirty-three undergraduate students in psychology (11).

to as "operant conditioning"—not to be confused with the conditioned reflexes of Pavlov. The essentials may be seen in a typical experimental arrangement. Figure 7 shows a hungry rat in an experimental space which contains a food dispenser. A horizontal bar at the end of a lever projects from one wall. Depression of the lever operates a switch. When the switch is connected with the food dispenser, any behavior on the part of the rat which depresses the lever is, as we say, "reinforced with food." The apparatus simply makes the appearance of food *contingent upon* the occurrence of an arbitrary bit of behavior. Under such circumstances the probability that a response to the lever will occur again is increased (44).

The basic contingency between an act and its consequences has been studied over a fairly wide range of species. For example, pigeons have been reinforced for pecking at transilluminated disks (Figure 8), monkeys for operating toggle switches which were first designed for that more advanced primate, man. Reinforcers which have been studied include water, sexual contact, the opportunity to act aggressively, and—with human subjects—approval of one's fellow men and the universal generalized reinforcer, money.

The relation between a response and its consequences may be simple, and the change in probability of the response is not surprising. It may therefore appear that research of this sort is simply proving the obvious. A critic has recently said that King Solomon must have known all about operant conditioning because he used rewards and punishment. In the same sense his archers must have known all about Hooke's Law because they used bows and arrows. What is technologically useful in operant conditioning is our increasing knowledge of the extraordinarily subtle and complex properties of behavior which may be traced to subtle and complex features of the contingencies of reinforcement which prevail in the environment.

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FIGURE 7. Rat pressing a horizontal bar attached to a lever projecting through the wall. The circular aperture below and to the right of the bar contains a food dispenser.

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FIGURE 8. Pigeon pecking a translucent disk. The square aperture below contains a food dispenser.

We may arrange matters, for example, so that the rat will receive food only when it depresses the lever with a given force. Weaker responses then disappear, and exceptionally forceful responses begin to occur and can be selected through further differential reinforcement. Reinforcement may also be made contingent upon the presence of stimuli: depression of the lever operates the food dispenser, for example, only when a tone of a given pitch is sounding. As a result the rat is much more likely to respond when a tone of that pitch is sounding. Responses may also be reinforced only intermittently. Some common schedules of reinforcement are the subject of probability theory. Gambling devices often provide for the reinforcement of varying numbers of responses in an unpredictable sequence. Comparable schedules are programmed in the laboratory by interposing counters between the operandum and the reinforcing device. The extensive literature on schedules of reinforcement also covers intermittent reinforcement arranged by clocks and speedometers (16).

A more complex experimental space contains two operanda—two levers to be pressed, for example, or two disks to be pecked. Some of the resulting contingencies are the subject of decision-making theory. Responses may also be chained together, so that responding in one way produces the opportunity to respond in another. A still more complex experimental space contains two organisms with their respective operanda and with interlocking schedules of reinforcement. Game theory is concerned with contingencies of this sort. The study of operant behavior, however, goes beyond an analysis of possible contingencies to the behavior generated.

The application of operant conditioning to education is simple and direct. Teaching is the arrangement of contingencies of reinforcement under which students learn. They learn without teaching in their natural environments, but teachers arrange special contingencies which expedite learning, hastening the appearance of behavior which would otherwise be acquired slowly or making sure of the appearance of behavior which might otherwise never occur.

A teaching machine is simply any device which arranges contingencies of reinforcement. There are as many different kinds of machines as there are different kinds of contingencies. In this sense the apparatuses developed for the experimental analysis of behavior were the first teaching machines. They remain much more complex and subtle than the devices currently available in education—a state of affairs to be regretted by anyone who is concerned with making education as effective as possible. Both the basic analysis and its technological applications require instrumental aid. Early experimenters manipulated stimuli and reinforcers and recorded responses by hand, but current research without the help of extensive apparatus is unthinkable. The teacher needs similar instrumental support, for it is impossible to arrange many of the contingencies of reinforcement which expedite learning without it. Adequate apparatus has not eliminated the researcher, and teaching machines will not eliminate the teacher. But both teacher and researcher must have such equipment if they are to work effectively.

Programmed instruction also made its first appearance in the laboratory in the form of programmed contingencies of reinforcement. The almost miraculous power to change behavior which frequently emerges is perhaps the most conspicuous contribution to date of an experimental analysis of behavior. There are at least four different kinds of programming. One is concerned with generating new and complex patterns or "topographies" of behavior. It is in the nature of operant conditioning that a response cannot be reinforced until it has occurred. For experimental purposes a response is chosen which presents no problem (a rat is likely to press a sensitive lever within a short time), but we could easily specify responses which never occur in this way. Can they then never be reinforced?

A classroom demonstration of the programming of a rare topography of response was mentioned on page 10. A hungry pigeon is placed in an enclosed space where it is visible to the class. A food dispenser can be operated with a handswitch held by the demonstrator. The pigeon has learned to eat from the food dispenser without being disturbed by its operation, but it has not been conditioned in any other way. The class is asked to specify a response which is not part of the current repertoire of the pigeon. Suppose, for example, it is decided that the pigeon is to pace a figure eight. The demonstrator cannot simply wait for this response to occur and then reinforce it. Instead he reinforces any current response which may contribute to the final pattern—possibly simply turning the head or taking a step in, say, a clockwise direction. The reinforced response will quickly be repeated (one can actually see learning take place under these circumstances), and reinforcement is then withheld until a more marked movement in the same direction is made. Eventually only a complete turn is reinforced. Similar responses in a counterclockwise direction are then strengthened, the clockwise movement suffering partial extinction. When a complete counterclockwise movement has thus been shaped, the clockwise turn is reinstated, and eventually the pigeon makes both turns in succession and is reinforced. The whole pattern is then quickly repeated, QED. The process of shaping a response of this complexity should take no more than five or ten minutes. The demonstrator's only contact with the pigeon is by way of the handswitch, which permits him to determine the exact moment of operation of the food dispenser. By selecting responses to be reinforced he improvises a program of contingencies, at each stage of which a response is reinforced which makes it possible to move on to a more demanding stage. The contingencies gradually approach those which generate the final specified response.

This method of shaping a topography of response has been used by Wolf, Mees, and Risley (65) to solve a difficult behavior problem. A boy was born blind with cataracts. Before he was of an age at which an operation was feasible, he had begun to display severe temper tantrums, and after the operation he remained unmanageable. It was impossible to get him to wear the glasses without which he would soon become permanently blind. His tantrums included serious self-destructive behavior, and he was admitted to a hospital with a diagnosis of "child schizophrenia." Two principles of operant conditioning were applied. The temper tantrums were extinguished by making sure that they were never followed by reinforcing consequences. A program of contingencies of reinforcement was then designed to shape the desired behavior of wearing glasses. It was necessary to allow the child to go hungry so that food could be used as an effective reinforcer. Empty glasses frames were placed about the room and any response which made contact with them was reinforced with food. Reinforcement was then made contingent on such activities as picking up the frames and carrying them about, in a programmed sequence. Some difficulty was encountered in shaping the response of putting the frames on the face in the proper position. When this was eventually achieved, the prescription lenses were put in the frames. A cumulative curve (Figure 9) shows the number of hours per day the glasses were worn, the final slope of which represents essentially all the child's waking hours.

Operant techniques were first applied to psychotic subjects in the pioneering work of Lindsley (26). Ayllon and Azrin and others have programmed contingencies of rein-

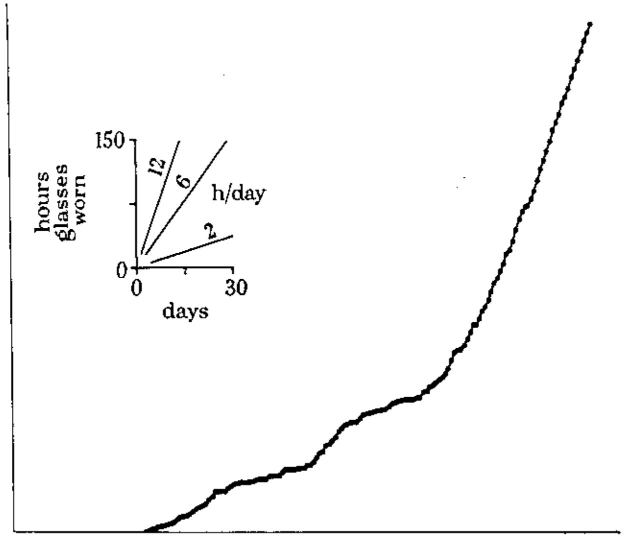

FIGURE 9. Curve showing the number of hours per day during which glasses were worn, plotted cumulatively. The final slope is about 12 hours per day. (After Wolf, Mees, and Risley.)

forcement to solve certain management problems in institutions for the psychotic (1). The techniques are not designed to cure psychoses but to generate trouble-free behavior. In one experiment a whole ward was placed on an economic basis. Patients were reinforced with tokens when they behaved in ways which made for simpler management, and in turn they paid for services received, such as meals or consultations with psychiatrists. Such an economic system, like any economic system in the world at large, represents a special set of terminal contingencies which in neither system guarantees appropriate behavior. The contingencies must be made effective by appropriate programs.

OTHER KINDS OF PROGRAMS

A second kind of programming is used to alter temporal or intensive properties of behavior. By differentially reinforcing only the more vigorous instances in which a pigeon pecks a disk and by advancing the minimum requirement very slowly, a pigeon can be induced to peck so energetically that the base of its beak becomes inflamed. If one were to begin with this terminal contingency, the behavior would never develop. There is nothing new about the necessary programming. An athletic coach may train a high jumper simply by moving the bar higher by small increments, each setting permitting some successful jumps to occur. But many intensive and temporal contingencies—such as those seen in the arts, crafts, and music—are very subtle and must be carefully analyzed if they are to be properly programmed.

Behavior is often effective only if properly timed. Individual differences in timing, ranging from the most awkward to the most skillful performances, affect choices of career and of artistic interests and participation in sports and crafts. Presumably a "sense of rhythm" is worth teaching, yet practically nothing is now done to arrange the necessary contingencies. The skilled typist, tennis player, lathe operator, or musician is, of course, under the influence of reinforcing mechanisms which generate subtle timing, but many people never reach the point at which these natural contingencies can take over.

A relatively simple device supplies the necessary contingencies (Figure 10). The student taps a rhythmic pattern in unison with the device. "Unison" is specified very loosely at first (the student can be a little early or late at each tap) but the specifications are slowly sharpened. The process is repeated for various speeds and patterns. In another arrangement, the student echoes rhythmic patterns sounded by the machine, though not in unison, and again the specifications for an accurate reproduction are progressively sharpened. Rhythmic patterns can also be brought under the control of a printed score.

Another machine has been designed in which a child

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FIGURE 10. A machine to teach "a good sense of rhythm." The child presses a button in unison with a series of clicks, presented at different speeds and in different patterns. Coincidences are reported by a flashing light. The machine can adjust the tolerance which defines a coincidence.

FIGURE 11. A machine to teach "musical thinking." The machine plays single notes, intervals, melodies, and so on. Keys may be lighted to indicate a set from which matching choices are to be made. Incorrect keys are silent. Correct matches may be reinforced additionally through the operation of the dispenser on the top of the machine which delivers tokens, candies, or coins. *Will Rapport*

learns to "think musically." He has access to a small keyboard on which an even smaller selection of keys may be indicated (Figure 11). In one arrangement, the device sounds a tone, and the child must strike the key producing a tone of the same pitch. Only the correct key may produce a tone. In another setting, the machine may sound one of two tones and indicate two keys. The child is to respond to the proper key. At first the tones are quite different, but they approach each other as the child learns to match pitch by pressing the proper key. The device can teach intervals, melodies, and so on.

Another kind of programming is concerned with bringing behavior under the control of stimuli. We could determine a rat's sensitivity to tones of different pitches by reinforcing responses made when one tone is sounding and extinguishing all responses made when other tones are sounding. We may wish to avoid extinction, however; the organism is to acquire the discrimination without making any "errors." An effective procedure has been analyzed by Terrace (58, 59). Suppose we are to condition a pigeon to peck a red disk but not a green. If we simply reinforce it for pecking the red disk, it will almost certainly peck the green as well and these errors must be extinguished. Terrace begins with disks which are as different as possible. One is illuminated by a red light, but the other is dark. Although reinforced for pecking the red disk, the pigeon is not likely to peck the dark disk, at least during a period of a few seconds. When the disk again becomes red, a response is immediately made. It is possible to extend the length of time the disk remains dark. Eventually the pigeon pecks the red disk instantly, but does not peck the dark disk no matter how long it remains dark. The important point is that it has never pecked the dark disk at any time. A faint green light is then added to the dark disk. Over a period of time the green light becomes brighter and eventually is as bright as the red. The pigeon now responds instantly to the red disk but not to the green *and has never responded to the green.*

A second and more difficult discrimination can then be taught without errors by transferring control from the red and green disks. Let us say that the pigeon is to respond to a white vertical bar projected on a black disk but not to a horizontal. These patterns are first superimposed upon red and green backgrounds, and the pigeon is reinforced when it responds to red-vertical but not to green-horizontal. The intensity of the color is then slowly reduced. Eventually the pigeon responds to the black and white vertical bar, does not respond to the black and white horizontal bar, *and has never done so.* The result could perhaps be achieved more rapidly by permitting errors to occur and extinguishing them, but other issues may need to be taken into account. When extinction is used, the pigeon shows powerful emotional responses to the wrong stimulus; when the Terrace technique is used it remains quite indifferent. It is, so to speak, "not afraid of making a mistake." The difference is relevant to education, where the anxiety generated by current methods constitutes a serious problem. There are those who would defend a certain amount of anxiety as a good thing, but we may still envy the occasionally happy man who readily responds when the occasion is appropriate but is otherwise both emotionally and intellectually disengaged. The important point is that the terminal contingencies controlling the behavior of both anxious and nonanxious students are the same; the difference is to be traced to the program by way of which the terminal behavior has been reached.

The discriminative capacities of lower organisms have been investigated with methods which require very skillful programming. Blough (6), for example, has developed a technique in which a pigeon maintains a spot of light at an intensity at which it can just be seen. By using a range of

monochromatic lights he has shown that the spectral sensitivity of the pigeon is very close to that of man. Several other techniques are available which make it possible to use lower organisms as sensitive psychophysical observers. They are available, however, only to those who understand the principles of programming.

A "discriminating" person can tell the difference between colors, shapes, and sizes of objects; he can identify three-dimensional forms seen from different aspects; he can find patterns concealed in other patterns; he can identify pitches, intervals, and musical themes and distinguish between various tempos and rhythms—all of this in an almost infinite variety. Discriminations of this sort are essential in science and industry and in everyday life as in identifying the school of a painter or the period of a composer. The remarkable fact is that the necessary contingencies of reinforcement are quite rare in the environment of the average child. Even children who are encouraged to play with objects of different sizes, shapes, and colors and given a passing acquaintance with musical patterns are seldom exposed to the precise contingencies needed to build subtle discriminations. It is not surprising that most of them move into adulthood with largely undeveloped "abilities." Relatively simple machines should remedy the defect. The machine shown in Figure 12 teaches the child to discriminate properties of stimuli while "matching to sample." Pictures or words are projected under translucent windows, which respond to the touch by closing circuits. A child can be made to "look at the sample" by requiring him to press the sample window at the top. He is reinforced for this response by the appearance of material in the lower windows from which a choice is to be made. He identifies corresponding material by pressing one of the lower windows and is reinforced again—possibly simply by the appearance of new material. If he presses a wrong window, the

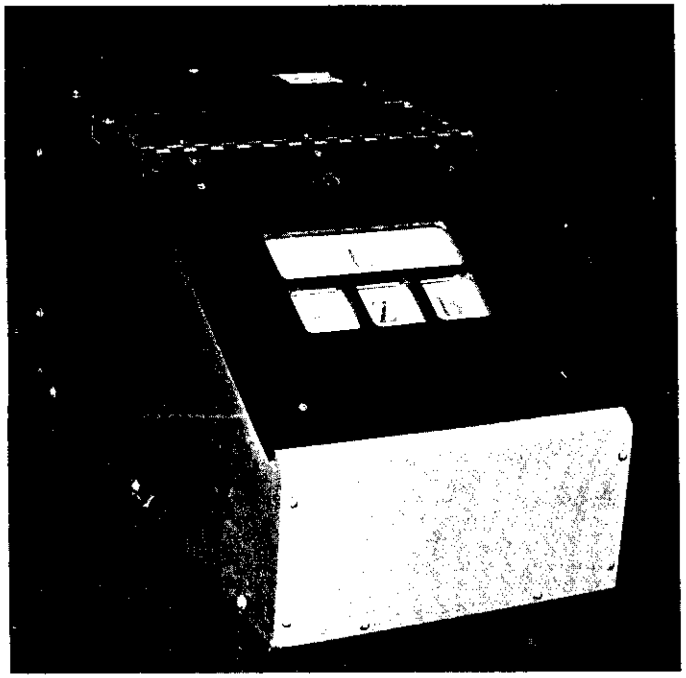


FIGURE 12. Early model of a machine to teach matching to sample or learning conventional correspondences among patterns. The sample appears in the top window, the choices below. Pressing the window over the correct choice causes the machine to move new material into place.

choices disappear until he presses the top window again—in the course of which he again looks at the sample. Many other arrangements of responses and reinforcements are, of course, possible. In an improved version of this machine (Figure 13) auditory stimuli can be generated by pressing sample and choice buttons. If devices of this sort were generally available in nursery schools and kindergartens, children would be far more skillful in dealing with their environments. All young children are now "disadvantaged" in this respect.

Some current work by Sidman and Stoddard provides a dramatic example of programming a subtle discrimination in

FIGURE 13. A more recent model of a machine to teach matching or related patterns. The machine presents auditory patterns as well as visual. Correct responses move new material into place. The machine can be used to teach both auditory and visual aspects of verbal behavior, music, and so on. It also teaches in the manner of the machines shown in Figures 4 and 5, a strip of paper being exposed at the right.

a microcephalic idiot. At the start of the experiment their subject (Figure 14) was 40 years old. He was said to have a mental age of about 18 months. He was partially toilet trained and dressed himself with help. To judge from the brain of his sister, now available for postmortem study, his brain is probably about one-third the normal size. Sidman and Stoddard investigated his ability to discriminate circular forms projected on translucent vertical panels (42). Small pieces of chocolate were used as reinforcers. At first any pressure against a single large vertical panel (Figure 15A) operated

FIGURE 14. Microcephalic idiot, 40 years old, operating a complex apparatus used to teach form discrimination. (After Sidman and Stoddard.)

the device which dropped a bit of chocolate into a cup within reach. Though showing relatively poor motor coordination, the subject eventually executed the required, rather delicate response. The panel was then subdivided into a three-by-three set of smaller panels (not easily seen in Figure 14, but represented schematically in Figure 15B), the central panel not being used in what follows. The subject was first reinforced when he pressed any of the eight remaining panels. A single panel was then lit at random, a circle being projected on it (Figure 15C). The subject learned to press the lighted panel. Flat ellipses were then projected on the other panels at a low illumination (Figure 15D). In subsequent settings the ellipses, now brightly illuminated, progressively approached

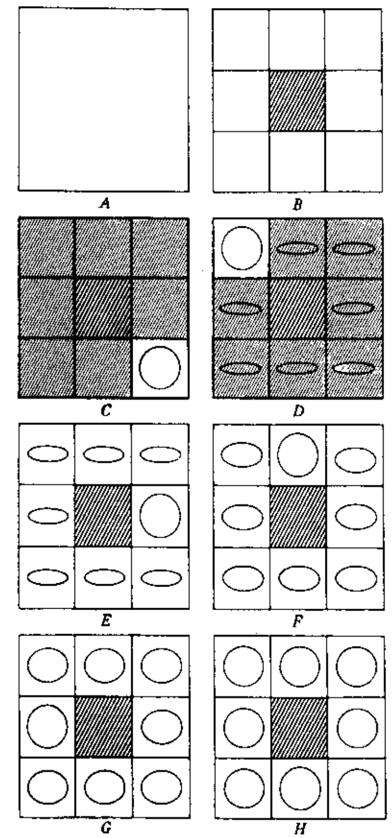


FIGURE 15. A program designed to teach form discrimination. Reinforcement was contingent on: (A) a response moving a large panel; (B) a response moving any one of nine smaller panels (with the exception of the center panel); (C) a response moving only the one panel on which a circle is projected; (D) as before except that flat ellipses appear faintly on the other panels; (E, F, G) a response to the panel bearing a circle, appearing in random position among ellipses the shorter axes of which are progressively lengthening; (H) a response to the panel bearing a circle among ellipses closely approximating circles.

circles (Figure 15E to G). Each stage was maintained until the subject had formed the necessary discrimination, all correct responses being reinforced with chocolate. Eventually the subject could successfully select a circle from an array approximately like that shown in Figure 15H. Using similar shaping techniques Sidman and his associates have conditioned the subject to pick up and use a pencil appropriately, tracing letters faintly projected on a sheet of paper.

The intellectual accomplishments of this microcephalic idiot in the forty-first year of his life have exceeded all those of his first 40 years. They were possible only because he has lived a few hours of each week of that year in a well programmed environment. No very bright future beckons (he has already lived longer than most people of his kind), and it is impossible to say what he might have achieved if he had been subject to a similar program from birth, but he has contributed to our knowledge by demonstrating the power of a method of instruction which could scarcely be tested on a less promising case. (The bright futures belong to the normal and exceptional children who will be fortunate enough to live in environments which have been designed to maximize *their* development, and of whose potential achievements we have now scarcely any conception.)

A fourth kind of programming has to do with maintaining behavior under infrequent reinforcement. A pigeon will continue to respond even though only one response in every hundred, say, is reinforced, but it will not do so unless the contingencies have been programmed. A fresh pigeon is no more likely to peck a disk a hundred times than to pace a figure eight. The behavior is built up by reinforcing every response, then every other response, then every fifth response, and so on, waiting at each stage until the behavior is reasonably stable. Under careful programming pigeons have continued to respond when only every ten-thousandth response has been reinforced, and this is certainly not the limit. An observer might say, for example, that the pigeon is "greatly interested in his work," "industrious," "remarkably tolerant to frustration," "free from discouragement," or "dedicated to his task." These expressions are commonly applied to students who have had the benefit of similar programming, accidental or arranged.

The effective scheduling of reinforcement is an important element in educational design. Suppose we wish to teach a student to read "good books"—books which, almost by definition, do not reinforce the reader sentence by sentence or even paragraph by paragraph but only when possibly

hundreds of pages have prepared him for a convincing or moving dénouement. The student must be exposed to a program of materials which build up a tendency to read in the absence of reinforcement. Such programs are seldom constructed deliberately and seldom arise by accident, and it is therefore not surprising that few students even in good universities learn to read books of this sort and continue to do so for the rest of their lives. In their pride, schools are likely to arrange just the wrong conditions; they are likely to maintain so-called standards under which books are forced upon students before they have had adequate preparation.

Other objectives in education need similar programming. The dedicated scientist who works for years in spite of repeated failures is often looked upon as a happy accident, but he may well be the product of a happy if accidental history of reinforcement. A program in which exciting results were first common but became less and less frequent could generate the capacity to continue in the absence of reinforcement for long periods of time. Such programs should arise naturally as scientists turn to more and more difficult areas. Perhaps not many effective programs are to be expected for this reason, and they are only rarely designed by teachers of science. This may explain why there are so few dedicated scientists. Maintaining a high level of activity is one of the more important achievements of programming. Repeatedly, in its long history, education has resorted to aversive control to keep its students at work. A proper understanding of the scheduling of reinforcement may lead at long last to a better solution of this problem (see Chapter 7).

A FEW EXAMPLES

Let us look at these principles of programming at work in one or two traditional educational assignments. Instruction in handwriting will serve as one example. To say that a child is to learn "how to write" tells us very little. The so-called signs of "knowing how to write" provide a more useful set of behavioral specifications. The child is to form letters and words which are legible and graceful according to taste. He is to do this first in copying a model, then in writing to dictation (or self-dictation as he spells out words he would otherwise speak), and eventually in writing as a separate nonvocal form of verbal behavior. A common method is to ask the child to copy letters or words and to approve or otherwise reinforce his approximations to good copy. More and more exact copies are demanded as the hand improves—in a crude sort of programming. The method is ineffective largely because the reinforcements are too long deferred. The parent or teacher comments upon or corrects the child's work long after it has been performed.

A possible solution is to teach the child to discriminate between good and bad form before he starts to write. Acceptable behavior should then generate immediate, automatic self-reinforcement. This is seldom done. Another possibility is to make reinforcement immediately contingent upon successful responses. One method now being tested is to treat paper chemically so that the pen the child uses writes in dark gray when a response is correct and yellow when it is incorrect. The dark gray line is made automatically reinforcing through generous commendation. Under such contingencies the proper execution of a letter can be programmed; at first the child makes a very small contribution in completing a letter, but through progressive stages he approaches the point at which he composes the letter as a whole, the chemical response of the paper differentially reinforcing good form throughout. The model to be copied is then made progressively less important by separating it in both time and space from the child's work. Eventually words are written to dictation, letter by letter, in spelling dictated words, and in describing pictures. The same kind of differential reinforcement can be used to teach such things as good

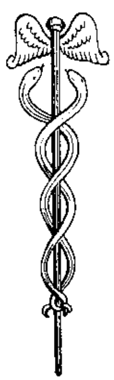
form and proper spacing. The child is eventually forming letters skillfully under continuous automatic reinforcement. The method is directed as much toward motivation as toward good form. Even quite young children remain busily at work for long periods of time without coercion or threat, showing few signs of fatigue, nervousness, or other forms of escape.

As a second example we may consider the acquisition of a simple form of verbal behavior. A behavioral specification is here likely to be especially strongly resisted. It is much more in line with traditional educational policy to say that the student is to "know facts, understand principles, be able to put ideas into words, express meanings, or communicate information." The behavior exhibited in such activities can be formulated without reference to ideas, meanings, or information, and many of the principles currently used in programming verbal knowledge have been drawn from such a formulation (47). The field is too large to be adequately covered here, but two examples may suggest the direction of the approach.

What happens when a student memorizes a poem? Let us say that he begins by reading the poem from a text. His behavior is at that time under the control of the text, and it is to be accounted for by examining the process through which he has learned to read. When he eventually speaks the poem in the absence of a text, the same form of verbal behavior has come under the control of other stimuli. He may begin to recite when asked to do so—he is then under control of an external verbal stimulus—but, as he continues to recite, his behavior comes under the control of stimuli he himself is generating (not necessarily in a crude word-by-word chaining of responses). In the process of "memorizing" the poem, control passes from one kind of stimulus to another.

A method of transferring control from text to self-generated stimuli makes a convincing classroom demonstration. A short poem is projected on a screen or written on a chalkboard. A few unnecessary letters are omitted. The class reads the poem in chorus. A second slide is then projected in which other letters are missing (or letters erased from the chalkboard). The class could not have read the poem correctly if this form had been presented first, but because of its recent history it is able to do so. (Some members undoubtedly receive help from others in the process of choral reading.) In a third setting still other letters are omitted, and after a series of five or six settings the text has completely disappeared. The class is nevertheless able to "read" the poem. Control has passed mainly to self-generated stimuli.

As another example, consider what a student learns when he consults an illustrated dictionary. After looking at a labeled picture, we say that he knows something he did not know before. This is another of those vague expressions which have done so much harm to education. The "signs or symptoms of such knowledge" are of two sorts. Shown the accompanying picture without the text the student can say "caduceus" (we say that he now knows what the pictured object is called) or, shown the word *caduceus,* he can now describe or reconstruct the picture (we say that he now knows what the word caduceus means). But what has actually happened?



caduceus

The basic process is similar to that of transferring discriminative control in the Terrace experiment. To begin with, the student can respond to the picture in various ways: he can describe it without naming it; he can find a similar picture in an array; he can draw a fair copy. He can also speak the name by reading the printed word. When he first looks at the picture and reads the word, his verbal response is primarily under the control of the text, but it must eventually be controlled by the picture. As in transferring the control

exerted by red and green to vertical and horizontal lines, we can change the control efficiently by making the text gradually less important, covering part of it, removing some of the letters, or fogging it with a translucent mask. As the picture acquires control the student can speak the name with less and less help from the text. Eventually, when the picture exerts enough control, he "knows the name of the pictured object." The normal student can learn the name of one object so quickly that the vanishing technique may not be needed, but it is a highly effective procedure in learning the names of a large number of objects. (The good student learns how, by himself, to make progressive reductions in the effectiveness of a text: he may glance at the text out of the corner of his eye, uncover it bit by bit, and so on. In this way he improvises his own program in making the text less and less important as the picture acquires control of the verbal response.)

In teaching the student "the meaning of the word caduceus" we could slowly obscure the picture, asking the student to respond to the name by completing a drawing or description or by finding a matching picture in an array. Eventually in answer to the question: What is a caduceus? he would describe the object, make a crude sketch, or point to the picture of a caduceus. The skillful student uses techniques of this sort in studying unprogrammed material.

"Knowing what a caduceus is" or "knowing the meaning of the word caduceus" is probably more than responding in these ways to picture or text. There are other "signs of knowledge," and that is one reason why the concept of knowledge is so inadequate. But other relevant behavior must be taught, if at all, in substantially the same way.

SOME COMMON OBJECTIONS

These examples do scant justice to the many hundreds of effective programs now available or to the techniques which many of them use so effectively, but they must suffice as a basis for discussing a few general issues. An effective technology of teaching, derived not from philosophical principles but from a realistic analysis of human behavior, has much to contribute, but as its nature has come to be clearly seen, strong opposition has arisen.

A common objection is that most of the early work responsible for the basic formulation of behavior was done on so-called lower animals. It has been argued that the procedures are therefore appropriate only to animals and that to use them in education is to treat the student like an animal. So far as I know, no one argues that because something is true of a pigeon, it is therefore true of a man. There are enormous differences in the topographies of the behaviors of man and pigeon and in the kinds of environmental events which are relevant to that behavior—differences which, if anatomy and physiology were adequate to the task, we could probably compare with differences in the mediating substrata—but the basic processes in behavior, as in neural tissue, show helpful similarities. Relatively simple organisms have many advantages in early stages of research, but they impose no limit on that research. Complex processes are met and dealt with as the analysis proceeds. Experiments on pigeons may not throw much light on the "nature" of man, but they are extraordinarily helpful in enabling us to analyze man's environment more effectively. What is common to pigeon and man is a world in which certain contingencies of reinforcement prevail. The schedule of reinforcement which makes a pigeon a pathological gambler is to be found at racetrack and roulette table, where it has a comparable effect.

Another objection is to the use of contrived contingencies of reinforcement. In daily life one does not wear glasses in order to get food or point to circles in order to receive chocolate. Such reinforcers are not naturally contingent on

the behavior and there may seem to be something synthetic, spurious, or even fraudulent about them. The attack on contrived contingencies of reinforcement may be traced to Rousseau and his amazing book, *Émile* (39). Rousseau wanted to avoid the punitive systems of his day. Convinced as he was that civilization corrupts, he was also afraid of all social reinforcers. His plan was to make the student dependent upon *things* rather than people. John Dewey restated the principle by emphasizing real life experiences in the schoolroom. In American education it is commonly argued that a child must be taught nothing until he can reap natural benefits from knowing it. He is not to learn to write until he can take satisfaction in writing his name in his books or notes to his friends. Producing a gray rather than a yellow line is irrelevant to handwriting. Unfortunately, the teacher who confines himself to natural reinforcers is often ineffective, particularly because only certain subjects can be taught through their use, and he eventually falls back upon some form of punishment. But aversive control is the most shameful of irrelevancies: it is only in school that one parses a Latin sentence to avoid the cane.

The objection to contrived reinforcers arises from a misunderstanding of the nature of teaching. The teacher expedites learning by arranging special contingencies of reinforcement, which may not resemble the contingencies under which the behavior is eventually useful. Parents teach a baby to talk by reinforcing its first efforts with approval and affection, but these are not natural consequences of speech. The baby learns to say "mama," "dada," "spoon," or "cup" months before he ever calls to his father or mother or identifies them to a passing stranger or asks for a spoon or cup or reports their presence to someone who cannot see them. The contrived reinforcement shapes the topography of verbal behavior long before that behavior can produce its normal con-