REVIEW LECTURE

The technology of teaching

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[Plates 50 and 51]

REFERENCES

More than 60 years ago, in his *Talks to teachers on psychology*, William James (1899) 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 (1962), 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 behaviour, 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 programmes 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 (1926) 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.

Some so-called teaching machines serve another conspicuous function of the teacher: they are designed primarily to attract and hold attention. The television screen is praised for its hypnotic powers. A machine has recently been advertised which holds the student's head between earphones and his face a few inches from a brightly lit text. It is intended that he will read a few lines, then listen to his recorded voice as he reads them over again—all in the name of 'concentration.' 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 programmes emerging from an experimental analysis of behaviour 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 behaviour in doing so under Socrates's careful guidance resembled Pythagoras's original unguided achievement.

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 the American psychologist, E. L. Thorndike, who more than 50 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 programme 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 behaviour which gave rise to the movement.

An important process in human behaviour is attributed, none too accurately, to 'reward and punishment.' Thorndike described it in his Law of Effect. It is now commonly referred 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 1, plate 50, 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 behaviour on the part of the rat which

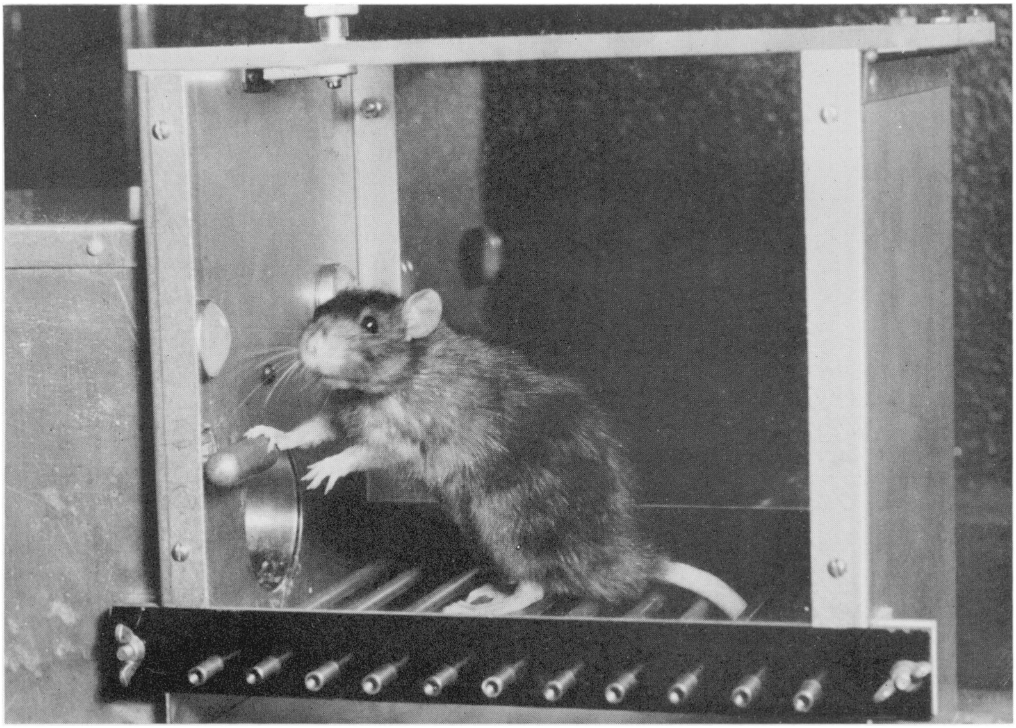

FIGURE 1. Rat pressing a horizontal bar attached to a lever projecting through the wall. The circular aperture below and to the right is a food dispenser.

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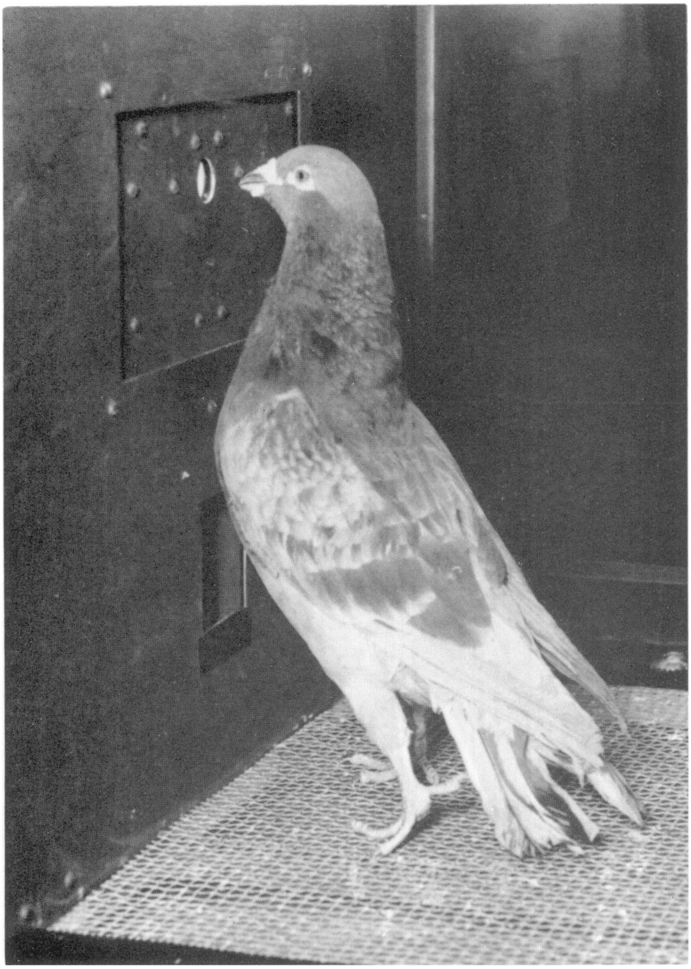


FIGURE 2. Pigeon pecking a translucent disk. The square aperture below contains a food dispenser.

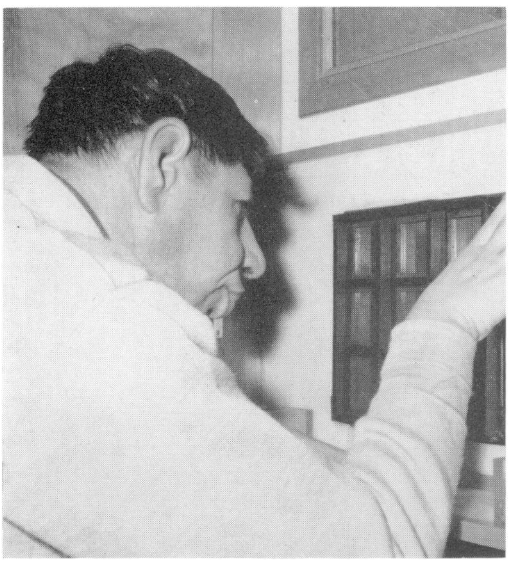


FIGURE 4. Microcephalic idiot, 40 years old, operating a complex apparatus used in teaching form discrimination.

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 behaviour. Under such circumstances the probability that a response to the lever will occur again is increased (Skinner 1938).

The basic contingency between an act and its consequences has been studied over a fairly wide range of species. Pigeons have been reinforced for pecking at transilluminated disks (figure 2, plate 51), monkeys for operating toggle switches which were first designed for that more advanced primate, man, and so on. 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 behaviour which may be traced to subtle and complex features of the contingencies of reinforcement which prevail in the environment.

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 (see, for example, Ferster & Skinner 1957) also covers intermittent reinforcement arranged by clocks and speedometers.

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 behaviour, however, goes beyond an analysis of possible contingencies to the behaviour 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 enviroments, but teachers arrange special contingencies which expedite learning, hastening the appearance of behaviour which would otherwise be acquired slowly or making sure of the appearance of behaviour 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 behaviour 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 behaviour which frequently emerges is perhaps the most conspicuous contribution to date of an experimental analysis of behaviour. There are at least four different kinds of programming. One is concerned with generating new and complex patterns or 'topographies' of behaviour. 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?

The programming of a rare topography of response is sometimes demonstrated in the classroom in the following way. 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.

Q.E.D. 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 programme 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.

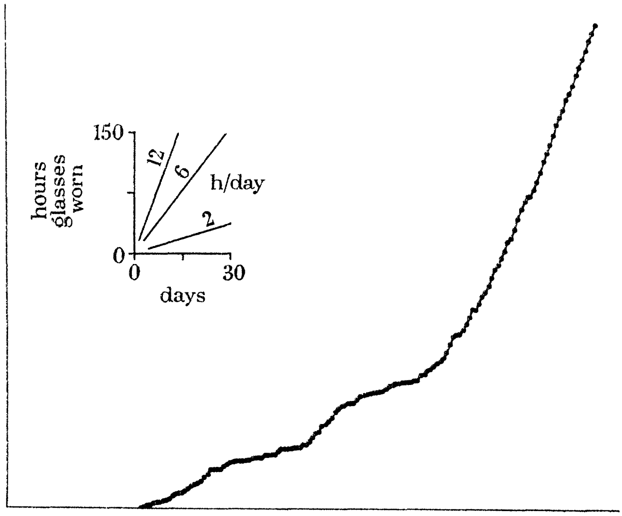


FIGURE 3. Curve showing the number of hours per day during which glasses were worn, plotted cumulatively. The final slope is about twelve hours per day.

This method of shaping a topography of response has been used by Wolf, Mees & Risley (1964) to solve a difficult behaviour 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 behaviour, 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 programme of contingencies of reinforcement was then designed to shape the desired behaviour 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 picking up the frames, carrying them about, and so on, 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. Wolf *et al.* publish a cumulative curve (figure 3) showing the number of hours per day the glasses were worn. The final slope represents essentially all the child's waking hours.

Operant techniques were first applied to psychotic subjects in the pioneering work of Lindsley (1960). Azrin and others have programmed contingencies of reinforcement to solve certain management problems in institutions for the psychotic (Ayllon & Azrin 1965). The techniques are not designed to cure psychoses but to generate trouble-free behaviour. 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 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 guarantee appropriate behaviour. The contingencies must be made effective by appropriate programmes.

A second kind of programming is used to alter temporal or intensive properties of behaviour. 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 behaviour 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 analysed if they are to be properly programmed.

Another kind of programming is concerned with bringing behaviour 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 analysed by Terrace (1963). 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 colour 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 behaviour of both anxious and nonanxious students are the same; the difference is to be traced to the programme by way of which the terminal behaviour has been reached.

The discriminative capacities of lower organisms have been investigated with methods which require very skilful programming. Blough (1956), 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.

Some current work by Murray Sidman provides a dramatic example of programming a subtle discrimination in a microcephalic idiot. At the start of the experiment Sidman's subject (figure 4, plate 51) 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 post-mortem study, his brain is probably about one-third the normal size. Sidman investigated his ability to discriminate circular forms projected on translucent vertical panels. Small pieces of chocolate were used as reinforcers. At first any pressure against a single large vertical panel (figure 5A) operated the device which dropped a bit of chocolate into a cup within reach. Though showing relatively poor motor co-ordination, the subject eventually executed the required, rather delicate response. The panel was then subdivivded into a three by three set of smaller panels (to be seen in figure 4, plate 51, and represented schematically in figure 5B), 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 5C). The subject learned to press the lighted panel. Flat ellipses were then projected on the other panels at a low illumination (figure 5D). In subsequent settings the ellipses, now brightly illuminated, progressively approached circles (figure 5*E* 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 5H. 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.

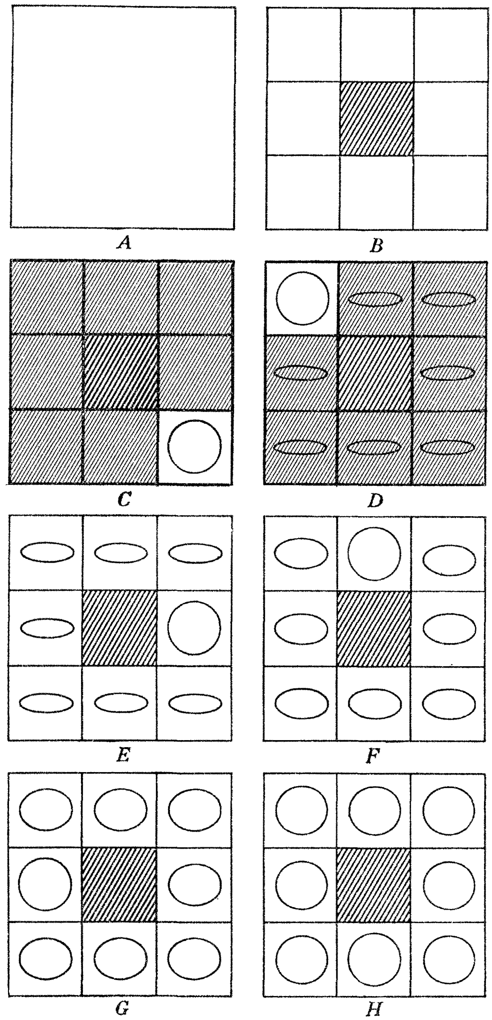


FIGURE 5. A programme designed to teach subtle form discrimination. Reinforcement was contingent on: (*A*) a response moving a large panel; (*B*) a response moving any one of nine smaller panels (with the exception of the centre panel); (*C*) a response moving only the one panel on which a circle is 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 axis of which is progressively lengthening; (*H*) a response to the panel bearing a circle among ellipses closely approximating circles.

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 programme 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 behaviour 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 behaviour is built up by reinforcing every response, then every other response, then every fifth response, and so on, waiting at each stage until the behaviour 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 that the pigeon is 'greatly interested in his work', 'industrious', 'remarkably tolerant to frustration', 'free from discouragement', 'dedicated to his task', and so on. 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 programme of materials which build up a tendency to read in the absence of reinforcement. Such programmes 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.

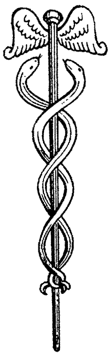
Other objectives in education need similar programming. The dedicated scientist who works for years in spite of repeated failures is often looked upon as a happy accident, but he may well be the product of a happy if accidental history of reinforcement. A programme in which exciting results were first common but became less and less frequent could generate the capacity to continue in the absence of reinforcement for long periods of time. Such programmes should arise naturally as scientists turn to more and more difficult areas. Perhaps not many effective programmes 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.

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 behavioural 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 behaviour. 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 behaviour 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 blue when a response is correct and yellow when it is incorrect. The dark blue 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 good form, proper spacing, and so on. The child is eventually forming letters skilfully 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 behaviour. A behavioural 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.' In *Verbal behaviour* (Skinner 1957) I tried to show how the behaviour exhibited in such activities could be formulated without reference to ideas, meanings, or information, and many of the principles currently used in programming verbal knowledge have been drawn from that analysis. 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 behaviour 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 behaviour 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 behaviour 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.



caduceus

FIGURE 6

A classroom demonstration of the transfer of control from text to self-generated stimuli illustrates the process. 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 labelled picture, as in figure 6, 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 picture in figure 6 without the text the student can say 'caduceus' (we say that he now knows what the object pictured in the figure 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?

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, and so on. 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 to make progressive reductions in the effectiveness of a text by himself: 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 programme 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 describes the object, makes a crude sketch, or points to the picture of a caduceus. The skilful 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. In other words, there are other 'signs of knowledge.' That is one reason why the concept of knowledge is so inadequate. But other relevant behaviour must be taught, if at all, in substantially the same way.

These examples do scant justice to the many hundreds of effective programmes 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 behaviour, 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 behaviour 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 behaviours of man and pigeon and in the kinds of environmental events which are relevant to that behaviour—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 behaviour, 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 analyse 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 race track 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 behaviour 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*. 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 purple 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 behaviour 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 behaviour long before that behaviour can produce its normal consequences in a verbal community. In the same way a child reinforced for the proper formation of letters by a chemical reaction is prepared to write long before the natural consequences of effective writing take over. It was necessary to use a 'spurious' reinforcer to get the boy to wear glasses, but once the behaviour had been shaped and maintained for a period of time, the natural reinforcers which follow from improved vision could take over. The real issue is whether the teacher prepares the student for the natural reinforcers which are to replace the contrived reinforcers used in teaching. The behaviour which is expedited in the teaching process would be useless it it were not to be effective in the world at large in the absence of instructional contingencies.

Another objection to effective programmed instruction is that it does not teach certain important activities. When required to learn unprogrammed material for an impending examination the student learns how to study, how to clear up puzzling matters, how to work under puzzlement, and so on. These may be as important as the subject-matter itself. The same argument could have been raised with respect to a modern experimental analysis of learning when contrasted with early studies of that process. Almost all early investigators of learning constructed what we now call terminal contingencies of reinforcement to which an organism was immediately subjected. Thus, a rat was put into a maze, a cat was put into a puzzle box, and so on. The organism possessed little if any behaviour appropriate to such a 'problem', but some responses were reinforced, and over a period of time an acceptable terminal performance might be reached. The procedure was called 'trial and error.' A programme of contingencies of reinforcement would have brought the organism to the same terminal performance much more rapidly and efficiently and without trial and error, but in doing so it could have been said to deprive the organism of the opportunity to learn how to try, how to explore—indeed, how to solve problems.

The educator who assigns material to be studied for an impending test presents the student with an opportunity to learn to examine the material in a special way which facilitates recall, to work industriously at something which is not currently reinforcing, and so on. It is true that a programme designed simply to impart knowledge of a subject-matter does not do any of this. It does not because it is not designed to do so. Programming undertakes to reach one goal at a time. Efficient ways of studying and thinking are separate goals. A crude parallel is offered by the current argument in favour of the cane or related aversive practices on the ground that they build character; they teach a boy to take punishment and to accept responsibility for his conduct. These are worthwhile goals, but they should not necessarily be taught at the same time as, say, Latin grammar or mathematics. Rousseau suggested a relevant form of programming through which a child could be taught to submit to aversive stimuli without alarm or panic. He pointed out that a baby dropped into a cold bath will probably be frightened and cry, but that if one begins with water at body temperature and cools it one degree per day, the baby will eventually not be disturbed by cold water. The programme must be carefully followed. (In his enthusiasm for the new science, Rousseau exclaimed 'Use a thermometer!') Similar programmes can teach a tolerance for painful stimuli, but caning a boy for idleness, forgetfulness, or bad spelling is an unlikely example. It only occasionally builds what the eighteenth century called 'bottom', as it only occasionally eliminates idleness, forgetfulness, or bad spelling.

It is important to teach careful observation, exploration, and inquiry, but they are not well taught by submitting a student to material which he must observe and explore effectively or suffer the consequences. Better methods are available. There are two ways to teach a man to look before leaping: he may be severely punished when he leaps without looking or he may be positively reinforced (possibly 'spuriously') for looking before leaping. He may learn to look in both cases, but when simply punished for leaping without looking he must discover for himself the art of careful observation, and he is not likely to profit from the experience of others. When he is reinforced for looking, a suitable programme will transmit earlier discoveries in the art of observation. (Incidentally, the audiovisual devices mentioned earlier which undertake to attract attention do not teach careful observation. On the contrary, they are much more likely to deprive the student of the opportunity to learn such skills than effective programming of subject-matters.)

Learning how to study is another example. When a teacher simply tests students on assigned material, few ever learn to study well, and many never learn at all. One may read for the momentary effect and forget what one has read almost immediately; one obviously reads in a very different way for retention. As we have seen, many of the practices of the good student resemble those of the programmer. The student can in a sense programme material as he goes, rehearsing what he has learned, glancing at a text only as needed, and so on. These practices can be separately programmed as an important part of the student's education and can be much more effectively taught than by punishing the student for reading without remembering.

It would be pleasant to be able to say that punishing the student for not thinking is also not the only way to teach thinking. Some relevant behaviours have been analysed and can therefore be explicitly programmed. Algorithmic methods of problem-solving are examples. Simply leading the student through a solution in the traditional way is one kind of programming. Requiring him to solve a series of problems of graded difficulty is another. More effective programmes can certainly be prepared. Unfortunately, they would only emphasize the rather mechanical nature of algorithmic problem-solving. Real thinking seems to be something else. It is sometimes said to be a matter of 'heuristics.' But relevant practices can be formulated as techniques of solving the problem of solving problems. Once a heuristic device or practice is formulated and programmed, it cannot be distinguished in any important way from algorithmic problem-solving. The will-of-the-wisp of creative thinking still leads us on.

Human behaviour often assumes novel forms, some of which are valuable. The teaching of truly creative behaviour is, nevertheless, a contradiction in terms. Original discovery is seldom if ever guaranteed in the classroom. In Polya's little book, *How to solve it* (Polya, 1945), a few boys in a class eventually arrive at the formula for the diagonal of a parallelopiped. It is possible that the teacher did not tell them the formula, but it is unlikely that the course they followed under his guidance resembled that of the original discoverer. Efforts to teach creativity have sacrificed the teaching of subject-matter. The teacher steers a delicate course between two great fears—on the one hand that he may not teach and on the other that he may tell the student something. Until we know more about creative thinking, we may need to confine ourselves to making sure that the student is in full possession of the contributions of earlier thinkers, that he has been abundantly reinforced for careful observation and inquiry, that he has the interest and industry generated by a fortunate history of successes.

It has been said that an education is what survives when a man has forgotten all he has been taught. Certainly few students could pass their final examinations even a year or two after leaving school or the university. What has been learned of permanent value must therefore not be the facts and principles covered by examinations but certain other kinds of behaviour often ascribed to special abilities. Far from neglecting these kinds of behaviour, careful programming reveals the need to teach them as explicit educational objectives. For example, two programmes prepared with the help of the Committee on Programmed Instruction at Harvard—a programme in crystallography constructed by Bruce Chalmers and James G. Holland and a programme in neuroanatomy by Murray and Richard Sidman—both reveal the importance of special skills in three-dimensional thinking. As measured by available tests, these skills vary enormously even among scientists who presumably make special use of them. They can be taught with separate programmes or as part of crystallography or neuroanatomy when specifically recognized as relevant skills. It is possible that education will eventually concentrate on those forms of behaviour which 'survive when all one has learned has been forgotten.'

The argument that effective teaching is inimical to thinking, whether creative or not, raises a final point. We fear effective teaching, as we fear all effective means of changing human behaviour. Power not only corrupts, it frightens; and absolute power frightens absolutely. We take another—and very long—look at educational policy when we conceive of teaching which really works. It has been said that teaching machines and programmed instruction will mean regimentation (it is sometimes added that regimentation is the goal of those who propose such methods), but in principle nothing could be more regimented than education as it now stands. School and state authorities draw up syllabuses specifying what students are to learn year by year. Universities insist upon 'requirements' which are presumably to be met by all students applying for admission. Examinations are 'standard.' Certificates, diplomas, and honours testify to the completion of specified work. We do not worry about all this because we know that students never learn what they are required to learn, but some other safeguard must be found when education is effective.

It could well be that an effective technology of teaching will be unwisely used. It could destroy initiative and creativity, it could make men all alike (and not necessarily in being equally excellent), it could suppress the beneficial effect of accidents upon the development of the individual and upon the evolution of a culture. On the other hand, it could maximize the genetic endowment of each student, it could make him as skilful, competent, and informed as possible, it could build the greatest diversity of interests, it could lead him to make the greatest possible contribution to the survival and development of his culture. Which of these futures lies before us will not be determined by the mere availability of effective instruction. The use to which a technology of teaching is to be put will depend upon other matters. We cannot avoid the decisions which now face us by putting a stop to the scientific study of human behaviour or by refusing to make use of the technology which inevitably flows from such a science.

The experimental analysis of behaviour is a vigorous young science which will inevitably find practical applications. Important extensions have already been made in such fields as psychopharmacology and psychotherapy. Its bearing on economics, government, law, and even religion are beginning to attract attention.

It is thus concerned with government in the broadest possible sense. In the government of the future the techniques we associate with education are most likely to prevail. That is why it is so important that this young science has begun by taking its most effective technological step in the development of a technology of teaching.

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