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RADIO AND ELECTRICAL ENGINEERING DIVISION

# AUTOMATION AND EDUCATION
# A REVIEW

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OTTAWA

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## ABSTRACT

The increasing demands being placed on educational facilities have resulted in efforts to apply the techniques of automation to the teaching process in an attempt to increase educational productivity. A review is presented of some of the initial approaches in the field of programmed instruction and of some of the research projects in computer-assisted instruction.

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## A Review

- J.W. Brahan -

## INTRODUCTION

The rapid increase in school population is placing growing demands on the educational facilities of most countries. The increase in school enrollment is due not only to the increasing birth rate, but also to the increase in educational requirements for employment which is resulting in students remaining in school for a longer period of time. In addition, pressure is being exerted on the educational system by the generation of new knowledge at an exponential rate. If the current rate of technological advance is to be maintained, more and more highly trained people will be required, and the general educational level of the population will have to be increased.

Further demands are being made on the educational system as a result of the increased leisure which people have as a result of technological advances. Porter (25) mentions the acceleration of the growth of a "leisure class" as one of the consequences of the application of automation. The educational requirements resulting from the growth of this leisure class will grow in importance as automation of industry spreads and available leisure time increases.

Not only is pressure being exerted on the school system, but industry also has a growing requirement for increased training facilities. Technological advances are being implemented in industry at a rapidly increasing rate. Thus industry must provide facilities for retraining employees in order to implement advances and to remain competitive.

Just as machines and automation techniques have been used to increase industrial productivity, teaching machines and auto-instructional methods offer the potential of increasing the "educational productivity" of our school system. A number of authors (3,19,35) have represented the teaching process as a feedback control system and this is an effective way of examining the effect of teaching machines and auto-instructional methods. A simple model of the teaching process is shown in Fig. 1.

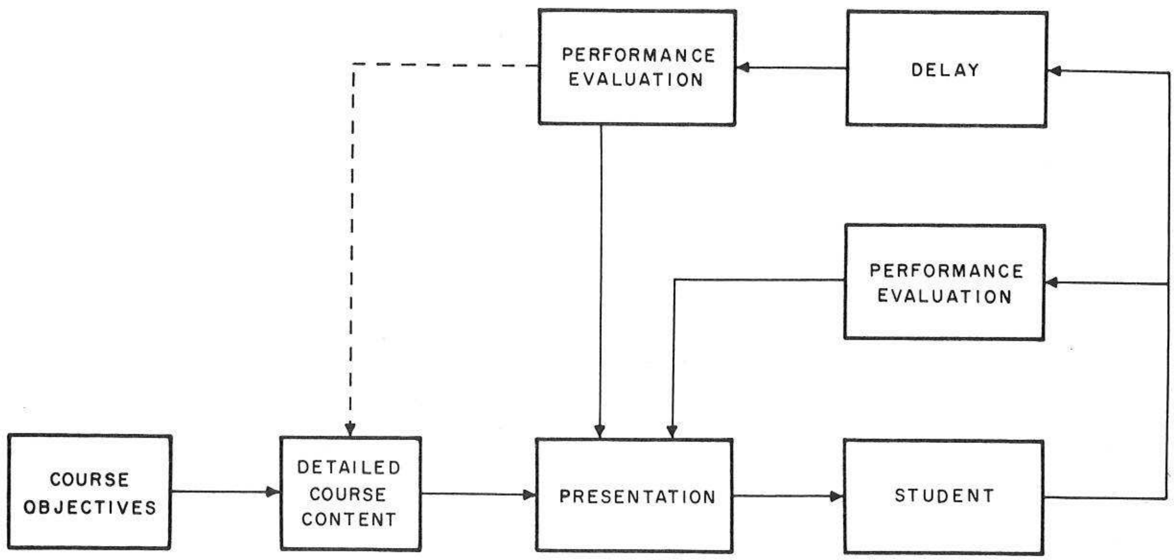


Fig. 1 Model of teaching process

In the situation involving a human teacher, the teacher prepares a detailed plan of instruction based on the course objectives supplied. His presentation involves the use of various devices, both audio and visual, and in some cases tactile, such as voice, blackboard, pictures, models, etc., to transmit the information to the student. To determine the effectiveness of his presentation, a response must be elicited from the student. This can take the form of questions applied immediately following the presentation of moderately small amounts of information, or it can take the form of testing at relatively widely spaced intervals in which case there is a delay between the time at which the information is presented and a response is made. The immediate-response channel provides a method whereby the information presented by the teacher can be reinforced if it has been received correctly or corrected if it has been received incorrectly. When only one, or even a small number of students are involved, the teacher can obtain an accurate measure of the effectiveness of his presentation through the immediate-response channel. He is also able to provide effective reinforcement by means of this channel. The delayed-feedback channel then simply provides a measure of retention of information by the student. However, when one considers the number of students in the normal school classroom, usually between 30 and 40 and in some cases exceeding 40, it is apparent that it becomes extremely difficult to obtain an effective measure of the individual student's progress except by testing, which does not provide the advantage of immediate reinforcement nor immediate correction of wrongly learned concepts. The large class introduces a further problem in that the rate of presentation of information must be geared to a level somewhat below the class average so that most of the students in the class can keep up. Thus there will be a number of students in a class who could progress at a faster rate but who are being held back by the slower members of the class.

One solution to the problem is to reduce the size of classes to a very small number of students or to use a "team teaching approach" (42) which has been shown to be very effective. However, both these methods would require a large increase in the number of available teachers and since there is currently a severe shortage of adequately trained teachers, these approaches to the problem do not appear to be practical. A more feasible solution is to extend the capabilities of the teacher by making use of teaching machines and auto-instructional methods.

## PROGRAMMED INSTRUCTION

The concept of using a machine to teach is not new. It is now forty years since S.L. Pressey (26) of the Ohio State University described a simple machine, the primary purpose of which was automatic testing, but which was also capable of teaching. The machine consisted of a drum on which was written a series of questions with multiple-choice answers which were exposed through a window. The student selected one of the answers offered by depressing one of four keys. When the machine was used in the testing role, a record was made of correct responses and a new question was presented after each trial until all the questions on the drum had been presented. When used in the teaching role, a new question was not presented until the correct answer to the current question had been indicated by depressing the correct lever. Later modifications to the machine (27) resulted in a mode of operation whereby, after the series of questions had been gone through twice, those questions which had been answered correctly on two successive attempts would be eliminated from the presentation. After each item had received two successive correct responses, the apparatus stopped automatically.

While the device was quite simple, it had three significant features. Firstly, information could be presented in the form of a number of small steps. Secondly, immediate reinforcement was provided in that as soon as the student pressed a key, he was informed whether or not his answer was correct, and he could only progress to the next step by supplying the correct answer. Finally, it permitted the student to progress at his own rate.

More recently, B.F. Skinner (32) of Harvard described a mechanical teaching device based on his laboratory studies of conditioned responses. The machine presented a program of instruction, which was written on a paper tape and moved through a series of small steps or frames to reach the desired objective. Before proceeding to the next frame, the student was required to respond to a question. The machine described by Skinner in his 1954 paper was designed to teach arithmetic, and answers were constructed by moving slides on which the numbers 0 through 9 were printed. The machine would not advance to the next frame until the right answer had been set up in the slides. A later device (33) consisted of a disc containing information printed in 30 radial frames. This disc was inserted in an apparatus which presented the frames sequentially. In this case, the student made his response by writing on a paper strip which was exposed through an opening in the machine. The disc was then advanced to expose the answer to the question contained in the frame and at the same time, the paper strip on which the student had written his answer was advanced so that the answer was covered by a transparent plastic window. The student then indicated whether or not his answer was correct by moving a lever which recorded his decision on the answer tape. When the lever was returned to its original position, the next frame was presented. He proceeded through the disc in this manner and then repeated the process. Each time he responded correctly to a question, that frame was omitted from future disc revolutions. When all frames had been responded to correctly, the disc rotated through a full revolution without stopping and the exercise was completed. Thus the machine is capable of providing immediate reinforcement of correct responses and wrong answers are corrected immediately.

The Skinner machine and the Pressey machine are essentially the same, the only significant difference being that the former required a constructed response while the latter used a multiple choice type of response.

While the machines themselves are essentially the same, Skinner placed much more emphasis on the program,and considered the machine itself of secondary importance. Each frame in the program is prepared in a way that will maximize the probability of a correct response from the student. This is accomplished by keeping the content of each individual frame low, and by making use of prompting to assist the student in arriving at the correct answer.

A second difference between Skinner's approach and Pressey's was in the application of their machines. Pressey looked upon the machine as a device for testing and, in its teaching role, as an adjunct to more conventional teaching techniques providing an effective method for review and study. Skinner's approach was that the device would be a self-contained method of instruction, and not simply a supplement to other instructional methods. Since the Skinner device is the main method of instruction, and not supplementary to other methods, the method of handling errors becomes extremely important. The approach taken by Skinner is to reduce the information content of each frame and to supply sufficient prompting to achieve a minimum error rate. However, it is impossible to write a program in such a way that a zero error rate can be achieved for all students, and the linear program offers no method for handling errors other than repetition of the same information. The linear program assumes that circumstances which are optimal for one student will be optimal for all students. Thus the program must be developed on the basis of the capabilities of the least capable student. This then implies that the program contains many more steps than are required for the average or above average student. One solution to this is the preparation of several programs for teaching the same subject to students of varying ability.

The occurrence of errors during the student's progress through a program receives much more attention in the "intrinsic" programming technique of Crowder (11,12). In this technique, the response to a given frame determines the next frame to be presented to the student. Each frame contains a limited amount of information, but, in general, considerably more information than is contained in a frame of a linear program. Questions are of the form with multiple-choice answers and thus if the student chooses the wrong answer, the succeeding frame or frames will contain information designed to overcome the mistake. In this way, the student with greater ability will be able to progress through the program at a higher rate than the student with less ability.

The devices which Crowder used for presenting the program to the student are the "Autotutor", a film projection device, and the scrambled book or "Tutortext". In the case of the Autotutor, the student uses one of several push-button switches to indicate his response. This action automatically selects the next frame to be presented. At the National Physical Laboratories in the United Kingdom a similar device (23) was developed which provides two push-buttons for the student response and facilities for branching 512 frames in either direction. The scrambled book directs the student to a specific page in the book for the next frame according to the answer he has selected. Each answer has a page number associated with it. Thus the student proceeds through the book in a sequence determined by his response to the questions presented and not by the order in which the pages appear in the book.

The intrinsic program technique results in a system which has a degree of adaptability to the individual student's requirements. However, it is limited in that decision operations are based only on the response to a given frame. There is no facility for adjusting the program by using information obtained from the student's past history, which is developed as he proceeds through the course. A further limitation in some cases is the restriction to questions with multiple-choice responses. In many cases, this may not be a limitation, but there are instances in which constructed responses appear to be more effective (15).

## COMPUTER-ASSISTED INSTRUCTION

A more versatile system becomes feasible if the control function is removed from the individual student's console and is provided by a central computer. Stolurow (35) and Smallwood (34) have emphasized the importance of adaptivity in the teaching-machine system. Two desirable characteristics of the automatic teaching system are, according to Smallwood, the ability to adjust its program to take advantage of the learning characteristics of individual students, and the ability to improve the quality of its instruction with experience.

The high-speed digital computer offers a means of incorporating the above features into a teaching-machine system. By means of time-sharing techniques, a single computer can control the teaching of a large number of students at one time with the further capability of teaching a number of different courses simultaneously and still provide practically unlimited access to the computer for each student.

A simplified block diagram of a computer-directed teaching system is shown in Fig. 2.

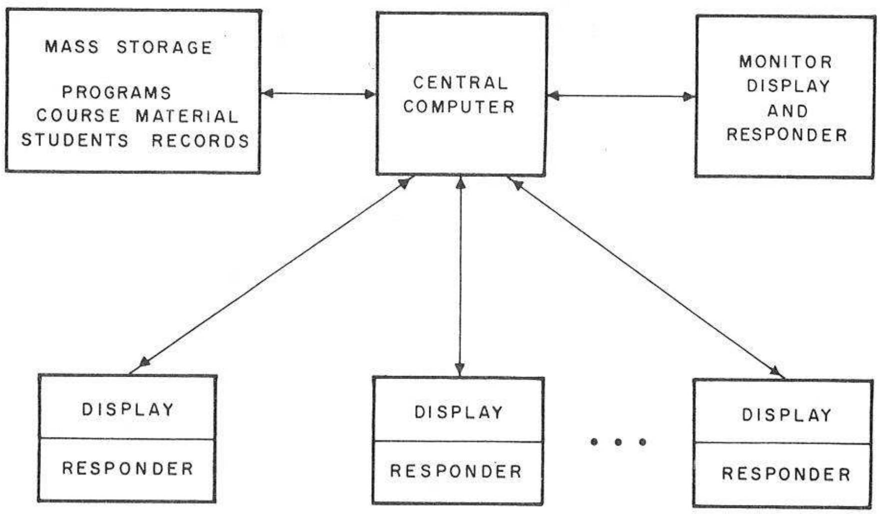


Fig. 2 Computer-assisted teaching system

The central computer performs the necessary decision functions to determine the information to be presented to the students on the displays, accepts and analyzes students' responses and updates students' records. It can also build up a history of the progress of a number of students through a particular course and use this information in arriving at a decision as to what information should be presented to a particular student in progressing through that course.

## DISPLAY AND RESPONSE EQUIPMENT

The display and response devices need not all be the same, and should be chosen on the basis of the requirements of the course material being taught, and the capabilities of the student. An extensive discussion of the student - subject matter interface requirements has been presented by Glaser, Ramage, and Lipson (17) in which stimulus and response requirements for several subjects have been discussed. The variety of devices which can be operated under computer control provides a means whereby the terminal equipment can be selected to optimize the learning environment.

For the presentation of visual information, devices commonly used in computer-based instruction systems include the typewriter, the electronic display which uses a cathode-ray tube for the presentation of alphanumeric information and line drawings, and the rear projection optical display which can present either still slides or motion pictures. The film projection device has the attractive property that it incorporates a large storage capacity within the display unit.

A second form of output which can be as important as or even more important than visual output in some applications is audio presentation. The effectiveness of audio presentation devices has been demonstrated by the performance of language-laboratory systems in the schools. In the computer-assisted instructed system, the audio output facility is desirable at all levels, but is particularly important in the case of younger children. One of the early IBM experiments (40) employed a random-access audio store, the audio RAMAC, in a system which was used for the computer teaching of stenotypy. Other systems with facilities for the output of audio messages include the initial Stanford System based on a modified PDP-1 with an IBM 7090 back up (36), and the IBM 1500 CAI System. In other areas of application, work has been done in the field of computer-controlled audio output, such as the computer-controlled inquiry answering device using the IBM 7770 and 7772 (39).

A third class of output devices comprises those providing tactile stimulus. This is an area which has not received much attention in computer-based instruction systems, though it has been used effectively in highly specialized training devices.

The most common input device for CAI systems is the keyboard - either the standard typewriter keyboard or a special keyboard. The other common input device is the light pen, used in conjunction with an electronic display. As with output devices, emphasis has been placed on visual input devices (if a keyboard can be classed as a visual device - probably true for a nontypist) and there has been very limited implementation of audio input devices. The reason of course is the increased technical complexity of audio man-machine communication over the visual methods. Even in going from a keyboard with a limited number of switches which provide a facility for multiple-choice responses to a full typewriter keyboard and constructed responses there is a significant increase in the complexity of the input subsystem. If constructed responses are permitted, consideration must be given to minor variation in responses (spelling errors, punctuation errors); if free-form responses are permitted, facilities must be present for the detection of key words for evaluation of the response. Consideration has been given to these problems in several of the CAI systems (1).

## COMPUTER PROGRAMMING

Programming of a computer-assisted instruction system can be divided into two parts; the control program, or system program, and the course-content program or instructional program. The systems program determines to a large extent the degree of adaptability of the system. It provides the control of presentation of the instructional material, facilities for branching, and presentation of remedial exercises and facilities for assessing the results of its presentation on the student. In addition, it should include facilities for the compilation of student records. It is a formidable task for a teacher to have to compile records for a large group of students each progressing at his own rate. In an experiment on the Continuous Progress Plan, which permits each student to progress at his individual rate using programmed instruction techniques, Cogswell and Egbert (8) reported that the task that almost overwhelmed teachers was that of keeping a record of the student's progress. The CAI system is ideally suited to carrying out this task. In addition, it should make the students' records available to the teacher on demand, and also should warn the teacher of those students who are not progressing satisfactorily.

The system program should also provide a facility for the preparation of instructional programs. Since most of the users of a CAI system will not necessarily be computer programmers, it should be possible to communicate with the system using a special "author" type language without having to make use of the basic machine language or even a higher-level language which is not specifically oriented to the application. One example of such an author language is the Coursewriter Language used in the IBM CAI system (18). The system should also provide a facility for modifying instructional programs, as information is gathered from application. With a computer-based system, it is possible to make use of the computer in the assessment of the effectiveness of the course presentation using the students' performance as the criterion. If a particular set of frames results in a large number of erroneous responses, some modification, possibly an expansion of the set of frames is required. Similarly, other frame sequences may be reduced. The system program can indicate these situations to the teacher who can then take the required steps to improve the course presentation.

## ADAPTIVE SYSTEMS

Stolurow and Davis (36) state that the teaching-machine system should make use of the student's past performance, and should also have the capability of modifying programs during the course of instruction. To accomplish these objectives, they suggest a two-phase operation: A pretutorial phase which specifies a program of presentation considering the initial conditions, the material available to the machine, and the final objective; and a tutorial phase in which the instructional material is presented to the student. During the tutorial phase, the program should be adjusted as information is acquired from the student's response pattern.

If the system is to select a program of instruction which arrives at an objective in an optimum manner for a given student, there must be available a library of instructional material from which the individual student's program can be prepared. A decision structure is required in the system program to select the course material to be presented to the student based on his entry level and the objective of the course, and also to modify the presentation of the material during the tutorial phase in a manner which is determined by the student's response. The decision structure must be so arranged that during the tutorial phase it presents material in such a way that the student can proceed through the course with a minimum number of errors, in order that the principle of reinforcement can be applied, and with a maximum amount of learning. The material should also be presented in such a way that it will maintain the student's interest and attention by presenting him with sufficiently difficult problems that he can achieve a sense of satisfaction (or reward) from successfully completing a frame or series of frames. Thus the system should include means for assessing the degree of difficulty the student is experiencing with the material and adjust its presentation to produce the optimum learning rate.

## CURRENT RESEARCH PROJECTS IN CAI

In mid-1966, Silvern and Silvern (31) reported the number of research installations in the United States as having grown to fifteen. Included in these are:

### PLATO (4,5,6) Programmed Logic for Automatic-Teaching Operation

The system is installed at the Coordinated Science Laboratory, University of Illinois. The project began in 1960 with a single student station connected to the Illiac I computer. The current version is PLATO III which consists of twenty student stations connected to a CDC 1604 computer (48-bit word, 32-k words of core memory). The basic output device is a CONRAC video display which can receive information from a slide bank which has a storage capacity of 122 slides and from an electronic storage tube which can be used to present diagrams and alphanumeric information. Input is by means of a main keyset which is similar to a typewriter keyboard and a supplementary keyset which is adapted to special purposes by changing the labeling on the keys. The system has been used to teach computer programming, science for the elementary grades, and theory of electrical circuits at the college level.

### CLASS (9,41) Computer-based Laboratory for Automated School Systems

An experimental computer-based schoolroom has been built by the System Development Corporation. The student is presented with information by means of film projectors, audio tape recorders, and television. Input is by means of a special purpose keyboard incorporating indicator lights to designate correctness of the response. The system uses a Philco 2000 computer. A teacher's console provides information required for monitoring students' progress. Facilities are also provided for group instruction by means of films and television.

SOCRATES (36) System for Organizing Content to Review and Teach Educational Subjects

This system has been under development since early 1963 at the Training Research Laboratory, University of Illinois. The system uses an IBM 1620 computer and an IBM 1710 control system. The main presentation unit is a modified Autotutor Mk II which is renamed a Master Tutor. Responses are entered by selecting one of fifteen buttons on the display unit. The system can handle up to fourteen student stations, and a variety of digital devices can be used.

SOCRATIC SYSTEM (13,14)

This is a conversational teaching-machine system developed by Bolt Beranek and Newman, which permits a dialogue between the student and the machine. The system was programmed for the PDP-1 computer with an on-line typewriter and auxiliary drum memory. The system has been applied in the areas of electronics, business finance, and medical diagnosis.

IBM 1500 Instructional System (18,20)

The IBM 1500 system is an outgrowth of early work at the Thomas J. Watson Research Center on a teaching system using the IBM 650 computer (29,40,41). The system can have up to 32 student stations. The basic student station includes a CRT display and keyboard, or can be simply a typewriter for both input and output. Other output facilities include a film-strip projector, and magnetic-tape units for audio messages. The basic language for communicating with the system is the Course-writer language which can be used to prepare or modify instructional programs. Software routines include provision for analysis of constructed responses and for determination of acceptability of partially correct responses.

Other research installations in the United States are at the Universities of California (Irvine, and Los Angeles), Pittsburgh, Michigan, Stanford, Texas, at Michigan State, Florida State, Pennyslvania State, State University of New York (Stoney Brook), and at Education Training Consultants, Los Angeles.

While most of the activity in the field of applying techniques of automation to education is taking place in the United States, work is going on in the United Kingdom, notably that of Pask (21,24) in the field of adaptive machines and also in the Union of Soviet Socialist Republics (30) where special-purpose machines have been built for teaching and testing.

SUMMARY

In summary, the computer-assisted instruction system should include the capability to perform the following functions.

1. Engage in a dialogue with the student using natural language.

2. Present instructional material in a manner determined from the student's performance.

3. Compile significant details of the student's behaviour.

4. Provide a means of assessing the effectiveness of an instructional program.

5. Analyze the performance of both individual students and groups of students.

6. Permit compilation of instructional programs using a problem-oriented or author language.

7. Inform the teacher of difficulties encountered by individual students or groups of students.

8. Adapt to the specific requirement of the individual student.

Current CAI systems can perform most of these functions to some extent, and many experiments with CAI systems have been very successful (38). However, there are areas of instruction for which the state of development of CAI is not sufficiently advanced to permit its effective application (37). Considerable research and development remains to be done to make computer-assisted instruction effective over a wide range of applications. Glaser, Ramage, and Lipson (17) suggest the following areas of research and development which should be explored.

Subject matter analysis
Instruction analysis
Development of prototype lessons
Analysis of learning behaviour
Equipment analysis

To these topics should probably be added

Classroom architecture requirements
Communication requirements

In the area of equipment development, the interface between the student and the machine requires considerable research and development to permit a more complete two-way conversation. To implement the adaptive system described by Stolurow and Davis, a large store or bank of instructional material must be available to the system.

The information-storage and data-processing capabilities of the digital computer offer a powerful tool for greatly expanding educational facilities. However, much work remains to be done, both in the development of systems hardware and software, and in the development of educational techniques to make full use of the potential offered by the digital computer. The most important immediate application of CAI appears to be as a research tool to study the most effective ways of applying the techniques of automation to the field of education. Very close cooperation will be required between the educator and the technologist if maximum benefit is to be derived from the application of computers in education.

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