

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

PROBLEMS OF PROGRESS IN INDUSTRY—14

TEACHING MACHINES and their use in industry

by

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HER MAJESTY'S STATIONERY OFFICE

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PREFACE

THE object of this series is to present briefly and simply the results of new research into the economic, technical and human problems of industrial progress—problems arising from automation and other advances in techniques and problems of management and social relations.

The series is commissioned and edited by the Department of Scientific and Industrial Research, which seeks to provide a forum for responsible new thinking and to stimulate independent discussion and action, including future research. The conclusions are those of the investigators, mostly from the universities and other well known research bodies.

The Department of Scientific and Industrial Research is currently supporting two research projects—one at the University of Sheffield and the other at the University of Aberdeen—into the development of programmed learning and the use of teaching machines. The results of these studies are not yet complete. However, in view of the growing interest in industry in the use of teaching machines and of the number of recent publications on their design, the Department considers that there is a need for a booklet on the ideas underlying these research studies and basic to an understanding of the function of machines as teachers.

This booklet, therefore, considers the fundamental concepts of instruction as a process of communication and control, and reviews their application to the development of programmed learning. It discusses the potentialities of teaching machines as a means of meeting the growing demand for trained personnel in industry and the shortage of training instructors.

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INTRODUCTION

There is today an urgent demand for training to meet the shortages of skilled manpower; training for the ever-increasing number of young people entering industry; and retraining for skilled adult workers as new processes are introduced. With the vast increase in technical knowledge and its rapid application in industry, a higher proportion of trained and technical manpower will be required than ever before. Yet there is little to indicate that training facilities are expanding at anything like a corresponding rate.

Can industry therefore train for new skills in new ways? One solution, in keeping with the new technical developments, is to teach by machine and so make up for the lack of human instructors. This booklet gives a factual account of teaching machines and what they attempt to achieve—with particular reference to industry. The authors are research workers asking '*Why should these machines work?*', '*Is there any evidence that they can teach?*'

Section I outlines the general thinking behind the development of teaching machines. Later sections discuss actual devices which have been constructed, their programmes, and the implications which these have for industry. The theoretical ideas underlying these methods are stressed so that the reader can both judge the possibilities of the system for himself and evaluate how satisfactory present developments are.

One point should be stressed. These are such early days for teaching machine methods that describing them is like describing the uses of the motor car or aeroplane after the first ten years of development. In considering the future of teaching machines, allowance must be made for the effects not only of mass-producing existing machines but of developing them further—perhaps beyond anything that can at present be foreseen.

It is convenient to adopt certain terminology, though most terms in this field are unsatisfactory. A '*teaching machine*' is a device for giving instruction on the spot without the presence of a human teacher. It may range from a simple book to a complex electronic device. It contains a carefully prepared text called a '*programme*'. The machine presents individual items of the programme, each of which is called a '*frame*'. In most cases the student is required to respond to the machine by answering a question. According to the type of machine, information about the student's progress is used to control and improve the teaching process.

I. CONTROL SYSTEMS FOR TEACHING

Teaching machine methods are essentially control systems in the transmission of information and may be described in communication engineering terms. Much learning and training takes place in everyday life quite fortuitously, but from the present point of view teaching begins where learning ceases to be accidental. One aim of all machine methods is to exercise control over learning. In order that this approach should not appear too far removed from conventional methods, it will perhaps be easiest if the elements of a teaching system are first identified in situations involving a human teacher.

(a) SYSTEMS INVOLVING HUMAN TEACHERS

It can be argued that teaching occurs whenever a person's interaction with his environment is controlled so as to facilitate the acquisition of some knowledge or skill. In principle, it makes no difference whether the control is exercised by the learner himself (self-instruction), by another person (conventional teaching), in some other way (by a teaching machine), or some combination of the three. But in practice the learner himself is rarely, if ever, able to provide adequate control, either because he lacks the skills or knowledge needed to do so, or because the nature of the task precludes him from doing so. The deficiency is rectified by providing a teacher who has to take on many roles.

One essential component in any teaching system will be the store of knowledge which it is intended to transmit to a student. In the block diagram (Fig. 1) this is labelled the '*subject matter store*' and in the

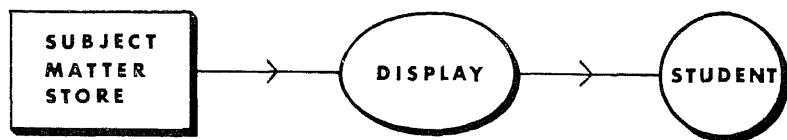


Figure 1. Open-ended system of teaching. Transmission of information (whether by lecture, film, or television, etc.) can only take place in one direction.

conventional case it represents the teacher's knowledge of the subject.

The next component of the system is the 'channel' through which the information can be passed to the student. This is labelled the *display*, and is simply the means the teacher employs to communicate with his students, for example, his voice, blackboard, charts and slides.

This display may be transmitted to any number of students. It is also easy to multiply the number of displays and from this derives the popularity of film or television presentation, which is a satisfactory channel for transmitting information to large audiences. But when judging the efficiency of a teacher it is more important to know what his students have gained than what he has told them. In other words, it is not merely the responsibility of the teacher to transmit information but also to ensure that it is received and understood. The nature of means of communication such as television, radio and film prevents the audience from feeding back to the instructor the necessary information about their understanding and progress, or lack of it. In communication terms this is an 'open-ended' system. In the conventional lecture the channel which feeds this important information back to the instructor is incomplete, and end-of-term examinations tell their (often sorry) tale too late to be of much help to the instructor. By then he cannot remedy his failure to communicate, nor can he discover where the failure occurred.

An efficient teaching system must therefore have some means of discovering that information has been received and understood. The most respected of all teaching systems, the tutorial, is in one respect ideal for ensuring this control. The tutor not only communicates with his student but changes his presentation of material in the light of the student's responses. This is a 'closed-loop' situation in which the feed-back to the instructor is as immediate as is possible with a human agent.

(b) SYSTEMS INVOLVING TEACHING MACHINES

Teaching machines are an attempt to introduce the necessary control without the direct participation of a human teacher. There are several types of device but, before they are described, it may be helpful to consider their general functions in relation to the scheme just outlined. It is more important to appreciate what these various systems achieve than to devote attention to them as mechanisms, ingenious or otherwise.

Figure 2 is an extension of the system already discussed with the human teacher. The diagram represents logical, not physical, elements in a teaching system. With machine methods the store of knowledge to be imparted to a student is carried in some convenient form on paper, film or magnetic tape in contrast to the human teacher's knowledge of his material. How can information from this 'subject matter store' be presented to the learner? With machine procedures the display may consist of a printed page, information on the screen of the machine, or an auditory message relayed from magnetic tape.

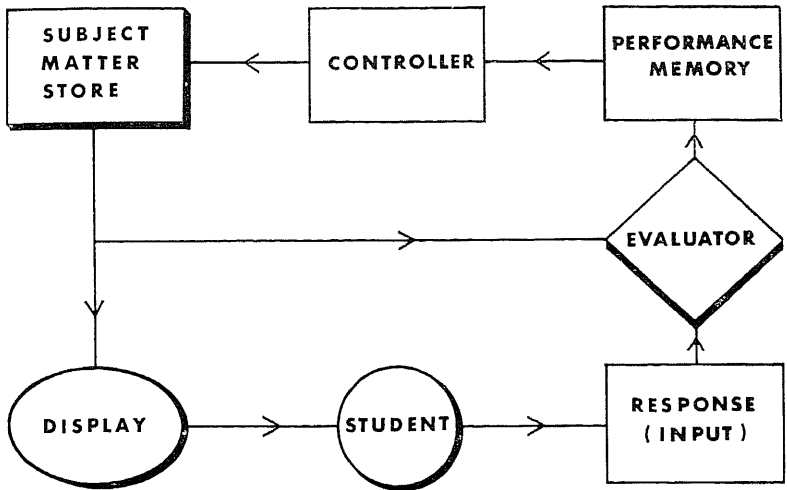


Figure 2. Closed-loop system of teaching. This attempts to control teaching by ensuring that the information transmitted to the student has been received and understood. The material to be taught is adapted on the basis of the student's responses.

These two components, the store of information and a channel by which it can be passed to a student, form an 'open-ended' system as represented by the first three elements in Fig. 2. An example would be a student with an ordinary text-book. It is a system from which a student can learn provided he is motivated and is able to act as his own controller. But the system offers little help to the student and often he does not learn. This has important implications, for if 'open-ended' systems were efficient, mass education would be so easy. From a single store there can be any number of displays and hence transmission is possible to any number of students at one time. How can a machine system discover that the student has received and understood the information? One way, the one a human teacher would adopt, is to ask a question and evaluate the answer. A teaching machine therefore requires a 'response input' and a 'response evaluator', i.e. it must provide a way for the student to record his answer and aid to check its accuracy. He may write down his answer, or he may record it by pressing a button on the machine. The accuracy of his answer may be checked either by the machine or, alternatively, by the student himself when he compares his answer with one provided by the machine. In either case the information is fed back into the machine.

Thus the blocks in Fig. 2 represent functional components and need not correspond directly with physical machinery of the system. So far the components included represent:

- (a) The material to be taught.
- (b) A means of presenting this to the student.
- (c) A means of discovering whether this presentation has been successfully received.

The most important element is yet to be introduced—the ‘controller’—that is a means of selecting the information from the ‘subject matter store’ to ensure the most effective teaching.

The ‘controller’ will determine what information should be passed to the student at any time and will decide this on the basis of the student’s present state of knowledge and past performance. This implies another component—a store of information about the student’s performance. When these two units, a performance store and a controller, are included they close the loop. It will be obvious now that whether or not this system will teach depends on the controller, that is, on the means of implementing rules that govern the whole operation. In a strict sense the teaching machine is this set of rules and the means of implementing them, rather than the hardware assembly.

II. THE MACHINE AND THE METHODS

Many different machines are now available but nearly all of them are based upon one of three or four different systems. The machines are therefore discussed here in relation to the kinds of programme that they are designed to present.

LINEAR PROGRAMMES—SKINNER

With this system, developed by Professor Skinner at Harvard, the aim is to lead a student to an understanding of the material by a series of small and relatively easy steps. These steps—the *frames*—are so written that the learner can make few errors, and thus the system need not incorporate remedial procedures. This means that a sequence of items can be prepared which will be presented to a student in a fixed order. Such a sequence is referred to as a *linear programme*.

Although only a minimal rate of error is expected with this kind of programme, each item requires a student to make a response which indicates that he has understood. The responses in this system are constructed by the student himself, rather than chosen from a set of

given alternatives. As soon as he responds, the machine displays the correct answer, so that he knows whether he was right. Though the same material is presented to everybody, individual students complete the programme at different rates according to their respective abilities.

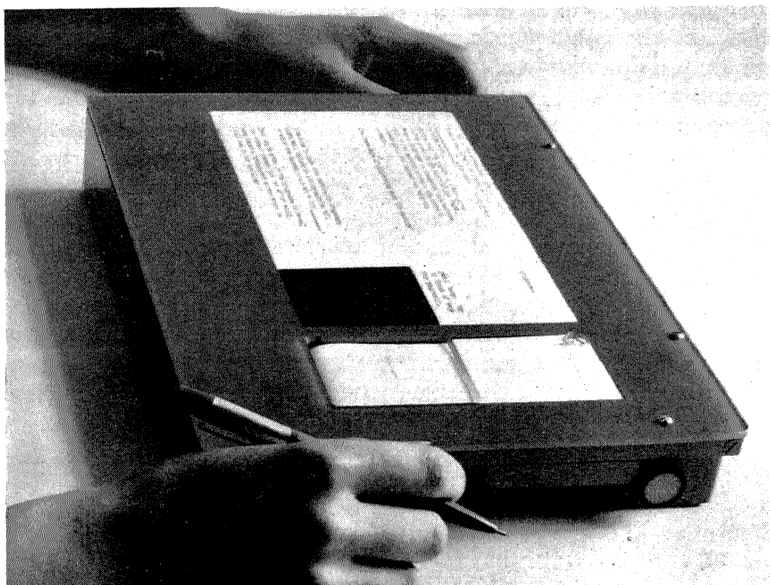


Figure 3. The Aberdeen Machine, a cheaply-priced but efficient linear machine. The student writes his responses in the lower half of the right-hand panel, then turns the knob at the left of the machine to wind on the programme. The next question and the answer to the previous question are both revealed, and the student can make a comparison with his own answer which is still visible under the 'Perspex' screen at the top of the right-hand panel.

The requirements of a machine to present such a linear programme are modest. A good example is the machine (Fig. 3) developed at the Psychology Department at Aberdeen University. The machine ensures that the student reads the items in the intended order, that he provides his own response *before* being given the correct answer, and that a record is made of the responses. It can be argued, however, that where a student wishes to do so he himself can supply these controls. In this case the material may be presented in book form. Since it is wasteful to present only a few lines on a page, with often no more than a one-word answer on the following page, publishers economize by dividing the page into a number of sections.

LINEAR PROGRAMMES—PRESSEY

S. L. Pressey introduced some teaching machines as early as the 1920's, after he had observed that students learned rapidly when

using machines to present and score tests automatically. Many devices have been derived from the basic Pressey system; a good example is the 'Atronic Tutor'. This is a mechanical device designed to present successive items of linear programme. Information with a question and a set of alternative answers is presented on a card which is viewed through a plastic cover. The student selects his answer and responds by pressing one of four keys. If his choice is correct, the next card is presented, if not, he must try again and counters record the number of errors.

Belonging to the same family of devices are the 'Pressey punchboards', a simple version of being the *Tester Rater* illustrated in Fig. 4. These punchboards are scoring, rather than teaching devices, but can be incorporated into a teaching system. The student selects an answer from a given number of alternatives and indicates his choice by pressing a stylus against the appropriate number on the paper strip which covers a template. The sequence of correct choices is determined by the punched template, and the student discovers whether he is correct if the stylus penetrates the punched hole. Thus

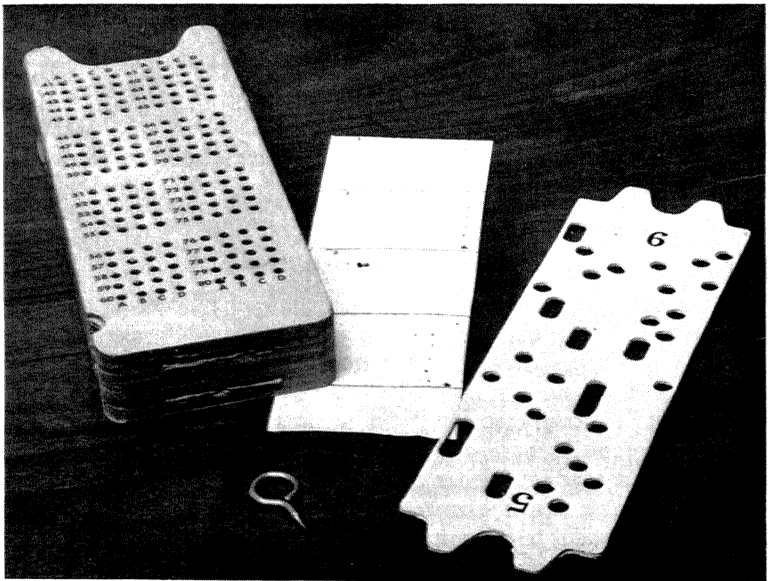


Figure 4. *The Tester-Rater* (shown here dismantled), a simple version of the Pressey punchboard. The student selects an answer by means of a stylus, and a record of his attempts is left on the paper strip (centre) which is placed just above the template (right). Templates can of course be easily changed to provide different sequences of correct choices.

each attempt leaves a record in the paper strip fitting over the template. Punchboards can be used in conjunction with a programmed sequence of items.

With this type of system, as with Skinner's, there is a fixed sequence of material, but the student has to reply to a multi-choice question instead of making a constructed response. In Table 1 Skinner's system has accordingly been characterized as a linear programme with a constructed response, Pressey's as a linear programme with multi-choice questions.

Table 1. Linear and branching programmes
The table shows four typical systems.

				Type of Response	
				Constructed	Multi-choice
Linear Programme	..	..	..	Skinner	Pressey
Branching Programmes	..	..	..	Sheffield	Crowder

BRANCHING PROGRAMMES—CROWDER

A machine using multi-choice questions is simple to construct since it has only to cater for a specified number of contingencies. But an important development occurred when N. A. Crowder saw a way of using the information from both right and wrong responses. He constructed a programme in which the particular sequence of items presented to a particular student is determined by his answer to each question. This is called a 'branching programme' and it is illustrated in Figure 5. More material is presented on each frame than in the

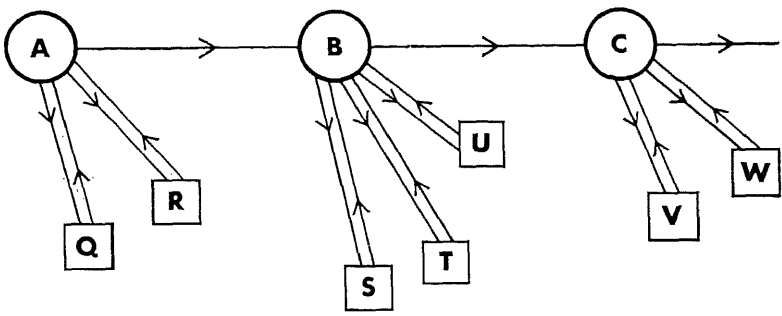


Figure 5. Crowder's Branching Programme. A student who always makes the correct answer choice will proceed from frame A to B to C, etc. Wrong answer choices send the student to 'remedial' frames (e.g. Q, R) which explain his error. The student is then sent back to the main sequence frame for another attempt.



Courtesy of U.S. Industries Inc.



Courtesy of International Tutor Machines Limited

Figure 6. The 'AutoTutor' (top) and 'Grundytutor' each employ the same branching system. The student indicates his answer choice by pressing one of the buttons on the front of the machine, and is routed to the next appropriate frame.

linear programme, a direct question is asked at the end of each frame, and the student's response is restricted to a number of specified alternatives. Where his choice is wrong, the student is directed to the 'frame' which explains the particular mistake he has made. He is then required to go back to the question again. Hence students who have selected different responses are branched to different frames in the programme.

The Crowder type of programme requires a somewhat more elaborate device than the previous two systems. Examples of machines that present a Crowder-type programme are the '*Auto-Tutor*', Mark II and the '*Grundytutor*' illustrated in Fig 6. Material stored on film is viewed on a 9½ in. by 7 in. rear-projection screen. Each frame presents material to the student, who has to make a response to the test question by selecting one of the buttons on the panel to the right of the screen. The machine then presents the frame that the programmer has decided should follow that particular response to the question.

Branching programmes can be presented in a form known as a 'scrambled book'. In such a book the pages are numbered sequentially but the reader does not proceed through them in numerical order. Branching is achieved by having the alternative answers to a question associated with page numbers. When a student has selected an answer, he turns to the page indicated. In Fig. 5 the answers are associated with the response buttons *A*, *B*, *C* and *D*; in a scrambled text they might be marked pages 42, 53, 50, etc.

In contrast to the simple machine procedure of selecting a button, scrambled books involve the student in a good deal of page turning and place finding, but they give more control over how the text is read than the conventional books.

BRANCHING PROGRAMMES—SHEFFIELD

As with Crowder's procedure, the system developed at the Psychology Department of Sheffield University, is designed to use information derived from a student's answer to determine whether he should progress to new material or receive further explanation on some point. But in the Sheffield system, constructed, instead of multi-choice, responses are required. A machine for presenting this

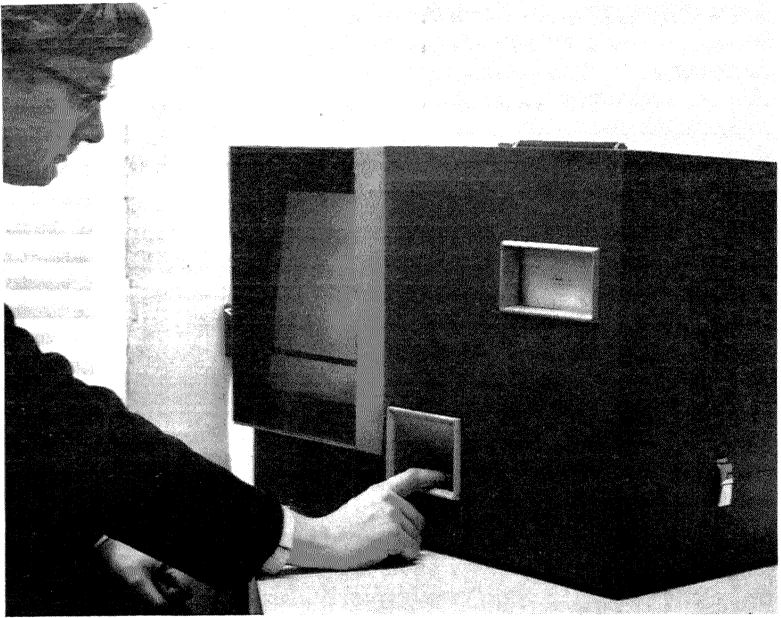


Figure 7. The Sheffield Machine. The student reads the information and question on the screen and writes his response on a card which he posts into the slot at the top. This causes the correct answer to appear at the bottom of the screen, and the student compares this with his own card which has fallen behind the glass screen (top right). He marks himself 'Correct' or '?' by means of the buttons at the front of the machine and the next appropriate frame appears.

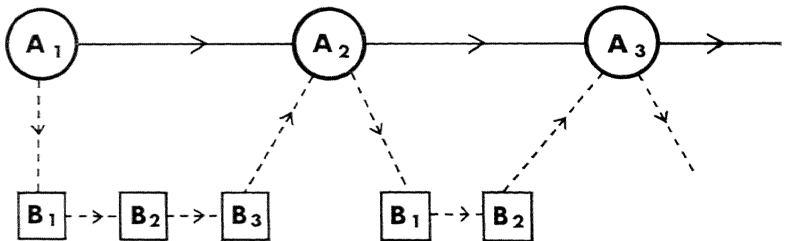


Figure 8. The Sheffield System. If the student fails to understand the 'A' frame he is presented with a sub-sequence of 'B' frames, and must go through *all* of these, including a final test frame, before he re-enters the main sequence.

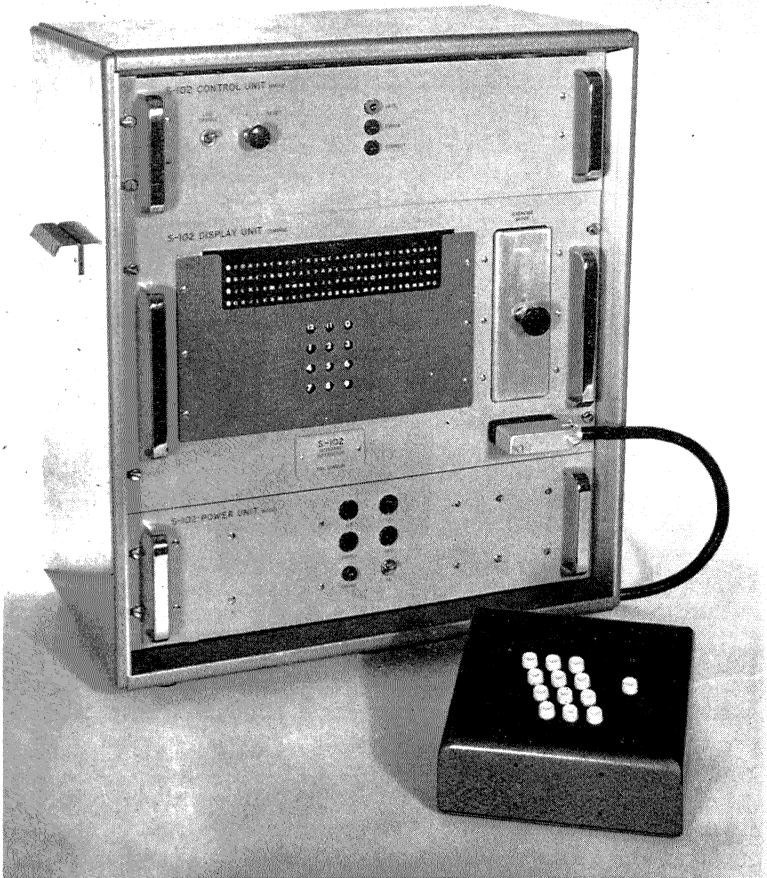
type of programme is illustrated in Fig. 7. As with the 'Auto Tutor', material is stored on film and presented on a rear-projection screen. The student responds by writing his answer to the question on a card and posting it into the chute to the right of the screen. This automatically presents the correct answer on the lower part of the screen and the student now has to select one of the two operating keys. If he is satisfied with his response, he presses the key marked 'correct' and proceeds to the next frame. If for any reason he is not satisfied, he presses the 'query' key, and is given a set of remedial frames, which provides a more detailed explanation. The rules governing the procedure are illustrated in Fig. 8, where the main sequence of frames is labelled 'A' and the remedial sequence 'B'. Any number of 'B' frames may be inserted, the only restriction being that the final 'B' frame should test that the student understands the point in question before returning him to the main sequence of 'A' frames. A record is obtained of all written responses and the particular key selected at each frame.

This system, too, can be presented in book form. The 'A' sequence frames are printed on the right-hand pages, with the 'B' sequence on the following left-hand pages. The system does not give as much control as a scrambled book, but it is much easier for the reader and does not make such a violent break with conventional book-reading habits.

A TEACHING MACHINE FOR A MANUAL SKILL—'SAKI'

All the machines discussed so far could present any number of different programmes and are therefore capable, in theory, of teaching any subject matter. For this reason they may be considered as general-purpose machines, in contrast to teaching machines built specifically to instruct in a single subject. An operation must be of considerable importance to justify constructing a specific teaching machine, but industry in fact has many such tasks and a need for such machines. A good example of them is the *Self-organizing Automatic Keyboard Instructor* ('SAKI') shown in Fig. 9 and designed by G. Pask to train card punch keyboard operators (e.g. *Powers-Samas*, *Hollerith* or *IBM* keyboards). To operate the keyboard, the trainee must know which key to press in relation to any character, and must be able to enter sequences of characters at a high rate.

Exercises are presented on a display consisting of four lines of characters. The characters in a line are illuminated successively by a spot of light, and the student responds by pressing the appropriate key on a modified version of the actual keyboard for which he is being trained. When the correct answer has been made or when a



Courtesy of Cybernetic Developments Limited

Figure 9. 'SAKI' can be linked to any keyboard. The top half of the display comprises the letters or numbers to be entered on the keyboard, while the lower half is a replica of the keyboard itself. A light appears on both the upper and lower panels behind the digit to be entered. As the operator becomes more proficient the rate of presentation of new digits speeds up, and the lights behind the lower half of the display grow dimmer and finally disappear.

certain time interval has expired, the light moves to the next character in the line. A second display, below the exercise display, is a replica of the keyboard. This display is used to give 'cue information' by indicating the correct answer. The machine stores informa-

tion about the accuracy and speed of the student's responses to each character and uses this information to modify both its speed of presentation and the amount of cue information. As proficiency increases, the speed of presentation is increased and the amount of help given by the 'cue' display is decreased. When a mistake occurs the process is reversed. The system is designed to ensure that the task is never too easy or too difficult, so that it keeps up the student's interest and desire to learn. The successive lines of exercise material are graded in difficulty and the machine continues to repeat a given line until a specified level of performance is reached, whereupon the next line is presented.

With the exception of 'SAKI' the machines mentioned so far have presented verbal material by some visual means. But teaching machines are not limited to this kind of display. One form of machine, the '*Empirical Tutor*', is designed so that any frame of its programme may bring in associated apparatus. For example, when giving instruction on an oscilloscope or some auditory phenomenon, it employs a very simple means to switch in the display on the oscilloscope or to start the tape recorder so that the appropriate action accompanies that frame of the programme. So far no teaching machine has been constructed that employs only an auditory presentation, but it would not be technically difficult.

III. PROGRAMMING

There are several types of programme, but they all attempt to control the progress of a student. This function of the programme should never be overlooked. The actual programme for a teaching machine is a sequence of frames which have been carefully put together on a particular subject matter, and in Fig. 2 (page 7) it could correspond to the 'subject matter store'. But the programme is very much more than this. The programme for a computer is a set of instructions which determine the operations the computer performs on the data. In an analogous way a teaching-machine programme incorporates the set of rules or instructions which determine how the student shall learn the subject matter. A teaching-machine programme is written and presented in such a way that it controls the method by which the student learns. It makes him *do* the things he must do in order to learn—to read the text carefully for example.

Different programmers have adopted different means to achieve this control. These means may now be considered.

Skinner, after carrying out laboratory studies for many years, has built up exact procedures for controlling animal behaviour and now aims at the same precision in controlling human behaviour. He argues that what is learned is behaviour. When trying to teach, it is necessary to specify both the behaviour which is to be learned and the behaviour of which the student is at present capable. Further, the student should be active in learning. For this reason a Skinner-type programme always requires a student to construct an appropriate response, which is part of the total behaviour he is learning.

Skinner is definite about the way to teach. Animals can be effectively taught by a process known as 'reinforcement'. For example, if a hungry animal is given food whenever he makes a desired response then it tends to repeat this response more frequently. Complex patterns of behaviour can be built up by the selective reinforcement of small items of behaviour.

Skinner's programming practice follows these principles. He believes that for human learners the knowledge of being right is sufficient to act as reinforcement. The situation must be so arranged that the student will make an appropriate response and this must be reinforced immediately by giving him the results. Complex behaviour is built up from many simple acts.

The practical implication for a Skinner programme is that the material should be so written that a student is nearly always making correct responses and being told that he is right. This is the main reason for the very short frames so characteristic of the Skinner-type programme.

Some behavioural responses which Skinner has taught are complex, but these patterns can be built up or 'shaped' from simpler units of behaviour. In the laboratory, Skinner begins by reinforcing a response that was only approximately correct; but gradually, by rewarding only those responses which were more and more accurate, he shapes the behaviour within finer limits. One of the basic techniques in programming is 'cueing and fading', which may be illustrated by an example from the teaching of engineering. A labelled diagram is presented to the student and questions are put which can be answered by reference to the labels. Over a series of frames the labels are gradually withdrawn so that the student can answer more and more questions without these cues, until finally he requires no assistance. Completely verbal forms of cueing and fading are used widely in linear programmes. In the first presentation the hints or cues may be elaborate so as to ensure that a student makes the correct response. But these are systematically withdrawn so that the student learns to build up the complete response for himself. The

technique may be used for developing a single concept or for illustrating the relation between concepts; but at no stage should there be a serious risk of response errors.

In applying these principles the following steps may be distinguished in the preparation of an actual programme.

Step 1

Identify in objective terms the behaviour to be taught, that is, what actual responses are required for specific or general situations.

Step 2

Identify the present abilities of the students.

Step 3

Analyse the concepts to be taught and arrange them as far as possible in a logical order, drawing up examples and practice items for each concept. Where there are specific relations between concepts, see that these are brought out in the arrangement of material.

Step 4

The construction of frames can now begin. At this stage test the material tested on typical students to ensure that each individual frame is intelligible.

Step 5

When a set of intelligible frames is obtained try them on a sample of typical students to ensure that sequences are successful in teaching the required behaviour. Revise any misleading or unsuccessful sequence as often as is necessary.

Step 6

Try out the programme under actual working conditions with a representative sample of students. This is the final evaluation, where the teaching efficiency of the programme is examined before it is used in practical training, but more than one revision may be necessary at this stage. If, for example, a programme is intended to be widely used, it is important to ensure that it will be successful in a variety of situations. Where a programme is evaluated for daily sessions throughout a week, it may not be adequate for weekly classes at night school. A programme for teaching grammar school students may not be suitable, without revision, for adults in technical colleges.

In general the aim of Step 6 is not only to produce a final programme but also to provide data showing the degree of success which can be achieved with any type of student under specified working conditions. This ideal, of course, sets a more stringent standard than the production of a normal textbook, but it must be remembered that more is claimed for a programme—namely that it will teach without the help of a human teacher. Thus data should be produced which support this claim.

The above outline of a Skinner programme is intended only as a rough guide to the kinds of procedure which have to be adopted. It is no easy alternative to teaching but an exacting and careful exercise which attempts to evaluate its presentation at every step.

BRANCHING AND MULTIPLE-CHOICE PROGRAMMING

Here the process of specifying the desired behaviour and arranging the material in a logical sequence is essentially the same as for linear programmes. Frame construction appears to be less of a problem, since there is no special requirement beyond clear unambiguous prose. This type of programme is not claimed to be designed according to any principles of learning, but immediate testing of each frame ensures that the teaching is successful. It follows that the crucial technique lies in devising test items which genuinely diagnose a student's difficulties. The remedial item, or items, in the branch sequence (see Fig. 5, page 11) should rectify the student's lack of understanding, but it can only do so to the extent that it has given him a fair opportunity of responding. The aim of the test is not to mislead or to 'floor' the student but to diagnose his difficulty. The multiple-choice alternatives are, therefore, not simply 'distractions' (as they have been called) but answers which a student may make if he has misunderstood in a particular way. The list of alternatives should be exhaustive, even if this means using a 'don't know' category. It is also important to write the question so that a student cannot arrive at a correct solution merely by considering the alternatives offered. An item is a bad one if a student can make the correct choice by some short cut without full understanding. One helpful technique is to use items such as 'Is the answer *A* or *B*, or neither of these'?

Given a logical arrangement and good test items, a process of empirical evaluation should take place as for linear programmes. It can be helpful in the early stages for the programmer to present the main sequence of items to a student and to supply, in person, the remedial frames which explain the difficulty. These can then be incorporated into the text.

BRANCHING AND CONSTRUCTED-RESPONSE PROGRAMMING

The technique can be used in a variety of ways. For example, the A frames (see Fig. 8, page 14) may be a series of test items on the basis of which the student is directed to the instruction he needs. The main load of instruction is then undertaken in the sub-sequence of B frames. This is a useful technique where the student population is very heterogeneous. A more common procedure is for the main sequence to carry the instructions and for the sub-sequences to play a remedial role as in the Crowder type of programming. In any one

programme the styles can be mixed, as where student knowledge may be varied only up to a certain point and thereafter all the material is new. Procedures called 'skip branching', where a student can omit certain series of frames, are useful when some students have prior knowledge of the material, or when varying amounts of revision are needed.

IV. DO THEY TEACH?

As in any new venture, standards are difficult to set and some inferior programmes will inevitably become available to the public. At this early stage it is as mistaken to assume that a programme is bad because it does not follow the established format, as to conclude that it is an effective tool because it looks like a programme. The value of a programme should be judged on the basis of independent evidence that it does, or does not, teach. It is desirable, though it happens infrequently, that a published programme should specify three things:

1. Precisely what the programme aims to teach.
2. The level of students for whom it is intended.
3. The evidence for its effectiveness, for example, the evaluation studies which have been conducted.

Two questions which are often asked are '*What subject matters are particularly suited or unsuited to machine teaching?*' and '*Are teaching machines suitable for all types of student?*' If the programming procedures outlined above can be applied, then in principle at least the subject can be taught by machine. The subject matter is likely to give difficulty where the 'terminal behaviour' cannot be readily specified or agreed, or if it cannot be sub-divided and the points arranged in some logical order. Art appreciation might give rise to this kind of difficulty and, of course, such a subject is not easy to teach by any method—for just the same reasons. On the other hand, subjects such as mathematics and science can be most readily programmed, because their structure lends itself to programming methods. Tables 2 and 3 give an idea of the types of subject matter and the different levels of students with which programming methods have been used.

These tables illustrate what has actually been done and not necessarily what might be done. The bias towards mathematics and science subjects and towards college students may roughly indicate that the concepts of machine-instruction have been more readily and rapidly accepted by university departments. It may be expected in

Table 2. Different subject matters which have been programmed in a sample of 62 linear and 19 branching programmes.

Subject Matter	Linear (constructed response) Programmes	Branching (multi-choice response) Programmes
Maths. including Logic + Statistics ..	26	6
Pure and Applied Science	20	11
Arts, Languages, etc.	16	2
Total	62	19

Table 3. Different kinds of students for whom programmes have been written. Some programmes are recommended for more than one level of student.

Type of Student	Linear Programme (constructed response)	Branching Programme (multi-choice response)
Adult	19	9
College	38	10
Secondary School	21	2
Primary School	10	4

Footnote: Tables 2 and 3 are based on data collected and published by J. W. Rigney and E. B. Fry in 'Current Teaching Machine Programs and Programming Techniques'.—*Audio-Visual Communication Review*, 1961, 9(3), Supplement 3.

the next few years not only that programming activity will increase at school level, but also that programmes for industrial trainees will be written.

On the basis of the previous discussion teaching-machine methods would seem likely to be successful for the following reasons:

1. Material is first carefully planned into what appears to be a logical teaching sequence.
2. This initial programme is then evaluated so that where it fails to communicate efficiently it is rewritten. To this extent the students write the programme.
3. The purpose is to teach, not to baffle, the student. The level of a programme is set for the particular individuals whom it aims to teach.

4. The aim is to control teaching by a constant interaction between the student and the material. To this end each frame is relatively short and each requires a response. The student has to read the material and by reason of his response is actively engaged in learning.
5. The system not only requires a student's responses but uses them both to evaluate the programme and to select the next appropriate material to present to the learner.
6. A student knows immediately whether his response is correct. The value of giving immediate knowledge of results is generally accepted.
7. It is an individual teaching situation, and this may save some of the embarrassments of classroom teaching.
8. It is self-paced. The freedom to take longer over any particular material is useful, especially for older trainees.
9. It is available at any hour of the day, for as long as a student wishes, and does not get impatient or tired as a human teacher might do.

PRESENT EVIDENCE

A comparatively short time ago many educationalists were sceptical about the possibility of machine teaching. Recently, however, many devices have been used successfully to teach both children and adults.

Table 4 summarizes 42 unselected studies which were reported up to Autumn 1962. The machines used ranged from simple programmed textbooks to complex electronic devices. The comparisons were between results obtained by standard 'chalk-and-talk' methods in class and individual tuition by machine. In 39 cases where learning was measured soon after the completion of the lessons, 37 of the machine tuition studies gave equal or better results. In 13 cases where retention was measured over a longer period, 10 showed better retention with machine teaching than with conventional methods. This disposes of the notion that what is easily learned will be easily forgotten. Again, in 14 cases where study time was compared, 13 showed a significant reduction. In short, in most cases machines were teaching to a higher standard, students were retaining more, and this was achieved in less time than by traditional methods.

Although these comparisons are clearly favourable, caution is needed in interpreting them. It may be that some studies have not been reported where machines failed to teach. On the other hand in some examples of failure the experimenter has made an elementary

Table 4. Results of 42 experiments comparing instruction by programme and by human teacher

(Not all 42 experiments quote all three measures).

Measure Taken	Number of Studies	Programmed Instruction Group		
		Better	Equal	Worse
Immediate Retention	39	27	10	2
Long-term Retention	13	10	3	0
Learning Time	14	13	0	1

mistake. Again the question of motivation is particularly difficult. It has been argued that because teaching machines give the student immediate information about whether his answer is correct, this method of teaching maintains the student's interest and desire to learn more than normal class-room methods of instruction. This is true but it may be because at present machines are novel and interesting in themselves. They have not yet been tried in any context where they, and not traditional methods, give the major part of the instruction. Even so, when used on a training course in conjunction with human instructors, in addition to providing variety in teaching methods they make their own specific contribution.

When considering machine and human instruction, the basic comparison is between the efforts of one individual, a programmer, with those of another individual, a teacher using conventional methods and results will be influenced by the respective efficiency of each. Nevertheless, when results are examined in detail, the success of machine methods appears not to be due to chance factors. Some typical case studies illustrate this point.

Both the Royal Navy and the Royal Air Force have conducted evaluation studies of a trigonometry branching programme used in conjunction with *AutoTutor Mk. II* (see page 12). The R.A.F. compared machine instruction with normal classroom teaching on the air radar and air wireless fitters course. The control group was made up of 30 students in three sets of 10, each set being taught by a competent instructor, while there were 29 in the experimental group being taught individually by the machine. The two groups were closely matched on pre-instruction tests, and both groups showed substantial improvement in their post-instructional tests. But the group taught by machine had learned as much in less than

half the time taken by the conventionally taught group, and in several cases in less than a third of the time.

The Royal Navy used the same course for junior electrical mechanics in three groups of 24. One group was taught by an instructor, one by the '*Auto Tutor*,' and one by the same programme in scrambled-book form. In this study, again, all three groups showed substantial improvement, but the '*Auto Tutor*' and scrambled-book groups were better than the instructor group. Again the conventionally instructed group took nearly twice as long as the machine-taught group, and the scrambled-text group. On a subsequent retention test, two weeks later, the instructor group showed a slightly greater loss than the other two groups.

A different kind of study was conducted using programmed work-books for training mail order billing clerks. The normal training consisted of 32 hours of classroom instruction by a supervisor with groups of 15 trainees, followed by 20 hours of on-the-job practice with a further 8 hours of classroom instruction. Eleven programmed work-books were substituted for the class instruction with four groups of trainees. The instructor handed out these booklets and was available for individual tuition when needed. The 60 trainees taught in this way achieved a satisfactory performance in an average of 26 hours of classroom time as compared with 40 hours previously—a saving of 35 per cent. In addition, the programming process revealed several difficult points in the task which were subsequently modified. It was concluded that instructors using this method could deal adequately with larger classes.

A research team at Aberdeen University has carried out several evaluations of a programme on paper-making. The subject matter was carefully selected in consultation with the industry's experts, so that the programme should teach the properties of cellulose fibres used in paper-making, the beating process, and the effects on the finished sheet that result from variations in beating and choice of fibre. The programme also aimed to teach students to identify certain types of paper by eye, to give them some understanding of micro-photographs of paper fibres at different stages of treatment, and to provide instruction about the working of paper-making machinery.

A linear programme with constructed responses was written for graduate trainees. In its early version the programme was covering too much ground in too few frames, but the size of step was reduced by increasing the number of frames in the final version. Micro-photographs and sheet samples were used in conjunction with the

programme. Various small groups were tested in the final version with the following results:

Table 5

Trainees	Number	Time to Complete Programme (min)	Error Rate (percentage)	Pre-test score Percentage Correct	Post-test Percentage Correct
Graduates	14	250	5.2	26	83
Higher National Certificate level	12	252	5.2	26	72
Apprentices in Technical College	9	303	6.8	44	66

The group of apprentices started with more knowledge and ended with less than the other groups. It appears that their previous knowledge of the subject, much of which was inaccurate, may have interfered with learning. Students were also tested on an essay-type examination, where they described what they knew about a number of specified subjects in paper-making, such as beating, opacity and absorbency. Results clearly indicated that learning with understanding, rather than rote learning, had been achieved.

Careful programming of material often reveals unsuspected difficulties in a subject, but an equally interesting finding emerges from an investigation with students of different intellectual abilities. A linear programme to teach spelling was presented by a cheat-proof machine, and it was found that progress was much quicker than with normal instruction. But, whereas with normal teaching the higher I.Q. students had the better test scores, with the machine-taught groups there was no correlation between I.Q. and final test score. Results of such studies support the contention that teaching machines may be particularly valuable in overcoming the difficulties of less-gifted students. A student has to respond at each step, so that when he has completed a programme he should at least have learned its minimum content. This is important for industrial personnel who cover a wide range of abilities.

In certain cases the 'inhumanity' of a machine may give it an advantage. Some students fail because of social difficulties in the conventional training situation, which do not arise with a machine. For example, older trainees do not have to compete in the open class with younger men, who may be quicker but not necessarily more intelligent. Again, it is not always convenient or desirable to train together personnel whose status within a firm may be very different,

but who may require training in some new procedure. Machine methods can cope with this type of problem. Furthermore, the machine will not have human failings such as getting annoyed, impatient or just plain tired. The last man on the last shift is treated with the same courtesy as the first.

Finally, is there any evidence that one type of machine or system of programming is superior? Only by equating the various examples can this comparison be made, and so far no one system has been shown conclusively better than another. Early prejudices against multi-choice techniques have not so far been justified, nor have branching procedures dealt any better with individual differences than linear programmes. These issues remain to be settled by research.

V. IMPLICATIONS FOR INDUSTRY

GENERAL EDUCATIONAL AND BACKGROUND COURSES

There is a continuous demand in industry for these courses and so there will be a large market for programmes produced in such subjects as electronics and mathematics. The training departments of many large firms have close links with technical colleges and in many cases provide both teachers and students. In this field and in internal training of a general nature, a company can reasonably expect to improve teaching efficiency by sponsoring programmes in the relevant subjects.

It is envisaged that teaching machines will take their place as standard equipment in training schools. They will save the time of an instructor by relieving him of such duties as lecturing upon the necessary background material for a course, and they will give him the opportunity to devote more time to individual requirements and practical demonstration.

NO EXISTING FACILITIES

At the other end of the scale some companies, particularly the smaller ones, do not have facilities for instruction in certain areas. No case has yet been reported where a teaching machine was used simply because there was no instructor available, yet this could be one of the most worthwhile applications.

SAVING THE TIME OF THE EXPERT

It often happens that only top-grade men have the necessary experience in particular subjects and much of their time is spent in passing on this knowledge. Obvious cases are the use of highly skilled

engineers to train maintenance personnel particularly for electronic equipment, or computer experts to train programmers. Suitable machine-taught courses would save the valuable time of these men.

DIVERSITY OF LOCATION

Even though a company may be large enough to bear the normal costs of training, it may have many scattered branches, as in banking and insurance, which multiply training costs. Concerns with overseas interests, such as airline and oil companies, have to spend a great deal merely to bring trainee and instructor together. The Armed Services epitomize this problem. They must either maintain expensive central training schools or send instructors to many different locations. Teaching machines can overcome this problem; they are currently being used, for example, aboard long-range submarines. Within industry a prominent drug firm has obtained encouraging results by mailing linear programmed texts on a new product to its representatives.

CUSTOMER TRAINING

As products become more complex and reach wider markets, manufacturers are more and more obliged to train customers in the use of them. A computer firm has taken an early lead in training its customers' programmers by teaching machine methods.

INTERMITTENT SUPPLY OF TRAINEES

Many industries are plagued by seasonal fluctuations in the demand for their goods and services and so take on temporary labour at peak periods. The food-processing and the photographic industries are good examples. In some cases the amount spent on training can be almost as much as that eventually paid to the trainee in wages for his work. One mail-order house has used programmed instruction successfully to cope with such a problem. Machine teaching can also help to solve the problem of the trainee who arrives after the course has begun and is the odd man out.

RETRAINING

As the rate of technical change increases, jobs which have remained much the same for a century or more may change overnight. The days are passing when a man's trade stayed the same through his lifetime, and in the future flexibility will be the rule rather than the exception. The consequence of technical change is either redundancy or retraining. A man experiences stress in learning a new job, and so is unwilling to train for a new occupation. But many features of teaching machines contribute to reducing this stress, which makes

them suitable for training older workers. The instruction is individual and self-paced, and the accent is upon carefully arranged sequences of small steps designed to teach in the clearest possible manner. In so far as teaching machines promise to be a painless tool for retraining, the whole attitude to retraining and redundancy could, in time, be altered. Trade unionists, in particular, may be interested in this point. Teaching machines could play an important part in providing the flexible work force increasingly demanded by the economy.

COSTS AND ADMINISTRATION

At first sight teaching machines appear to be expensive. A fully automatic machine costs between £200 and £300 and, since it aims to give individual tuition, only one student can use it at a time. This would seem to make the costs extremely high; but, under suitable conditions of use, the unit cost per pupil can be shown to compare favourably with that for chalk-and-talk methods.

Table 6. Approximate costs of training by machine and human instructor

		Machine	Teacher
A	Capital outlay . .	£300 + £50 maintenance	Training £1000
B	Annual cost over 5 years	£70	Salary £1000 Training £200—£1200
C	Hours of instruction per week	40 (Theoretically 24 hours per day but could function throughout a working week. Present figures use working week.)	25 (actual teaching time)
D	Hours of instruction p.a.	$40 \times 48 = 1920$	$25 \times 48 = 1200$
E	Pupil hours p.a.	One student at a time 1920	20 students at a time 24 000
F	Cost per pupil hour	B divided by E 0.73 shillings	B divided by E 1.0 shillings

It is extremely difficult to make any definite comparison between the cost of a teaching machine and that of a skilled instructor. The hypothetical example in Table 6 illustrates some of the factors which must be taken into account. The machine needs a film which for

standard subjects will cost about £1 per hour running time. If the film is used 100 times this comes to just over 2*d.* for each pupil hour, making the total cost only slightly less than for the teacher. But research has shown that a machine on average can teach twice as much in an hour as the human teacher with a class. It may be argued, therefore, that in reasonable circumstances a machine can cut direct training costs by half. The two factors that would increase this cost are (1) using the machine only occasionally, and (2) teaching obscure subject matters, which inflate initial programming costs.

Many firms have, of course, attempted their own programming, and some have used cheaper paper 'machines' or programmed textbooks. Programming is expensive because it is such a time-consuming exercise, but the return in increased efficiency will probably more than repay the outlay. An experienced programmer can produce an average of one or two frames an hour, taking into account research time, writing time, evaluation and revision time. A student may use 50 frames an hour. The cost of writing and evaluating a one-hour programme can easily be between £50 and £100. The practical cost depends on three factors: how many students will use the programme; the cost of not training them effectively; and the normal administrative costs of training, which can be very much higher than the 1*s. od.* an hour shown in Row F of Table 6, when factors such as travel, accommodation, and obtaining a specialist instructor are involved.

Finally, it is worth emphasizing that teaching-machine methods are in the early stages of development and costs are bound to be high until machines can be mass-produced and systematic techniques of programming developed. When considering the cost of a new method, the innovator often finds it difficult to cost the old methods. This is particularly true of training, where the major cost is probably to be found in the hidden long-term effects of inefficient methods—accidents, substandard work and dissatisfaction on the part of workers.

CONCLUSION

This booklet has presented the kind of communication system which is necessary when a flexible human instructor is replaced by a highly specific machine. So far emphasis has been placed on the machine method of controlling teaching, but future research will have to investigate the relative advantages of highly adaptive systems, and of more simple machines using less flexible programmes. But already teaching machines offer an immediate and practical solution to industry's demand for trained personnel. It is not an easy solution; any instructor who attempts to make his own programme is taking on an exacting task. The problems of originating programmes and of applying the techniques in an industrial setting are considerable, but they must be faced by industrial training officers and their staff if the advantages of teaching machine techniques are to be realized. The potential rewards are high. When teaching machines are used with systematically evaluated programmes, they will raise the level of industrial training, and provide a permanent means of satisfying the increasing demand for trained personnel.